This section presents the results of the assessment of the impacts of each of the five predefined GIWA concerns i.e. Freshwater shortage, Pollution, Habitat and community modification, Overexploitation of fish and other living resources, Global change, and their constituent issues and the priorities identified during this process. The evaluation of severity of each issue adheres to a set of predefined criteria as provided in the chapter describing the GIWA methodology. In this section, the scoring of GIWA concerns and issues is presented in Tables 11, 13, 15 and 18. Detailed scoring information is provided in Annex II of this report.

**Table 11** Scoring table for Lake Turkana.

<table>
<thead>
<tr>
<th>Assessment of GIWA concerns and issues according to scoring criteria (see Methodology chapter)</th>
<th>Environmental impacts</th>
<th>Economic impacts</th>
<th>Health impacts</th>
<th>Other community impacts</th>
<th>Overall Score**</th>
<th>Priority***</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freshwater shortage</td>
<td>1.8*</td>
<td>1.8</td>
<td>1.6</td>
<td>1.8</td>
<td>2.2</td>
<td>2</td>
</tr>
<tr>
<td>Modification of stream flow</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pollution of existing supplies</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Changes in the water table</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pollution</td>
<td>1.6*</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>2.0</td>
<td>3</td>
</tr>
<tr>
<td>Microbiological pollution</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eutrophication</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemical</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suspended solids</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid waste</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radionuclide</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spills</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Habitat and community modification</td>
<td>2.5*</td>
<td>2.6</td>
<td>2.3</td>
<td>2.5</td>
<td>2.6</td>
<td>1</td>
</tr>
<tr>
<td>Loss of ecosystems</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modification of ecosystems</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unsustainable exploitation of fish</td>
<td>0.9*</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.9</td>
<td>5</td>
</tr>
<tr>
<td>Overexploitation</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excessive by-catch and discards</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Destructive fishing practices</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decreased viability of stock</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Impact on biological and genetic diversity</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global change</td>
<td>2.1*</td>
<td>2.0</td>
<td>2.4</td>
<td>3.0</td>
<td>2.1</td>
<td>4</td>
</tr>
<tr>
<td>Changes in hydrological cycle</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sea level change</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increased UV-B radiation</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Changes in ocean CO2 source/sink function</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* This value represents an average weighted score of the environmental issues associated to the concern. For further details see Detailed scoring tables (Annex II).

** This value represents the overall score including environmental, socio-economic and likely future impacts. For further details see Detailed scoring tables (Annex II).

*** Priority refers to the ranking of GIWA concerns.
Lake Turkana Basin

Freshwater shortage

The only perennial river, and by far the most dominant source of water to the Lake (90%) (Cerling 1986), is the Omo River. The Omo River drainage basin lies mostly within Ethiopia, while the Lake lies within Kenya. Rainfall in the Lake Basin varies from more than 1500 mm in the Ethiopian plateau (Halfman & Johnson 1988), to less than 255 mm per year in the lake area (Survey of Kenya 1977). The Omo River discharge is about 19 billion m³ of water each year (Beadle 1981). All the other rivers are seasonal or intermittent, thus there is little overland surface run-off into the Lake from the surrounding watershed.

The lake water itself is not suitable for drinking due to its high alkalinity and total dissolved solids concentration (cf. Yuretich & Cerling 1983), but the affluent river waters and shallow wells along the rivers are used as sources of potable water. The Turkwel River, entering the Lake from southwest, was dammed in 1991 for hydroelectric power generation at Turkwel Gorge, about 150 km west of the Lake (Figure 13). There is currently no evidence that abstraction of water from aquifers exceeds natural replenishment. Very little hydrogeological data is available for effective evaluation in the Lake Basin. Groundwater recharge zones and amount of groundwater recharge to the Lake are largely unknown. Nevertheless, on account of the land degradation and increasing number of settlements, it is likely that the groundwater recharge has, to some extent, decreased.

Environmental impacts

Modification of stream flow

The freshwater shortage in the Basin is due mainly to modification of stream flow. Along the Omo River in Ethiopia, there has been an extensive increase in small irrigation schemes diverting water from Lake Turkana. For example, in the Lower Omo Valley in Ethiopia (rainfall 300 mm/year), fodder and food crop production depends almost entirely on seasonal floodwater from the River Omo and recession farming in the old river channels (Kay 2001), and the delta (Raymakers 2003). Alexander (1990, in Haack & Messina 2001) estimates that the Omo River discharge has been reduced by 50% because of these activities. Development and commissioning of the large Turkwel River Dam in 1991 has also probably significantly impeded the flow of freshwater in the Turkwel River, and this may have impacted negatively on the fisheries in Ferguson’s Gulf through lowered lake levels. Studies are, however, required to quantitatively determine the environmental effects of the dam construction.

Pollution of existing supplies

Heavy grazing along the lower Omo valley, especially along watering routes and overnight pastures, and settlement close to the rivers indicates that there is some pollution particularly from human and livestock wastes. In Marsabit District (Kenya), only 5.7% of the households (1700 out of 30 000 households) have access to potable water, and the average distance to the nearest potable water point is 25 km (Republic of Kenya 2002a). In Turkana District, the situation is somewhat better, with 28% of households (23 000 out of 80 921 households) having access to potable water, and the average distance to the nearest potable water point is 10 km (Republic of Kenya 2002b).

Socio-economic impacts

The people in the area are mainly pastoralists, and to a lesser extent, agro-pastoralists. Most of the lake drainage basin is used as pastureland (47.5%) compared to only 2.5% used as crop fields (World Lakes Database 2002). The main people affected by freshwater shortage due to abstraction of water for irrigation, and pollution, would be mainly those downstream close to the deltas of the Omo and Kerio-Turkwel Rivers (cf. Raymakers 2003). The degree of impact to these downstream users is probably fairly significant, particularly because water abstraction is a continuous activity, with resultant loss of agricultural uses (crops and livestock) and productivity, and increased effort to dig more water wells.

In Africa, nomads have the least access to any health services, and no satisfactory strategy has been devised to deliver proper health care to remote populations (Sheik-Mohamed & Velema 1999). Lack of access to safe water and adequate sanitation remains particularly acute in rural areas of Ethiopia (CIHI 1996) and Kenya (CIHI 1995) and are major underlying causes of several diseases. Common diseases related to quality of water and sanitation include diarrhoeal diseases, intestinal worms, schistosomiasis, common eye infections such as trachoma, and skin diseases (CIHI 1996, Republic of Kenya 2002a and b). Most watering points are, however, along the rivers and the delta area where permanent settlements and livestock populations are growing. Due also to lack of health care facilities in this remote region (the average distance to the nearest health facility in Turkana and Marsabit areas of Kenya is 50 km and 80 km respectively (Republic of Kenya 2002a and b), it is expected that more than 25% of the population are affected by bacterial-related gastroenteritis disorders. The freshwater shortage is an endemic, age-old situation because of the climatic setting, and the respective governments are continually making concerted efforts to improve the situation by digging new wells and boreholes in rural areas, as well as increasing access to piped water in urban settlements.
Although there is no direct information on the impact of freshwater shortages resulting from human interventions on the communities, it is known that only 10% of the rural people in Ethiopia have access to potable water, while human waste disposal facilities are non-existent, and health services are limited and reach only 46% of the population (Waktola 1999). This situation likely reflects the prevailing conditions in the relatively poor and mainly nomadic regions of southwestern Ethiopia and northern Kenya. There would be increased potential for upstream/downstream conflicts that could be quite explosive, and population migration to areas not traditionally within the pastoralists normal range of movement. For example, there are some international conflicts (e.g. between the Turkana and the Merele of Ethiopia), and local ones as well, arising from livestock related issues such as grazing grounds and watering wells (Raymakers 2003); there have been several reports of armed conflict over ownership of water wells in the region. The government-supported irrigation schemes on the Turkwel River have impinged on traditional croplands of the Turkana, consequently, disputes have arisen between the traditional cultivators and the irrigation schemes (Barrow 1988).

**Conclusions and future outlook**

The freshwater resources of the Basin are critical for the livelihoods of the pastoralists and agro-pastoralists in the largely semi-arid drainage basin. River water is used for subsistence agriculture, but the rate of abstraction is currently unsustainable and is impacting Lake Turkana. The construction of dams in the region appears to impact negatively on the livelihoods of downstream river users and the lake ecosystem. Studies are, however, required to quantitatively determine the environmental effects of the dam construction. Most of the population rely on river and shallow water wells for water, and proper sanitation facilities are basically non-existent. Heavy grazing along the lower Omo valley, especially along watering routes and overnight pastures, and settlement close to the rivers indicates that there is some pollution particularly from human and livestock wastes, but incidences of waterborne diseases do not appear to have increased significantly. There is a need to establish groundwater resource value and to initiate its sustainable development as a source of potable water in the region. Food security is inextricably linked to the freshwater resources. With the very low rainfall in the region, an increasing number of people are shifting from pastoralism to agro-pastoralism and becoming more vulnerable as a consequence. The unsustainable abstraction of Omo River waters in upstream areas is beginning to impact on downstream users. Droughts in the past have exacted high costs in terms of loss of life of humans and livestock and the drought impact will likely increase as the freshwater resources dwindle. Freshwater shortage is likely to become more acute as more and more water is diverted from the rivers to adjacent farms, and will be acutely accentuated during periods of drought. The higher populations close to the riverbanks are also likely to pollute the waters to significant levels, thus rendering the freshwater shortage more acute because of its reduced quality. Economic impacts on downstream settlers will become worse because it would become increasingly more difficult to maintain high agricultural productivity and gain relatively easy access to potable water (i.e. from relatively shallow wells) as more of the freshwater is diverted for use upstream. Health impacts will increase due to lack of sufficient and potable water supplies, and as well to unsanitary conditions in the increasingly settled downstream parts. These factors can lead to a host of diseases such as cholera and typhoid. The potential for upstream/downstream conflicts will further increase, as will population migration.

**Pollution**

Pollution generally is not a highly ranked problem within the Lake Turkana Basin. It is concentrated mainly in the relatively highly populated Omo River drainage basin. Little or no use of agrochemicals in the adjacent floodplain farms means that water pollution is mainly through contamination by human and livestock waste. The relatively low population density also suggests that pollution of the waters would be a gradual, rather than rapid process, partly constrained by the dilution and dispersion capacities of the rivers and Lake vis-à-vis the initial pollution load.

There is no evidence available to show that microbiological and chemical pollution, solid wastes, thermal, radionuclide, and spills are currently of any threat to the Lake and its rivers. There are basically no industrial, large-scale agricultural or other types of developments in the Basin that can singularly or collectively substantially contribute to pollution of the water bodies. As mentioned before, lack of access to safe water and adequate sanitation remains particularly acute in rural areas of Ethiopia (CIHI 1996) and Kenya (CIHI 1995), but there are no reports available in relation to microbiological pollution to indicate that there is above normal incidence of, or an increase in, bacterial related gastroenteric disorders in fisheries product consumers. There have not been any fisheries closures or advisories due to outbreaks of gastroenteric disorders. Most heavy metals are present in low and stable concentrations and are naturally derived: aluminium, iron and manganese fluctuate with rather large changes in concentration in connection with the influx of organic matter (Kallqvist et al. 1988). There is no evidence of significant fertiliser...
use in the agricultural activities being undertaken along the principal rivers banks (World Lakes Database 2002).

Environmental impacts

Eutrophication

Although fluvial activity is generally infrequent (only the Omo River is perennial), the sediment load is high, in common with other arid environments (up to 1600 tonnes/km²/year), and delta construction is rapid (Frostick & Reid 1986). There is also increased soil erosion on the banks of the affluent rivers due to human activities (Waktola 1999, Haack & Messina 2001). This has partly contributed to the growth of the Omo River delta, reflecting a measurable shallowing of the depth range of macrophytes. Input of nutrients during the Omo River flood season has been noted as driving phytoplankton population dynamics (Ogari 1981), although there has not been any monitoring programme to determine whether there has been an increasing trend in abundance of epiphytic and planktonic algae with time. During surveys carried out from 1972 to 1975, nitrate and nitrates were frequently undetectable, with maximum concentrations of 17.7 µg/l being noted in the Omo delta and thought to be derived from the Omo River (Ferguson & Harbott 1982). From the low levels of nitrate and nitrite in the inshore and open water of the Lake, Ferguson & Harbott (1982) surmised that nitrates are very rapidly utilised; no nitrate was detected in the highly productive waters of Ferguson's Gulf despite a potentially abundant supply from the excreta of the rich avifauna, cattle and goats, and heterocystous blue-green algae.

Suspended solids

The principal pollution problem in Lake Turkana Basin is that of suspended solids. Yuretich (1979) observed that sediment plumes up to 100 km long extend southward from the Omo River delta during flood seasons. More recent imagery from Landsat and other spaceborne sensors clearly show the heavy sedimentation flow into the Lake (Haack & Messina 2001). The rapid and extensive growth of the Omo River delta over the past few decades reflects significant changes in sedimentation. Today the lake colour, especially in the north, is brown because of increased suspended solids (Haack & Messina 2001). The euphotic zone is about 6 m, and the Lake is always turbid (Kallqvist et al. 1988). Increased population pressure in the drainage basin of the Omo and Turkwel rivers, as well as in the northern part of the Lake, have probably affected the local aquatic benthic and/or pelagic biodiversity (e.g. through sediment blanketing and increased turbidity), but studies are needed to ascertain the type and extent of change.

Socio-economic impacts

There are no known studies on the economic impacts of pollution in Lake Turkana. Economic impacts are related to costs incurred to treat diseases (both human and livestock) arising from lack of access to safe water and poor sanitation. There could also be a problem of reduced fish stocks since many of the fish that spawn in the inflowing rivers could be adversely affected by increased sedimentation and turbidity. Additionally, the food chain could have been disrupted as phytoplankton, and other pelagic or benthic organisms, may have been negatively impacted by increased turbidity.

The health impacts are similar to those mentioned under freshwater shortage above. An additional effect may be loss of traditional fishing grounds due to increased sedimentation and turbidity, and hence reduced fish catches and lower protein intake that could lead to malnutrition. Loss of a traditional protein source would increase the vulnerability of the people living in this area to food or essential nutrient shortages. Communities may migrate to areas where there is safe water and/or are suitable for agriculture, resulting in conflicts over land-based resources.

Conclusions and future outlook

The main pollution problem is that of high suspended sediment loads in the affluent rivers, particularly the Omo River. Conservation efforts should be directed at minimising soil erosion. Settlements within the area need to be planned and have proper sanitation facilities, better animal husbandry needs to be incorporated, and clean water sources of potable water, such as groundwater should be explored and harnessed to serve the communities.

If there are no intervention measures taken soon, then increased agricultural activities and land degradation along the rivers will result in increased suspended solids being transported to the Lake. There is a likely increase in the use of agro-chemicals as the land becomes less productive, and this will increase the nutrient loading to the Lake and thus increase the rate of eutrophication. Microbiological pollution which is currently not a major problem will increase due to sanitary problems that accompany the growth of settlements. Livestock waste would also significantly contribute to microbiological pollution of the water bodies. Economic impacts will become worse as sediment blanketing and increased turbidity influences changes in benthic and pelagic biodiversity, affecting the fisheries resources particularly in the riverine, shallow water and deltaic areas where subsistence fishermen
fish. Health would be affected as a result of an anticipated increase in microbiological and chemical contamination from organic wastes (e.g. settlements and agro-chemicals). Other social and community impacts would increase as upstream/downstream conflicts increase. Oil exploration efforts offshore of Lake Turkana have been done by several oil companies, including Project PROBE, Amoco Kenya Petroleum Company and National Oil Corporation of Kenya. No economically viable oil deposits have been discovered so far, but this is a prospect which can significantly raise the threat of pollution in the region.

### Habitat and community modification

Lake Turkana Basin is characterised by arid and semi-arid type vegetation in the lowlands, and forest in highland areas of the Omo River. Grassy plains with Yellow spear grass and Commiphora and Acacia sp. characterise the vegetation of the lake region, while Acacia thorn scrub, with larger acacia trees along the river courses, grow around the Lake (Hughes & Hughes 1992). Galleries of forest occur along the affluent watercourses, being characterised by Acacia elatior, Balanites aegyptiaca and Hyphaene coriacea (Hughes & Hughes 1992). The Omo River is bordered by leevale forest and the delta was forested in comparatively recent times (Hughes & Hughes 1992).

In the north Omo zone, deforestation is increasing as a consequence of rapidly growing population (Waktola 1999). Cleared lands are more and more being put under cultivation in the highlands, leading to rapid depletion of soil nutrients and forest resources (Waktola 1999). On the other hand, the pastoralists of the Lake Turkana region occupy arid and semi-arid environments where climatic variability causes distinct pulses of plant production followed by long periods of plant dormancy, but in which the pulses of production are not predictable in terms of time or magnitude (Ellis & Swift 1988). The pastoralists have, with time, developed rational sustainable land use systems based on the mobility of their livestock herds, and making optimal use of the land both geographically and ecologically (Barrow 1988). Thus, the major perturbations on the Turkana Basin ecosystem are droughts of a year's duration or longer (Ellis & Swift 1988) rather than human influence through, e.g. over-grazing and biomass burning.

### Environmental impacts

#### Loss of ecosystems or ecotones

The habitats that are affected to varying degrees are the swamps, riparian belts, deltaic wetlands, river floodplains and the periodic standing water in Ferguson's Gulf. There have not been any comprehensive studies on the biodiversity and ecological structure of these ecosystems. It was concluded that loss of ecosystems is occurring in these areas through habitat fragmentation as a result of nutrient rich soils being cleared for agriculture and settlement, and some of the swamps with lush vegetation being used as grazing areas for livestock.

At the Omo River entrance to Lake Turkana, there has developed a highly complex and spatially fluctuating floodplain and delta (Haack & Messina 2001). Landsat imagery has provided spatial information on the extent of the deltaic growth (particularly significant since 1979) (Haack & Messina 2001). Aquatic vegetation has taken hold on the emerging delta at the possible expense of, e.g., shallow water benthic organisms.

#### Modification of ecosystem habitats or ecotones

Due to climate change and to the extensive land use changes in the region, particularly in the Omo River catchment, the amount of freshwater entering the Lake has declined steadily over the years, resulting in the growth of the Omo delta by about 380 km² between 1973 and 1989 as seen from Landsat images (Haack & Messina 2001). The expansion of the delta wetland is potentially maintaining or increasing the biodiversity of fauna and flora, both locally and regionally (Haack & Messina 2001). On the other hand, the good soil, lush vegetation and availability of water is also attracting permanent human populations, most likely in conflict with flora and fauna (Haack & Messina 2001). Similarly, the areas with gallery forest that occur along the affluent rivers (Hughes & Hughes 1992) are being cleared for cultivation.

The Lake has little-modified fauna and a low level of endemicity with few cichlids (Lowe-McConnell 1995). Shallow areas which are flooded during seasonal rises in lake level may be important for the reproduction of certain fish species e.g. tilapia (Kallqvist et al. 1988), and many of the fish retain the habit of spawning in the inflowing rivers (Lowe-McConnell 1995). Construction of artificial banks to create more room for agriculture, changes of the flow characteristics of the rivers due to diversion of water to irrigate adjacent farms, and increased turbidity, may place these fish at risk. It has been reported that there is a decrease in abundance of some species e.g. Hydrocynus, Alestes and Schilbe, and a decrease in individual mean size at first maturity of fish.

### Socio-economic impacts

The economic impact of deforestation in this area has not been determined. However, the decline in fish landings due to the collapse of the tilapia fisheries in the Ferguson Gulf had a relatively high economic impact. The number of people estimated to be involved in commercial fisheries in Turkana District in 1982 was 30 000 to 40 000 (Kallqvist et al. 1988). However, the decline in fish landings due to the collapse of the tilapia fisheries in the Ferguson Gulf had a relatively high economic impact. The number of people estimated to be involved in commercial fisheries in Turkana District in 1982 was 30 000 to 40 000 (Kallqvist et al. 1988).
1988). This is a significant proportion of the districts total population of 230 000 in 1988 (lower in 1982) (Kallqvist et al. 1988). Reduced fish landings and marketing problems subsequently led to fisheries being much less profitable: the main reason for the decline in fish landings was the collapse of the tilapia fisheries in the Ferguson’s Gulf area due to overexploitation and habitat change resulting from lowered lake levels (affecting spawning grounds), and today Lake Turkana has less than 3% of total fish catches in Kenya (Ikiara 1999). Loss of existing income in the only economic sector (fisheries) had therefore a severe effect, and the effects of the fisheries collapse due to habitat change have persisted over time. There are virtually no other employment opportunities for the local populations.

Fish is a primary source of protein in the area. Drastically reduced fish landings due to habitat change particularly in Ferguson’s Gulf and reduced opportunities for fisheries in the Omo River delta area has negatively impacted on the nutritional status of the population. Although the food poverty level in some areas, e.g. Turkana District is high (81%) (Republic of Kenya 2002b), the degree of severity is not very high as there are alternative protein sources (primarily livestock). The lack of adequate protein supply is continuous, and its improvement is dependent on revival of the fisheries industry.

High rates of deforestation are recorded in the arid and semi-arid lands of Kenya (including the Lake Turkana Basin area), resulting in loss of indigenous biodiversity, destruction of vital ecosystems and habitats (Kirubi et al. 2000). Reduced capacity to meet the basic human need for food and fuel affects the welfare of the family unit. Global acute malnutrition rates in Turkana have increased to between 18–37% in May 2003 compared to 11–21% during the same time in 2002 (UN Kenya 2003). It is estimated that fuel wood and charcoal constitute 95-99% of the total energy demand for cooking, heating and lighting in the arid and semi-arid lands of Kenya (Kirubi et al. 2000). With the ongoing destruction of vital ecosystems and habitats, the already acute situation is likely to get worse. Loss of alternative income has probably affected the family units’ ability to afford education, health services, etc., although there is no quantitative information available on its impact.

**Conclusions and future outlook**

There have not been any comprehensive studies on the biodiversity and ecological structure of the wetland ecosystems that are being increasingly impacted by human activities including sedimentation and modification of river flow. Studies need to be carried out to establish what types of ecosystem habitats have been lost. The economic impact of deforestation in this area has not been determined. Fisheries offer a source of livelihood for the locals and attempts should be made to revive the commercial fishery. There are virtually no other employment opportunities for the local populations.

Better land use practices are critical for the conservation, sustainable use and management of habitats. There is a critical need to initiate studies to understand the natural and socio-cultural drivers of the habitat dynamics that have been observed in the region so that effective implementation policies can be drafted. In the absence of any interventions, it is expected that the economic impact would become more severe as a result of further ecosystem loss and habitat modification. Subsistence fisheries would be most affected as shallow aquatic areas are lost to land, reducing the local populations capacity to meet basic food needs. This, in turn, would increase health risks. The prospect of human conflict would also increase as populations migrate to areas which still retain their ecosystem integrity.

### Unsustainable exploitation of fish and other living resources

There are four fish communities in the Lake (Table 12): littoral, from the lakeshore to about 4 m deep; inshore demersal, from the littoral zone to 10-15 m deep; offshore demersal, from 8-20 m offshore and about 3-4 m above the lake bottom; epipelagic, subdivided into a superficial pelagic community above a midwater scattering layer and a deep pelagic community below this layer down to the demersal zone, extending down to some 60 m in the deepest part of the Lake (Lowe-McConnell 1995). The boundaries of the various communities shift seasonally, depending on the depth of light penetration (Lowe-McConnell 1995).

The Lake is currently largely unexploited but has the potential for fishing and tourist attraction (Republic of Kenya 2002a and b). There is no evidence of decreased viability of stocks through contamination and disease, nor of destructive fishing practices.

### Environmental impacts

**Overexploitation**

Fishing takes place both in the unprotected Omo River delta (Hughes & Hughes 1992) and in the Lake. Based on measured primary phytoplankton productivity, an empirical model predicted a total fish yield of 22 000 tonnes per year for Lake Turkana, and the sustainable yield of traditionally exploited fish from the offshore areas of the Lake is estimated at 15 000 to 30 000 tonnes per year (Kallqvist et al. 1988). The fisheries of Lake Turkana are, today, operating way below their
sustainable yield limits. The impact of overexploitation is scored as slight based on the criteria that “commercial harvesting exists but there is no evidence of overexploitation”.

**Excessive by-catch and discards**

Although there is no information on current excessive by-catch and discard, the issue was categorised as having a slight impact based on the fishing practices that partly led to the collapse of the fisheries sector in the 1980s and the under-recovery of the fish stocks in traditional fishing bays such as Ferguson’s Gulf.

**Impact on biological and genetic diversity**

The introduction of alien stock (Nile perch) is considered as having a slight impact because there is, apparently, no evidence that it has caused major changes in the community structure of the Lake.

**Socio-economic impacts**

Fisheries is currently mainly a subsistence activity that is not contributing much to the economy of the area. Today, Lake Turkana has less than 3% of total fish catches in Kenya (Ikiara 1999), and most of the proceeds from fish sales are expatriated to other parts of the country. There are no known health impacts except those that may arise from consumption of naturally diseased fish (which has a very low probability). There are no social impacts as the current fish landing rates are far below the sustainable yield of the Lake’s fisheries resource. Fishing is mainly at subsistence level.

**Global change**

The Lake Turkana Basin is prone to frequent droughts. Drought is reportedly occurring more frequently (Waktola 1999), with elders in Turkana recalling recent droughts in: 1984, 1992-93, 1996, 1997, 1999, and 2000 (Hann et al. 2003). The rainfall pattern and distribution is erratic both in time and space, and it tends to fall in brief, violent storms that result in flash floods (Republic of Kenya 2002b). Lake Turkana responds drastically to climatic variability.

There is no evidence (no studies carried out) of increased UV-B radiation as a result of ozone depletion or of changes in lake CO₂ source/sink function. Some gas charged sediments are reported in Lake Turkana from seismic profiling, but no further work has been done to verify and quantify the flux.

**Environmental impacts**

Changes in hydrological cycle and lake circulation

The growth of the delta (Haack & Messina 2001) is partly a result of increased aridity. Both a decrease in precipitation within the catchment basin and an increase in temperature can be contributing factors. An increase in temperature would increase evaporation rates from the surface of the Lake and elsewhere in the region and decreased soil moisture would lessen run-off.
An annual cycle of stratification of the lake waters was observed in 1988: stable stratification from March to May and complete circulation in June to July (Kallqvist et al. 1988). The stratification influenced the distribution of fish in the deep water over as much as 20% of the lake area (Kallqvist et al. 1988). For the rest of the year, there is partly restricted vertical mixing with a temperature gradient of 1 to 2°C from the surface to the bottom at 70 m (Kallqvist et al. 1988).

Lake-level change

On a perennial basis the lake level fluctuates about 1 m every year from the seasonal flooding of the Omo River (Ferguson & Harbott 1982) and has fluctuated over 20 m in the past century (Butzer 1971). It was 15 m higher at the end of the 19th century and 5 m lower in the 1950s (Figure 14). These changes were climatic and to a lesser extent geomorphological in origin. The changes since then are more dramatic and more likely to be anthropogenic (Haack & Messina 2001).

Socio-economic impacts

Lack of potable freshwater and food during periods of drought have incurred high economic costs to the two countries at large in terms of resettlement and food aid (Waktola 1999, Hann et al. 2003). Declining water levels in Lake Turkana led to the collapse of the fishing industry at Kalokol as the catch declined and the shoreline moved 6 km away from the only cooling and fish-processing plant. Lack of potable water and food during periods of drought leads to malnutrition and even deaths. In southern Ethiopia, for example, during the famine in 1985-86, there was a 40% increase in mortality among children under five years old in “traditional and stable societies” and a three- to fourfold increase for those who were living in relief shelters (CIHI 1996). A lack of potable water and food during periods of drought leads to large-scale displacement of populations and fragmentation of family units. Most of the poorest people in Turkana District dwell in the northern part and central plains where there is recurrent drought and disease (Turkana District Development Plan 2003). Social conflicts increase over the sharing of limited resources (cf. Raymakers 2003). It takes a fairly long time to revert back to the normal way of life after such events. For example, during the severe drought that was experienced in 1999–2000 in the Lake Turkana area, there was heavy loss of livestock resulting mainly from lack of forage and disease outbreaks, reduced agricultural production, necessitating the remobilisation of resources to save the lives of both humans and livestock through the provision of water, relief food and food supplements, disease control, and provision of health services (Republic of Kenya 2002b). Cattle rustling, which is rampant in the area around Lake Turkana, is probably partly driven by the need to re-stock livestock herds that have been devastated by drought. Cattle rustling and bandit raids lead to loss of life, loss of property, displacement of families, destruction of infrastructure such as schools, health and water facilities, and disruption of education and farming (Republic of Kenya 2002b).

Conclusions and future outlook

The projected increases in global temperatures are expected to lead to significant local changes in precipitation and evaporation. The volume and level of Lake Turkana is likely to continue fluctuating widely, with a probable overall downward trend due to global warming and to the intensification of land and water use in the catchment (Nyamweru 1992). These changes in lake level will have significant effects on the lacustrine wetlands (Nyamweru 1992) and biodiversity, e.g., upstream of the Omo River delta is an extensive floodplain: the existing combined wetland (4°28’–5°13’ N; 35°44’–36°13’ E) covers 120 000 ha (Hughes & Hughes 1992). Higher temperatures may also result in longer periods of stratification in lakes with reduced dissolved oxygen contents. During periods of stable stratification, there can be conditions where reduced dissolved oxygen will affect fishes, as was noted in May 1988 when stable stratification influenced the distribution of fish in the deep water over as much as 20% of the lake area (Kallqvist et al. 1988). Reduced lake levels will also result in increased salinity and pH of the water, which would have adverse effects on phytoplankton, zooplankton, fish biodiversity and fish stocks. Changes in water quality will also affect the avian fauna, particularly water-edge and migrating birds.

Priority concerns

The concerns that are recommended for further analysis based on the outcome of the GIWA assessment are: Habitat and community modification and Freshwater shortage. The concerns were ranked in descending order of severity:
1. Habitat and community modification
2. Freshwater shortage
Habitat modification is a result of all the other four GIWA concerns, although Unsustainable exploitation of fish and other living resources is the least significant in this case and is not discussed further. With respect to Global change, the trend of reducing precipitation and higher temperatures can result in increased concentrations of pollution in the Lake due to reducing lake level (and volume). However, global change is more important in its influence on freshwater through the hydrological cycle. It can also drive habitat change but this, as a naturally occurring process, would be on the order of decades to millennia. Pollution, which in this case is due mainly to suspended sediments that originate from habitat change (land clearance, degradation and increased erosion rates) in the principal river catchments, can affect natural habitats in the Lake by limiting light penetration and smothering benthic organisms. High microbiological load also reduces the availability of potable water. Freshwater shortage is most closely linked to habitat modification. The freshwater shortage arises primarily due to abstraction of river water for irrigation, and damming. This has, in part, led to rapid delta growth and hence modification (e.g. loss of ecosystems and changes in population structure) of the wetland areas in the deltaic and floodplain areas of the principal rivers, as well as in the littoral waters of the Lake. The linkages between the GIWA concerns are shown in Figure 15.

**Figure 15** Linkages between the GIWA concerns in Lake Turkana.
Lake Victoria Basin

Table 13  Scoring table for Lake Victoria.

<table>
<thead>
<tr>
<th>Assessment of GIWA concerns and issues according to scoring criteria (see Methodology chapter)</th>
<th>Environmental impact</th>
<th>Economic impacts</th>
<th>Health impacts</th>
<th>Other community impacts</th>
<th>Overall Score*</th>
<th>Priority***</th>
</tr>
</thead>
<tbody>
<tr>
<td>No known impacts</td>
<td>1</td>
<td>0.1</td>
<td>0.6</td>
<td>1.0</td>
<td>1.3</td>
<td>5</td>
</tr>
<tr>
<td>Slight impacts</td>
<td>2</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.1</td>
<td>1</td>
</tr>
<tr>
<td>Moderate impacts</td>
<td>3</td>
<td>1.1</td>
<td>1.2</td>
<td>1.8</td>
<td>1.5</td>
<td>3</td>
</tr>
<tr>
<td>Severe impacts</td>
<td>4</td>
<td>1.3</td>
<td>1.4</td>
<td>1.0</td>
<td>1.3</td>
<td>4</td>
</tr>
</tbody>
</table>

The arrow indicates the likely direction of future changes.

- Increased impact
- No change
- Decreased impact

Table 14  Demographic and biophysical characterisation of the inlet drainage basins of Lake Victoria.

<table>
<thead>
<tr>
<th>River basin</th>
<th>Countries sharing basin</th>
<th>Basin size (km²)</th>
<th>Population density 2000 (people/km²)</th>
<th>Total population 2000</th>
<th>Mean annual rainfall (mm)</th>
<th>Sediment transport capacity index*</th>
<th>Average % slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nzoia/Yala</td>
<td>Kenya</td>
<td>15 143</td>
<td>221 (±154)</td>
<td>3 346 000</td>
<td>1 306</td>
<td>0.14</td>
<td>2.3</td>
</tr>
<tr>
<td>Nyando</td>
<td>Kenya</td>
<td>3 517</td>
<td>712 (±127)</td>
<td>611 000</td>
<td>1 360</td>
<td>0.30</td>
<td>5.0</td>
</tr>
<tr>
<td>Sondu-Miriu</td>
<td>Kenya</td>
<td>3 583</td>
<td>788 (±148)</td>
<td>842 000</td>
<td>1 415</td>
<td>0.14</td>
<td>2.3</td>
</tr>
<tr>
<td>Gucha</td>
<td>Kenya</td>
<td>6 612</td>
<td>1 481 000</td>
<td>1 300</td>
<td>0.16</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Mara</td>
<td>Tanzania</td>
<td>13 915</td>
<td>640 000</td>
<td>879 000</td>
<td>0.15</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>Gurumeti</td>
<td>Tanzania</td>
<td>12 290</td>
<td>258 000</td>
<td>897 000</td>
<td>0.12</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>Mbalaget</td>
<td>Tanzania</td>
<td>5 702</td>
<td>211 000</td>
<td>766 000</td>
<td>0.05</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Duma/Simiyu</td>
<td>Tanzania</td>
<td>9 702</td>
<td>485 000</td>
<td>804 000</td>
<td>0.06</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Magoga/Muale</td>
<td>Tanzania</td>
<td>5 104</td>
<td>469 000</td>
<td>842 000</td>
<td>0.05</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Isonga</td>
<td>Tanzania</td>
<td>3 972</td>
<td>430 000</td>
<td>897 000</td>
<td>0.04</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Kagera</td>
<td>Tanzania/Uganda/Rwanda/Burundi</td>
<td>59 158</td>
<td>10 711 000</td>
<td>1 051</td>
<td>0.24</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Lake edge</td>
<td>Tanzania/Uganda</td>
<td>40 682</td>
<td>5 411 000</td>
<td>1 077</td>
<td>0.21</td>
<td>1.4</td>
<td>1.4</td>
</tr>
</tbody>
</table>

Freshwater shortage has only slight impact in Lake Victoria Basin. The freshwater shortage in the Lake Basin, most of which is due to pollution of existing supplies, is driven principally by pollution as a major concern. This issue is, therefore, tackled in more detail in the section on Pollution.

Environmental impacts

Modification of stream flow

Some of the inflowing rivers from the catchment have been modified by activities involving irrigation (Nyando, Yala and Kagera rivers), valley dam construction (Sondu-Miriu and Yala rivers) and for others, the flood plains and wetlands have been degraded (most of the affluent rivers). This leads to reduction of inflow (Scheren et al. 2000, Lowe-McConnell 1994, Awiti & Walsh 2002), but the effects are constrained mostly in the specific river drainage basins where water is being abstracted, since direct precipitation on the Lake is by far the dominant principle source of water in the lake system. Out of the total irrigation potential of 469 400 ha in Kenya, 214 000 ha (46%) lies within the Lake Victoria Basin where the unexploited potential is still large (Marenya & Nyaguti 2000).

Table 14  Demographic and biophysical characterisation of the inlet drainage basins of Lake Victoria.

* Areas with high indices are those with higher potential for erosion. (Source: Shepherd et al. 2000)

### Freshwater shortage

The waters of Lake Victoria and its shoreline are shared between three countries; Kenya (6%), Uganda (43%) and Tanzania (51%). Additionally, the catchment of the principal affluent river, the Kagera, runs through the countries of Rwanda and Burundi. There are 11 main rivers draining into Lake Victoria: Nzoia, Yala, Nyando, Sondu-Miriu, Gucha, Mara, Gurumeti, Duma, Simiyu, Magoga, Isonga and Kagera (Figure 16, Table 14) (Shepherd et al. 2000). Of these, only two are shared; the Kagera by Tanzania, Rwanda, Burundi and Uganda; and the Mara by Kenya and Tanzania. The only surface outlet is the Nile River, which has the Owen Falls hydroelectric power station at its source.
Pollution of existing supplies

Lake Victoria provides freshwater supply for domestic, agricultural, livestock and industrial use. Tropical lakes are at particular risk from pollution hazards, owing to the lower oxygen saturation levels and high oxygen consumption rates which occur at high temperatures (Cohen et al. 1996). In Lake Victoria, pollution is a major problem. Since the 1960s, the Lake has experienced a serious decline in water quality (microbiological and chemical contamination, increased suspended solids, etc.) negatively impacting on dependent communities. Several chemical pollution studies have detected low levels of trace metals and pesticides in the water, sediments, plants, and fish species of the Lake (Wandiga 1981, Wandiga & Oryani 1987, Ejobi et al. 1994, Ruud 1995, Wasswa 1997, Ssentongo 1998, Henry & Kishimba 2000, Tole & Shitsama 2000, Kituyi et al. 2001, Kasozi 2001). However, though the concentration levels are below the acute toxicity level they may be of concern to the food chain (Wandiga 2002).

Many rivers and even sewerage outlets drain through swamp areas before discharging to the open waters of Lake Victoria. When flowing slowly through the swamp, the biological oxygen demand (BOD), nutrients, pathogens and other pollutants in the water generally reduce (Kansiime & Nalubega 1999, LVEMP 2001). The wetlands environmental function as a sink for pollutants is, however, potentially in danger through loss of ecosystem function as a result of harvesting, clearing, cultivation and diversion of water for irrigation agriculture (Balirwa 1998, Chapman et al. 2001, LVEMP 2001).

Figure 16  The major drainage basins of Lake Victoria.
Changes in the water table
Groundwater stored within the Lake Victoria catchment was estimated in 1979 to be of the order of 70 000 million m³, while the total annual groundwater discharge was about 18 million m³, of which 7.5 million m³ was discharge to streams and 4.9 million m³ was that extracted by pumping (Ongwenyi 1979). These are broad estimates in view of the fact that no quantitative assessment has been attempted (Ongwenyi 1979). In the Kenya sector, the groundwater is of excellent chemical quality (total dissolved solids concentration is of the order of 500 ppm and rarely exceeds 1000 ppm) and can be put to a variety of uses (Ongwenyi 1979). The only problem is that in places the groundwater contains excessive fluoride concentrations far in excess of the 1.5 ppm stipulated for drinking water purposes (Ongwenyi 1979). The expansive and continual land degradation, soil erosion and deforestation that has been taking place over the past few decades within Kenyan sector of the catchment (Swallow et al. 2002), provides indirect evidence that there is declining base-flow in rivers. There have been reports of over-abstraction of water in some wells within the region, but the regional extent of this is not known. Studies are required to quantify base-flow in rivers and to establish the regional nature of the groundwater aquifers in the Lake Basin, their quantity and yield, in order to be able to sustainably manage the resource.

Socio-economic impacts
There are no significant economic impacts arising from freshwater shortage in the Lake Basin. Treatment of common water-borne diseases and loss of income due to incapacitation has some effect on economic activities and livelihoods in the Basin, and is particularly exacerbated by the generally high poverty levels. Many of the people living in villages along the shoreline and close to the rivers in the catchment area as a whole draw their water directly from these sources for domestic use and consumption without any treatment (Bwathondi et al. 2001, Thompson & Cairncross 2002). Except for the urban centres, the rural settlements do not have any treated water supply networks nor sanitation infrastructure. Although more homes are today supplied with piped water, the supply is irregular and unevenly distributed (Thompson & Cairncross 2002). Nzoia, Yala, and Nyando rivers (Shepherd et al. 2000) and the lake area around the large urban centres such as Kisumu, Kampala and Mwanza, are the most polluted. Along the lake edge, the problem has become worse because the water is often dirty and smelly because of the rotting mats of hyacinth weed (NEMA 1998, Mailu 2001), even in areas that are far removed from urban centres. Groundwater development projects conducted by NGOs in these areas have somewhat mitigated the impact of use and consumption of polluted water. Polluted water supplies compel the affected communities to search farther away from their villages for sources of clean water. These sources are normally groundwater wells and boreholes that have been constructed by NGOs and national governments.

Conclusions and future outlook
Other than the pollution of existing supplies, freshwater shortage is not yet a critical problem in the Lake Basin. The Kenya National Water Master Plan includes plans for dams and water transfer projects from the Basin to other river basins or sub-basins in the country (UNECA 2000). There are several localities within the Lake Basin in Kenya where dams have been proposed, and recently the Sondu-Miriu Dam on Sondu-Miriu River has been built mainly for hydroelectric power supply. Tanzania also plans to transfer water from the Lake to the Vembere Plateau in the Manonga River Basin in central Tanzania to irrigate between 88 000 and 230 000 ha of land (UNECA 2000). The effects of this structure and others proposed may lead to freshwater shortages. Land degradation and deforestation in the watershed regions and the catchment as a whole will steadily lead to the depletion of natural water supply (both surface and groundwater) in the drainage basin, with adverse consequences.

Interventions are required to initiate sustainable development within the catchment to protect the critical watershed areas and aquatic systems. Maintenance of the status quo would have adverse impacts in the long run. Economic impacts will arise due to loss of; agricultural uses and productivity (crops, livestock, aquaculture), hydroelectric power production, and industrial uses. There would also be increased costs of intake treatment and damage to water-related equipment. Freshwater shortage would also lead to loss of human drinking water supplies, recreational use and aesthetic values, and waste assimilative capacity. There will be increased potential for upstream/downstream conflicts, and reduced availability of fish as food.

Pollution
In Lake Victoria and its influent rivers, pollution is a major problem. From the catchment areas, there are: diffuse pollution sources such as silting and agrochemicals which increase biological oxygen demand (BOD) and fertilise the Lake; and point pollution sources including industrial wastewater effluents and solid wastes, domestic sewage and organic and microbial loads (Wandiga & Onyari 1987, Kansiime & Bugenyi 1996, Kansiime & Nalubega 1999, Scheren et al. 2000).

Most of the farming systems in the Lake Basin are associated with slash and burn land management practices. Burning residues left in forest
timber harvesting produce an even greater increase in the release of ions from the forest litter and mineral soil than the harvesting operation itself. The impact of these ions (most of which are nutrients like nitrate, phosphate and sulphate) on the Lake has been an increase in eutrophication (Hecky 1993). Nutrient loads to the Lake are associated mainly with atmospheric deposition (natural and biomass burning) and land run-off (e.g. agriculture), and these together account for about 90% of phosphorus and 94% of nitrogen input to the Lake (Scheren et al. 2000). Other nutrient sources include riverine input, nitrogen fixation, the upward flux of nutrients from the water layers below (Hecky 1993), and sewerage effluents from urban centres. Millions of litres of untreated sewage sludge flow into the Lake every day from major urban centres along the lake shore (Scheren et al. 2000). In Uganda for example, expired chemicals as well as drugs and partially treated domestic sewage from the Kampala area is dumped into public waterways, which finally ends up in Lake Victoria (Kiremire 1997).

**Environmental impacts**

**Microbiological**

Microbial pollution is a big problem with many incidences of epidemics of cholera, dysentery and intestinal problems (e.g. Karanja 2002). There are major urban centres located near the Lake, such as Kampala and Entebbe in Uganda, Bukoba and Mwanza in Tanzania, and Kisumu in Kenya. Large sectors of these and other urban-periurban centres either do not have, or are poorly served by a public sewerage system; raw sewage is discharged directly into the Lake (Nriagu 1992). Pit latrines are the most common method of on-site sanitation in Mwanza. This leads to seepage of sewage to low-lying areas and streams. In 1995, with the exception of the Mwanza Tanneries, which had a wastewater treatment facility, all the industries in Mwanza drained their wastewaters into Lake Victoria without any treatment (Kishimba & Mkenda 1995), and the situation remains significantly unchanged to date.

**Eutrophication**

Eutrophication has increased drastically within the last four decades due to high levels of nutrients (Hecky 1993). Landscape disturbance from the 1930s onwards, and the resulting increase in soil erosion and sedimentation is the dominant cause of the ongoing eutrophication (Verschuren et al. 2002). Algal blooms have increased since the 1960s (Mugidde 1993). The filamentous and colony forming blue-green algae, known for causing hypoxic conditions that occasionally lead to fish kills is now very dominant in Lake Victoria (Kling et al. 2001). Domestic biological oxygen demand exceeds industrial loads in all regions (Scheren et al. 2000). The use of agrochemicals is increasing in the Lake Basin where there are large-scale farms of coffee, tea, cotton, rice, maize, sugar and tobacco (Ntiba et al. 2001). Consequently, nearly half of the lake floor currently experiences prolonged anoxia for several months of the year, compared to the 1960s when anoxia was localised and sporadic (Talling 1965 and 1966; Hecky 1993). Algal concentrations are three- to fivefold greater in the surface waters today than in the 1960s, reflecting higher rates of photosynthesis (Mugidde 1993). In consequence, dissolved silica concentrations in the water column have plummeted to 10% of their 1960s values (Hecky 1993, Verschuren et al. 2002). Enhanced denitrification has lowered the N:P ratio and blue-green algae have replaced diatoms as the dominant phytoplankton in the Lake (Hecky 1993, Verschuren et al. 2002).

From satellite imagery, it has been observed that nutrient-rich sediment plumes originating from agricultural run-off and the low-lying, deforested riparian zones and other areas surrounding the Lake are feeding the water hyacinth (Wilson et al. 1999). For instance, in September 1998 the water hyacinth mat covered 400 000 ha of the Kavirondo Gulf in Kenya (Figure 17). In the same year, four-fifths of Uganda’s shoreline was covered by the hyacinth mat. Its spread has disrupted fishing activities, transportation, and has threatened the functioning of various lakeshore-based installations such as water purification and hydroelectric power plants (e.g. Twongo 1996). Proliferation of the water hyacinth leads to reduced oxygen levels, and hence reduced floral and faunal diversity (Kudhongania et al. 1996). A study in the Ugandan part of Lake Victoria has shown that in the vicinity of the water hyacinth mats, fish species number, biomass and diversity are reduced, the former two very significantly (Willoughby et al. 1996). It, however, provides a protective habitat for some of the endangered haplochromine species, hippopotamus, crocodiles, snakes, as well as bilharziasis carrying snails and mosquitoes.

The extinction of the haplochromine species have been attributed to occurrence of seasonally persistent deep-water anoxia since the late 1970s (Kaufman & Ochumba 1993, Hecky et al. 1994); decimation
of demersal haplochromine fish stock by Nile perch since the former deep-water refugium that protected them from predation had been destroyed by lack of oxygen; and historical land use that resulted in massive nutrient load with subsequent algal production in Lake Victoria (Verschuren et al. 2002). The last cause indicates that landscape disturbance rather than food-web alteration or climate change is the dominant cause of the ongoing eutrophication. All the three factors have contributed to species decline with the major cause being attributed to land management whose control remains the significant remedy for saving the Lake.

Chemical
The use of agrochemicals is increasing in the Lake Basin where there are large-scale farms of coffee, tea, cotton, maize, sugar and tobacco (Ntiba et al. 2001). In the industrial sector, the polluters include e.g. breweries, sugar refineries, soft drink and food processing factories, oil and soap mills, leather tanning factories and mining companies (Ntiba et al. 2001). Pollution has also been reported in feeder rivers and streams (e.g. Wandiga & Onyari 1987, Kishimba & Mkenda 1995). Beer brewing, pulp and paper production, tanning, fish processing, agro-processing and abattoirs discharge raw/untreated waste to feeder rivers and lakes (e.g. Wandiga & Onyari 1987, Ntiba et al. 2001). All these have contributed to the degradation of river and lake water quality for habitat and drinking use (Wandiga & Onyari 1987, Ntiba et al. 2001).

Several chemical pollution studies have detected low levels of trace metals and pesticides in the water, sediments, plants, and fish species of the Lake (Wandiga & Onyari 1987, Wasswa 1997, Ejobi et al. 1994, Kasozi 2001, Ssentongo 1998, Henry & Kishimba 2000, Wandiga 1981, Kituyi et al. 2001, Ruud 1995, Tole & Shitsama 2000). However, though the concentration levels are below the acute toxicity level they may be of concern to the food chain (Wandiga et al. 2002). The increase of small-scale gold mining in Tanzania in particular (gold mining also takes place in Kenya) is leading to some contamination of the local waterways by mercury which is used to amalgamate and recover the gold; some traces of heavy metals such as chromium and lead are also found in the Lake, although the problem has not yet reached major proportions. Expired pesticides are disposed of in the Lake, for example, used chlorine has been dumped into the Lake killing a lot of aquatic organisms. Some companies have stockpiles of banned substances such as DDT and may potentially dispose of these in the Lake.

Suspended solids
Lake Victoria Basin is mainly (80%) an agricultural catchment (Majaliwa et al. 2000). The current population pressure (more than 30 million people in the catchment) on forests, wetlands, rangelands and marginal agricultural lands as well as inappropriate cultivation practices, forest removal and high grazing intensities (that, in extreme cases, leave barren environments) lead to unwanted sediment and stream flow changes that impact mainly the downstream communities (Magunda & Majaliwa 2000, Botero 1986). Forests and bush are cleared, and wetlands are encroached to create space for human settlement, roads construction and to satisfy wood fuel energy demands. Similarly, pastoral areas are subjected to growing human and livestock populations, leading to land degradation, soil erosion and to an increase in the load of non-point pollutants. Land use activities that alter the type or extent of vegetative cover on watersheds frequently will change water yield and in some cases, maximum and minimum stream flow. The overall effect of deforestation/change of plant species because of population pressures has increased sediment loading to rivers and lakes in the Basin (Swallow et al. 2002). The sediment loads from such areas are normally high in nutrients and organic matter (Ffolliot & Brooks 1986).

Solid waste
Solid waste pollution is localised in areas with high population densities, such as the downstream sections of the rivers, and around the lake edge close to urban centres or settlements (personal observations). These waterways are used for dumping of various types of solid wastes such as plastics, scrap metals, paper, wood and other types of waste from cottage industries, etc. (personal observations).

Socio-economic impacts
The costs are related to wastewater treatment, the cost of alternative supplies and the costs of removing invasive weeds (Twongo 1996) plus the costs of treating diseases (Karanja 2002). The cost of treating the water before supplying it to the public is high because of the diverse range and high concentrations of pollutants in the water. Suspended solids also raises cost in relation to reduced output capacity and cleaning of turbines at the hydroelectric power stations, and reduces the lifespan of dams. The fish kills, migration of fish from certain areas because of anoxic conditions (Hecky 1993) and the cyanotoxins (Mugidde 1993) negatively impact on the output from the fisheries industry. An additional effect on this sector is due to loss of income from fishing because of e.g. fish gill clogging by the suspended solids (Awiti & Walsh 2002, Kairu 2001). Pollution and unhygienic conditions resulted in great economic loss (estimated at 300 million USD) after the European Union temporarily banned fish imports/exports to Europe from East Africa in 1997 because of the fear of the contaminated fish.

There are many people affected by pollution through using and bathing in dirty Lake Victoria water or influent river waters. Dumping untreated sewage in the Lake and nearby rivers exposes people to water-borne
The riparian communities have relied on the Lake as a steady source of fish protein. In recent years the Lake has provided a near constant amount of about 20,000 tonnes of harvestable haplochromine fishes.

In the last 40 years the Lake’s ability to provide fish has been severely compromised by a host of human impacts. These range from increased soil erosion estimated at 690 million to 19,800 million tonnes per year (Verschuren et al. 2002) with high nutrients, fertilisers and pesticides loads from farming and deforestation activities; increased urban run-off and sewage spills; accidental introduction of water hyacinth; planned introduction of Nile perch; industrial and chemical wastes; and the destruction of wetlands with contaminant sink potential.

**Conclusions and future outlook**

Microbiological pollution, eutrophication, suspended solids and chemical pollution are the most important issues in this GIWA concern and occur over a significant proportion of the Lake Victoria Basin. All these pose many problems of an economic, social and/or health nature. The certain population increase will increase demand for freshwater and other land-based resources, leading to greater pressure to modify the stream/river flows and higher rates of land degradation. The governments of the region and international agencies such as GEF and the World Bank have provided funds for water quality assessments with a view to mitigate pollution.

Failure to address the pollution concern immediately would have far reaching and adverse consequences. Pollution in its various forms would lead to increased risks to human health, with attendant increased costs of human health protection, costs of medical treatment, cost of water treatment and clean-up, etc. Aquatic species would become increasingly endangered if pollution is not controlled. Because of the increase in population, increase in urbanisation, and with no poverty alleviation programme, there will be a measurable number of people whose health and livelihoods will be impacted, even if there is a general increase in awareness of the problem. Other economic impacts would include increased costs of weed control (hyacinth), intake cleaning and maintenance of monitoring programmes. Improvement in technology would make operations cheaper, despite the high capital cost of investment. The problem of pollution will have to be addressed within the context of a transboundary integrated land and water management plan. Critical habitats such as watershed areas, river banks and wetlands need to be urgently protected, and a quantitative assessment of sources, pathways and fluxes of various types of pollutants needs to be carried out in order to initiate effective interventions. Rules and regulations governing pollution at national and international level need to be reviewed and enforced, while governments need to put in more money into the provision of safe water and the enhancement of sanitation infrastructure in the Basin.
**Habitat and community modification**

Degraded and deforested lands (including wetlands) are becoming increasingly characteristic features in the Lake Victoria catchment (e.g. Shepherd et al. 2000, Swallow et al. 2002). Land use activities that alter the type or extent of vegetative cover on watersheds frequently will change water yield and in some cases, maximum and minimum stream flow. The overall effect of deforestation/change of plant species because of population pressures is increased sediment loading to rivers and lakes in the Basin. The sediment loads from such areas are normally high in nutrients and organic matter (Ffolliot and Brooks 1986). Most of the farming systems in the Lake Basin are associated with slash and burn land management practices. The estimated extent of change of land cover as a result of human activities has been outlined in the Regional definition section.

Lake Victoria is believed to have been invaded by water hyacinth in the late 1980s (Freilink 1991), through the Kagera River (Twongo 1996), and since then a constant stream of the plant to cover 3 ha per day has entered the Lake. On entering the Lake it found a fertile environment for its multiplication. The weed thrives in bays and inlets which are sheltered from strong offshore and along-shore winds; have flat or gently sloping, relatively shallow shores (rarely deeper than 6 m); and have a muddy bottom rich in organic matter (Twongo 1996).

**Environmental impacts**

**Loss of ecosystems or ecotones**

Land degradation and deforestation in the lake catchment area and along the river banks is probably contributing to loss of ecosystems (e.g. Shepherd et al. 2000, Swallow et al. 2002). The acreage under cultivation for cash and food crops (namely tea, tobacco, rice, beans, coffee and sugar cane) in Nyanza province, for example, has increased from about 15 400 ha in 1968 to 157 000 ha in 1991-1992 (Kairu 2001). Studies are, however, needed to quantify the level of ecosystem loss.

Much of the lake margin is swampy, and islands of Cyperus papyrus, with its typical associates, detach from the fringing swamps (Hughes & Hughes 1992). The continuous cropping of papyrus along the lake shore could have very serious ecological effects, including the loss of large quantities of nutrients removed with the harvested papyrus biomass that would otherwise be recycled (Muthuri et al. 1989). The interface of papyrus swamps and the open water is also often a chemically rich habitat that harbours a high diversity and biomass of aquatic organisms. The Lake itself contains submerged species such as Ceratophyllum demersum and Potamogeton spp. around the margins, waterlilies and Pistia stratiotes are found floating in quiet spots, and there are many animals including water turtles, aquatic snakes, monitor lizards, crocodiles, numerous birds, rodents, otters and Hippopotamus amphibius (Hughes & Hughes, 1992).

Ecosystem changes in the catchment area include, for example, the large-scale draining of the Yala swamp in Kenya to create land for agriculture and settlement (Grabowsky & Poort 1987). Also, clearing of riparian vegetation has led to erosion and loss of vegetation that acted as filters (Lowe-McConnell 1994). Indications are that the on-going and unregulated wetland conversion may contribute to a decline of floral and faunal diversity through loss of habitat, destruction of refugia, and floral/faunal mixing. Studies do, however, need to be conducted to estimate the loss of ecosystems in the swamps.

**Modification of ecosystems or ecotones**

As recently as the 1960s, Lake Victoria supported an endemic cichlid fish species flock of between 300 and 500 members, but these have progressively disappeared from the catches to become poorly represented today. The losses are attributed to habitat degradation in the catchment, introduction of alien species (particularly Nile perch), heavy fishing pressure (Ogutu-Ohwayo 1990, Witte et al 1999), proliferation of filamentous and blue-green algae, and development of anoxic conditions within the Lake (Kling et al. 2001). This indeed reflects a most startling loss of fish species that has resulted from modification of an ecosystem.

Land use change can potentially lead to extreme impacts on food security in the region. For example, approximately 46% of the 3 516 km² Nyando River Basin (or 1 624 km²) has experienced severe soil physical erosion, and it is estimated that only 868 km² remains unaffected by soil physicochemical degradation or soil nutrient deficiencies of one form or another (Swallow et al. 2001). The most degraded parts of the Nyando River Basin, both in terms of nutrient deficiencies and soil physical degradation, are areas currently used for open grazing and extraction of fuel wood; areas currently used for subsistence agriculture are also characterised by both types of degradation but at lower prevalence rates than grazing areas (Swallow et al. 2001). In the Mara, Mwanza and Kagera basins, clearing of forests has resulted in deforestation, a dominant feature in most parts of the area where land is left bare following the expansion of settlements, livestock keeping and agriculture (Hongo 2000). Further research is, however, required to establish the linkages between land degradation, and biodiversity and ecosystem change in the rivers and lake.

The wetlands of the Lake Victoria region have recently witnessed increased pressure from exploitation due to the need for land to
produce more food, space to settle the rapidly growing population and for other development projects. The full extent of wetland use and its impacts are not well known (Kairu 2001), but satellite imagery suggests that it is substantial, based on observed erosion from shoreline zones (Wilson et al. 1999). The current degree of modification of the littoral belt wetlands still needs to be quantified. Some data from the inland wetlands provides some clues. For example, the Nakivubo Urban Wetland close to Kampala, Uganda, is being reclaimed for agricultural, industrial and residential expansion; already, slightly over half of the total wetland close to Kampala, Uganda, is being reclaimed for agricultural, inland wetlands provides some clues. For example, the Nakivubo Urban littoral belt wetlands still needs to be quantified. Some data from the

Recent invasion of the Lake with water hyacinth (Twongo 1966, Twongo et al. 1995) exemplifies Lake Victoria as an interesting area for lake-wide scientific studies for years to come. The usually anaerobic conditions under which the decay process takes place lead to production of noxious gases like ammonia and hydrogen sulphide. Together with the light shading effects of the dense weed mats, which interfere with photosynthesis, the water environment under the weed mats influences changes in the diversity and distribution of aquatic biodiversity. The maximum water hyacinth cover in Lake Victoria was reached between 1994 and 1995 when 80% of the Uganda shoreline was covered with about 4 000 ha of water hyacinth, there was 6 000 ha coverage in Kenya, and about 2000 ha in Tanzania (Mailu 2001). The situation in June 2002 showed much reduced, disintegrated, and stunted water hyacinth cover along the shorelines of all three countries (Mailu 2001). It is argued that this reduction in water hyacinth is mainly due to the biological control method, achieved through the introduction of Neochetina weevils in 1996, but further studies are required to make a conclusive statement on this. Recent reports from the LVEMP Secretariats (Nyirambu, personal communication), indicate that about 80% of the hyacinth infestation has been cleared from the Lake.

**Socio-economic impacts**

The negative economic impact of the loss of fertile agricultural soils in the Lake Basin as a result of erosion could be fairly high, as described above. The immediate effect of wetland modification is somewhat mixed: although the economic benefits of wetland resources could be high as a result of income from agricultural activities, harvested papyrus sales, brick making, etc. (Schuitj 2002), wetland loss adversely affects the flora, fauna, and the natural buffering and other functions of the system. The economic costs of controlling the water hyacinth invasive weed (Twongo 1996, Twongo et al. 1995) and for restoration of the modified ecosystems are high. Costs related to hyacinth clean-up are substantial but they are in localised areas, for example the shipping harbours and water intake points. There have also been losses of earning opportunities when fishermen could not access fishing and fish landing sites, and through interference with fishing gear and clogging of pumps, as a result of water hyacinth infestation (Mailu 2001). Reduced access to water resources, possibly enhanced occurrence of diseases such as schistosomiasis, malaria, increased risk of snake bites etc., are important health outcomes that are in part contributed to by loss or modification of habitats, particularly as a result of the water hyacinth infestation. The negative health knock-on effects of water hyacinth are inconclusive (see Mailu 2001). Studies need to be carried out to determine the relationship between habitat modification or loss vis-à-vis human health.

Other social and community impacts include losses of aesthetic values of these ecosystems, risks to human populations and capital investments, and reduced capacity to meet basic human needs. For example, the high export demand for the introduced Nile perch (which forms about 80% of total fish catch) has driven the price of fish to levels which cannot be afforded by many local consumers; this has diverted cheap protein food from local consumers, threatening their nutritional status as the consumption of fish declines (World Bank 1996).

**Conclusions and future outlook**

Although there is general land degradation and deforestation in the Lake Basin as a whole, there are some critical habitats that need to be urgently protected. These include the watershed areas, riparian zones along river banks, river deltas, and wetlands along the lakeshore. The lake habitat itself also needs to be protected from further degradation to protect the human populations, fisheries sector and other industries that rely on it for transportation, tourism, agriculture, etc.: Sustainable agricultural practices and soil conservation activities need to be instituted immediately. There is also a need to measure the spatial extent of the land degradation under different land use/land cover scenarios and to assess the effect of human land uses on vegetation community
structure over the last several decades, in order to understand how the landscape can be better managed to reverse the negative trends and mitigate hotspots (Swallow et al. 2002).

Methods for controlling the water hyacinth weeds need to be developed through more scientific studies. Water hyacinth is very mobile and is moved by the wind easily from one corner of the Lake to the other. Therefore, its removal may require special tools. However, its shredding in the Lake as was done by the Kenya government results in seed dispersion. In addition, shredding adds organic matter to the lake bottom that further depletes the oxygen content. Water hyacinth seeds once dispersed in the lake bottom may take up to 15 years to germinate. This makes the weed management preferred over weed elimination. It has been noted, for example, that ecological succession has made a major contribution to the control of fringing water hyacinth in the Ugandan portion of Lake Victoria: pure mats of water hyacinth are invaded initially by aquatic ferns and/or sedges, often followed progressively by Hippograss (Vossia cuspidata) that eventually dominate and shade out the water hyacinth (Mailu 2001). Surveys conducted in 1999 indicated that water hyacinth showed increased weed stunting and disintegration of original mats, reflecting severe environmental stress including that occasioned by the weevils already released into the Lake (Mailu 2001).

Unsustainable exploitation of fish and other living resources

Fisheries resources of Lake Victoria have been the main concern of the riparian states since the early 1950s when a number of introductions took place in order to boost the decreasing level of biomass of fish (Fisheries Department 1950). Introductions of tilapiine species took place around 1954 to boost the production of the endemic (Fisheries Department 1950). Introductions of tilapiine species took place in order to boost the decreasing level of biomass of fish (Fisheries Department 1950). Introductions of tilapiine species took place in order to boost the decreasing level of biomass of fish (Fisheries Department 1950). Introductions of tilapiine species took place in order to boost the decreasing level of biomass of fish (Fisheries Department 1950). Introductions of tilapiine species took place in order to boost the decreasing level of biomass of fish (Fisheries Department 1950). Introductions of tilapiine species took place in order to boost the decreasing level of biomass of fish (Fisheries Department 1950). Introductions of tilapiine species took

The historical trends in the fish catches in Lake Victoria have shown that for each of the East African Community Partner States (through the 1970s to the late 1990s) a salient feature in the pattern of the fish output is that it is very low. In the 1960s and the 1970s the combined annual catch for the three countries was only 150,000 tonnes. The catch of the days that followed up to the early 1980s was dominated by haplochromines which were/are small-sized fish of the cichlid family of very limited commercial value. Other species comprising the catch were the mudfish (Clarias sp.), the native tilapia (Tilapia esculentus), Bagrus sp., the African lungfish (Protopterus sp.), and a mixture of other tilapia species. During this period the haplochromines formed a species flock of many closely related species renowned for their great evolutionary significance and scientific value. Morphological, behaviour and taxonomic studies (Barel et al. 1985, Greenwood 1951, 1981, 1984 and 1994) distinguished hundreds of separate species of haplochromines, of which different groups colonised different bottom types and inlets.

Hydroacoustic surveys indicated that the total biomass in the Lake is fairly constant at about 2 million tonnes, but the components of the biomass during 1999 and 2001 have changed, with Nile perch decreasing from an estimated 1.5 to 0.9 million tonnes while the small pelagics (R. argentea and haplochromines) increased concurrently from an estimated 0.5 to 1.2 million tonnes (Bwathondi et al. 2001). Bottom trawl surveys in Kenyan waters of Lake Victoria (1997-1998) revealed that areas with relatively consistent high fish catches extend from west of Maboko Island up to Mbita Channel in the depth range of 5 to 22 m (Getabu & Nyaundi 1999). This area is outside major urban and riverine influence and is where most of the fishing effort by artisanal fishermen is currently concentrated (Getabu & Nyaundi 1999).

The Universities of Northern England Consortium for International Activities (UNECIA) has reported on the indicators of overfishing exhibited by Lates niloticus as reduction in age/length at maturity; higher mortality caused by fishing pressure, reduction in catch per unit effort (CPUE), reduction in mesh size of nets used and increased proportion of immature fish in the catches. It was noted that similar trends were observed for Oreochromis niloticus and Rastineobola argentea. Of all the changes occurring in Lake Victoria, the impacts on the fish species, and thus the fishery and its trends, have immediate significance to the East...
Africans, particularly the riparian population. What did it mean for East Africa when the fishery changed from one made up of haplochromines and other multi-species fishery to one, after 1980s, principally dominated by the Nile perch? This new fishery has opened export markets and has thus turned the fisheries sector in Lake Victoria into one of the main foreign exchange earners for the riparian peoples and the East African countries. What are the challenges and prospects of the Lake Victoria fisheries sector for the East African peoples?

Environmental impacts

Overexploitation

In the late 1950s, the Nile Perch was introduced to Lake Victoria from Lake Kyoga. During the early 1980s the Nile perch exploded in numbers causing serious predatory impacts on the Lake’s native species (Ogutu-Ohwayo 1990). Oreochromis niloticus (Nile tilapia) also thrived as an introduced species (Lehman 1996). The population of haplochromines was collapsing due to these introductions (Ogutu-Ohwayo 1990). Signs of overfishing were reported as early as 1927 when catch rates for tilapia dropped from 50-100 fish per 50 m long net with 127 mm stretched mesh (Walthington & Walthington 1933) to less than 5 fish (Ssentongo 1972). Many food fish species such as Oreochromis esculentus (Graham), Bagrus docmak (Forsskål), Clarias gariepinus (Burchell), Labeo victorianus (Boulenger) and the haplochromines (once important for fishmeal) have almost disappeared (Mkumbo 1999). More recently, even L. niloticus, the most important fish in the fishery, shows signs of declining (Othina & Osewe-Odera cited in Mkumbo 1999). There are indications that the fishery yield in Uganda has declined from 135 000 tonnes in 1993 to 107 000 tonnes in 1997 (Odongkara & Okaronon 1999).

The introduction of Nile perch, overfishing, unregulated gill net mesh sizes and exploitive fishing techniques have led to the decline of nearly all endemic species, most notably the cichlid fish species (Bugenyi & Magumba 1996). These practices led to the removal of the phytophagous haplochromines and native tilapiines (Goldschmidt & Witte 1992). Indicators of overfishing in the Nile perch fishery are: reduction in age/length at maturity, high mortality (especially caused by fishing pressure), reduction in catch per unit effort, reduction in mesh size of nets used, and an increased proportion of immature fish in the catches (Bwathondi et al. 2001).

Despite a continuous decline in main endemic food species, there has been a rapid increase in total landings from early 1980 to a peak in the
early 1990s (Figure 19). By the late 1980s the Nile perch and Nile tilapia dominated the fish catch to near exclusion of all native species except for *Rastrineobola argentea* (Ogutu-Ohwayo 1990). The total catch in the late 1980s and early 1990s reached close to 500,000 tonnes. This attracted many more fishermen into the lake fishery. An export market, associated with fish processing, turned the low-keyed fishery sector of the Lake into one of the main foreign currency earner for the riparian countries. Overall, a fishery that was multi-species before 1980 is now a three species fishery dominated by the Nile perch, *Rastrineobola* and Nile tilapia, respectively. There are currently 31 licensed fish processing factories in the Lake Victoria Region (Ntiba et al. 2003).

![Figure 19](image)

**Figure 19** Total landings of fish in the three riparian countries of Lake Victoria. (Source: Knap et al. 2002)

**Excessive by-catch and discards**

Quantitative information on actual by-catch and discards is generally not available, but this aspect of overexploitation is reflected in the increasing number of juveniles caught, as well as by reduction in size at first maturity. In other words, excessive by-catch and discards has come about mainly through the destructive fishing practices which are outlined below, particularly the use of undersized mesh nets.

There has been a progressive decline in the modal length of Nile perch caught by experimental trawling; in 1988 the modal length was 7080 cm (Ligtvoet & Mkumbo 1991), and it decreased to 50-60 cm in 1992, and even further to 40-50 cm in 1994 and it remained around the same level to the end of the 1990s (Nisinda et al. 1999). Similar trends are found in tilapia and *Rastrineobola*, and the fishing mortality on *Rastrineobola* stocks from the mosquito seine fishery is very high (Bwathondi et al. 2001). Catch rates from the 5 mm and 10 mm mosquito nets for *Rastrineobola argentea* in Tanzanian waters show exploitation of a high proportion of immature fish (Bwathondi et al. 2001). For *Oreochromis niloticus*, fishing mortality has increased dramatically in Kenyan waters since the early 1990s (M. Njiru, unpublished data, cited in Bwathondi et al. 2001). Often the lusenga nets and beach seines are fitted with small mesh netting, even mosquito netting, which is thought to be especially destructive to stocks since it catches everything, including juveniles (personal observations). Trawling using undersized mesh nets for target species and indiscriminate fishing gears or poisons are considered serious and in most cases result in indiscriminate catches including juvenile fish.

**Destructive fishing practices**

From as early as 1905 to 1916, gill nets were introduced into the Lake to exploit the tilapiine cichlids, *Oreochromis esculentus* and *O. variabilis* (Katuizi 1996), and catches declined with time as the fishing activity increased (Graham 1929 cited in Katuizi 1996). As traditional fishing methods are now often considered inadequate for landing a sufficient catch, fishermen increasingly resort to deploying illegal fishing gear such as cast nets, fish poison and weirs to improve their catches (Ntiba et al. 2001). The recommended mesh size for gill nets is 5 inches (~127 mm), but around 36% of the nets in use are below this recommended size and this has increased from around 9% in 1990 (NRIL 2002). Gill nets below the minimum legal mesh size (5 inches) constituted about 15% of the gill nets in the fishery in Lake Victoria in 2000. Uganda had the highest number of gill nets followed by Tanzania and Kenya. Other types of gear in operation does not augur well for the sustainability of the fisheries within the Lake particularly within the Kenya part of Lake Victoria that had the highest number of beach seine and mosquito seine (Asila 2001).

The introduction and success of the nilotic species followed an episode of nearly unregulated reduction of gill net mesh sizes and collapse of the traditional tilapia fisheries, and was contemporaneous with initiation of commercial trawling for demersal haplochromines (Lehman 1996). Mesh sizes have progressively declined over the past 10 years with 24% of the nets (LVFO 2000, Kulindwa 2001) in Uganda now below the recommended mesh size of 5 inches, and now more recent beach surveys (Muhoozi cited in Bwathondi 2001) suggest that this is now as high as 50%. In Kenya and Tanzania, 3 and 18%, respectively, of the gill nets are below the legal mesh size limits (Bwathondi et al 2001). Trawling using undersized mesh nets for target species and indiscriminate fishing gears or poisons are considered serious and in most cases result in indiscriminate catches including juvenile fish. Trawling does have adverse biological implications. Bottom trawling disturbs the substrate, the water column and interferes with the breeding ground and the spawning process especially for tilapiines and other cichlids. It also destroys larvae and eggs of fish, macro- and micro-invertebrates at different strata of the Lake. Thus, trawling using non-selective mesh
nets may cause overfishing by taking away both adult and juvenile fish and therefore reducing their productive potential. Further to that it may result into mass unemployment by displacing artisanal fisherfolk (Mbuga et al. 1998). With the near disappearance of many food fish species (Mkumbo 1999) and signs of decline in L. niloticus (Othina and Osewe-Odera cited in Mkumbo 1999), a number of management measures were effected including a ban on beach seines and undersized mesh nets (<127 mm stretched mesh) in 1994, and a ban on trawlers in 1996 (Mkumbo 1999). The use of poison led to a ban on fishing and the sale of fish in March 1999 (Ntiba 2003).

Decreased viability of stock through contamination and disease

Recent studies have shown high incidence of infection of *Rastrineobola argentea* by *Ligula* sp., an endoparasite (Ntiba, pers. comm.). *Salmonella* spp. were detected by the Spanish Veterinary Authorities in February 1997, resulting in the imposition of compulsory and systematic checks on Nile perch fillets for Salmonella in the EU countries (Knaap et al. 2002). A cholera outbreak which occurred in 1997 led to a six-month ban of fish exports to the EU from January to June 1998, but this ban was considered to be unjustified in the region because fish products are expected to be further processed at their export destination (Knaap et al. 2002).

Impact on biological and genetic diversity

The Nile perch, introduced in the Lake during the middle to late 1950s, exploded in numbers during the early 1980s (Ogutu-Ohwayo 1990 and 1992, Ntiba & Ogana 2003) causing serious predatory impacts on the Lake’s fish species assemblages. At the same time another introduced species of tilapia, Nile tilapia (*Oreochromis niloticus*), and a native sardine-like cyprinid locally known as Omena/Dagaa/Mukene (*Rastrineobola argentea*) proliferated. According to Witte et al. (1992) a huge proportion of 400 endemic species of haplochromine cichlids were almost approaching extinction in Lake Victoria in the 1980s. The time and the cause of these dramatic shifts in the lake environmental conditions and biotic assemblages is subject to various scientific studies. Whether the answers can be attributed solely to the introduction of the Nile perch and subsequent changes in the trophic relationships in the ecosystem, or are due to environmental dynamics associated with increased human population growth, resulting in increased deforestation and agriculture in the Lake Basin, urbanisation and the setting up of towns around the Lake, is not conclusive.

Socio-economic impacts

The EU ban on the fisheries had a negative impact on the economics of the fishery. However, in 1999 with the fish ban and water hyacinth infestation, Kenyan fishermen still managed to catch and sell fish worth about 100 million USD (8 billion Kenyan Shilling). Tanzania was allowed to resume the export of perch products from Lake Victoria to the European Union in January 2000, followed by Uganda and Kenya in August and December 2000, respectively (Knaap et al. 2002). Other economic impacts of overexploitation include higher costs of management of fisheries, fuel costs of moving to new fishing grounds, and the loss of fisheries revenue.

A number of deaths were reported among fish consumers on the Lake because of the use of illegal poisoning to catch fish (Knaap et al. 2002). Consequently, the Uganda government self-imposed bans on fishing, consumption of fish from the Lake, and export in March 1999 which were eventually lifted in November 2000 (Knaap et al. 2002). The cholera outbreak of 1997, which resulted in an EU ban on fisheries, has not been clearly linked to the fisheries sector, but unhygienic conditions in this sector can easily trigger such outbreaks that can lead to high loss of human life. The high demand for fisheries products in export markets has resulted in a decline of available fish for local consumption (Jansen 1997), and thus contributes to malnutrition in the region (World Bank 1996).

The fisheries sector is important in all three riparian countries in terms of food security, employment and livelihoods, as well as foreign exchange earnings (NRIL 2002). Fish has traditionally been the most affordable source of animal protein (World Bank 1996, Jensen 1997) with an average regional per capita consumption of around 12 kg, and in recent years much of the contribution to economic development and employment has been associated with the export of Nile perch (NRIL 2002). The long-term decrease in the commercial viability of fishing operations has resulted in unemployment, increasing poverty and decreasing food security in the region (World Bank 1996). This is reflected in the increasing fish prices over time, declining per capita fish consumption, decreasing size of fish caught and decreasing average incomes (Abila personal communication).

Conclusions and future outlook

There is an immediate need to quantify the actual resource base in order to establish what would be the actual sustainable level of exploitation of Lake Victoria fish as the small-scale fishermen greatly depend on the sustainability of the fisheries for their livelihoods (Katunzi 1996). Mechanisms for the regulation of the fisheries sector, including the export markets and processing factories, the eradication of use of destructive fishing practices, and the creation of alternative avenues for income to sustain the livelihoods of the riparian communities is required if the overexploitation of fisheries is to be effectively addressed. For example, the high demand for the Nile perch from filleting factories,
and their preference for fillets from juveniles of 0.1-1 kg for some export markets, will inevitably lead to a collapse of stocks because too few fish will reach spawning size (Bwathondi et al. 2001). The domestic market is equally open for undersized fishes and thus urgent remedial measures have to be considered (Bwathondi et al. 2001).

Currently, projects such as the Lake Victoria Environmental Management Project (LVEMP) and the Lake Victoria Fisheries Organisation (LVFO) are addressing some of the issues, but these need to be nested within the wider framework of integrated land and water management, taking into consideration issues like population growth, and other development programmes that can diversify the economic base of the region. The introduction of new regulatory laws governing fisheries (e.g. restrictions on free access to fisheries), and participatory management of fisheries and other resources may lead to a sustainable use of the resources. This may lead to potentially new employment possibilities, and improved catch and earnings. There may, however, be conflicts between user groups for shared resources including space. Community participation and government policies may help to improve the current situation.

## Global change

The climatic characteristics of the region have been outlined in the section on Physical characteristics. Lake Victoria is sensitive to climate change as its water balance is dominated by rainfall on the Lake and evaporation, with river inflow and outflow making minor contributions (Spigel & Coulter 1996). Global warming will lead to higher temperatures estimated to be between 0.2 and 0.5°C per decade for Africa (Hulme et al. 2001). The major effects of climate change on African water systems will be through changes in the hydrological cycle, the balance of temperature, and rainfall (IPCC 2001). Lake Victoria, is now 0.5°C warmer than in the 1960s (Hecky et al. 1994, Bugenyi & Magumba 1996), in harmony with changes in surface temperature at tropical elevations above 1 000 m world-wide. There have been no studies on increased UV-B radiation as a result of ozone depletion, or on changes in lake CO₂ source/sink function in the region.

### Environmental impacts

#### Changes in hydrological cycle and lake circulation

Changes in the hydrological cycle and lake level are intricately intertwined as the water balance of the Lake is dominated by rainfall and evaporation. The lake level is therefore particularly sensitive to climatic and hydrological change. All the current impacts of global change are related to the El Niño phenomenon or unusually heavy rains in the region. These are recurrent features of the climate system that occur with some measure of predictability. The frequency of El Niño Southern Oscillation (ENSO) episodes in East Africa has become irregular and shorter. Through the hydrological cycle, it tends to disrupt mainly agricultural activities and food production.

#### Lake-level change

The observed lake-level changes in the past few decades have not shown any significant departure from the mean trends. The strong El Niño years such as the 1982/1983 and the 1997/1998 events tend to rapidly raise the lake level and causes widespread flooding along the lake shore and rivers (Birkett et al. 1999, Conway 2002). For example, the El Niño phenomenon in 1997/1998 resulted in the water level rise by 1.7 m in Lake Victoria, 2.1 m in Lake Tanganyika and 1.8 m in Lake Malawi (Birkett et al. 1999). The widespread heavy rainfall and flooding produced adverse wide-ranging agricultural, hydrological, ecological and economic impacts in east Africa (Conway 2002).

#### Socio-economic impacts

Besides the wide-ranging economic effects the health is also important with respect to global change. One of the effects of El Niño-related flooding is the widespread dispersal and elevated concentration of biological contamination of water resources from surface run-off, domestic and municipal sewage wastes and other organic pollutants. This leads to sporadic higher incidences of water-borne diseases. For example, malaria is the most climate sensitive vector-borne disease. In the two warming periods in the 1930s to 1940s and the late 1980s (IPCC 1996), malaria epidemics were observed in the East African region (Roberts 1964, Githeko & Ndegwa 2001). In 1997, during the El Niño, a cholera epidemic occurred in western Kenya. Between June 1997 and March 1998, 14 275 cholera admissions to hospitals in Nyanza Province in western Kenya were reported (Shapiro et al. 1999). According to WHO (1999) similar events occurred in Kenya, Mozambique, Somalia, Uganda, Tanzania, Zambia and Zimbabwe.

A common problem with flooding in the Lake region is related to the displacement of people from their villages, the disruption of normal day to day routine because of lack of exit and access to marooned areas, lack of shelter and food.

### Conclusions and future outlook

El Niño is a recurrent phenomenon in the region, but, due to global changes, the frequency and perhaps the intensity of these events will increase. The current impacts that it has on the communities of the Lake Basin are basically as a result of lack of investment in flood control measures, and lack of disaster preparedness by the governments.
The social, economic and health impacts of El Niño can be drastically reduced if the afore-mentioned measures are put in place.

Malaria and cholera epidemics have occurred to varying degrees in the eastern African in the last decade. It is critical to know what to expect in the future in terms of disease trends so that adaptive measures can be put in place. Equally it is important to establish the population’s adaptive capacity in terms of the ability to prevent and treat climate related illnesses.

**Priority concerns**

The concerns that are recommended for further analysis are: Pollution and Unsustainable exploitation of fish and other living resources. The concerns were ranked in descending order of severity:

1. Pollution
2. Unsustainable exploitation of fish and other living resources
3. Habitat and community modification
4. Global change
5. Freshwater shortage

Dramatic and highly adverse changes that have enormous ramifications for the tens of millions of inhabitants of the Lake Victoria Basin have taken place in the fisheries sector because of overexploitation of fishery resources. These changes have been spurred by various unsustainable practices within the catchment and the Lake itself. The adverse interactions have been related to environment, economy, society, governance and legislation at national, regional and global levels. Many of the consequences of Unsustainable exploitation, which has emerged as a principal GIWA concern for the region, have worked through various pathways that are linked to the other GIWA concerns, namely, Pollution, Habitat modification, and Freshwater shortage. Unsustainable exploitation may cause pollution and/or habitat modification through the use of pesticides or other chemicals to increase fish catches, or via deforestation which exposes soil to erosion. The linkages between the GIWA concerns are shown in Figure 20.

Pollution emerged as another important GIWA concern that merits further analysis. Pollution poses many problems of an economic, social and/or health nature. The problem of pollution will have to be addressed within the context of a transboundary integrated land and water management plan.

Although current climate scenarios project small increases in tropical temperatures, small changes in temperature and water balance can dramatically alter water levels, as well as mixing regimes and productivity (IPCC 1996). High temperatures would increase evaporative losses, especially if rainfall also declined (IPCC 1996). Minor declines in mean annual rainfall (10–20 %) for extended periods would lead to the closure of the African lake basins even if temperatures were unchanged (IPCC 1996). There is also likely to be an increase in the frequency and or severity of extreme events such as El Niño. Severe droughts and floods would adversely impact the socio-economic activities and livelihoods of the inhabitants of the lake basins.

![Figure 20 Linkages between the GIWA concerns in Lake Victoria.](image-url)
Lake Tanganyika Basin

Table 15  Scoring table for Lake Tanganyika.

<table>
<thead>
<tr>
<th>Assessment of GIWA concerns and issues according to scoring criteria (see Methodology chapter)</th>
<th>The arrow indicates the likely direction of future changes.</th>
<th>Priority***</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No known impacts</td>
<td>Increased impact</td>
</tr>
<tr>
<td>2</td>
<td>Moderate impacts</td>
<td>No changes</td>
</tr>
<tr>
<td>3</td>
<td>Severe impacts</td>
<td>Decreased impact</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lake Tanganyika</th>
<th>Environmental impacts</th>
<th>Economic impacts</th>
<th>Health impacts</th>
<th>Other community impacts</th>
<th>Overall Score**</th>
<th>Priority***</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freshwater shortage</td>
<td>1.0*</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>1.0</td>
<td>5</td>
</tr>
<tr>
<td>Modification of stream flow</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pollution of existing supplies</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Changes in the water table</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pollution</td>
<td>2.6*</td>
<td>1.4</td>
<td>1.0</td>
<td>1.3</td>
<td>2.2</td>
<td>3</td>
</tr>
<tr>
<td>Microbiological pollution</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eutrophication</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemical</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suspended solids</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid waste</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radionuclide</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salts</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Habitat and community modification</td>
<td>2.0*</td>
<td>2.6</td>
<td>0.9</td>
<td>2.0</td>
<td>2.4</td>
<td>2</td>
</tr>
<tr>
<td>Loss of ecosystems</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modification of ecosystems</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unsustainable exploitation of fish</td>
<td>2.1*</td>
<td>2.9</td>
<td>1.3</td>
<td>2.5</td>
<td>2.5</td>
<td>1</td>
</tr>
<tr>
<td>Overexploitation</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excessive by-catch and discards</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Destructive fishing practices</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decreased viability of stock</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Impact on biological and genetic diversity</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global change</td>
<td>0.9*</td>
<td>1.3</td>
<td>1.0</td>
<td>1.0</td>
<td>1.5</td>
<td>4</td>
</tr>
<tr>
<td>Changes in hydrological cycle</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sea level change</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increased UV-B radiation</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Changes in ocean CO₂ source/sink function</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* This value represents an average weighted score of the environmental issues associated to the concern. For further details see Detailed scoring tables (Annex II).

** This value represents the overall score including environmental, socio-economic and health impacts linked to this issue. For further details see Detailed scoring tables (Annex II).

*** Priority refers to the ranking of GIWA concerns.

Freshwater shortage

Lake Tanganyika has a water volume of 18 800 km³; precipitation on the lake surface and surface run-off represents about 63% and 37% of water input, respectively, while evaporation at 94% accounts for the major loss of water (Beadle 1981, Haberyan & Hecky 1987). The surface outflow through the Lukuga River controls the maximum and present lake level. Lake Tanganyika receives water from different rivers with different chemical compositions, the most important one is the Rusizi River in the north which supplies more than 50% of the total dissolved salts. Except for rice production, agriculture in the region is rain-fed. Irrigated rice production is seasonal and small-scale and currently does not have a significant impact on water levels in the Rusizi River or Lake Tanganyika. Power companies utilise the Rusizi River for hydroelectric power generation and have been exploring possibilities to expand the network. There is little modification or diversions of Tanganyika’s affluent water supply and the Lake, consequently, has relatively few problems with respect to freshwater shortage. There is currently no evidence that abstraction of water from aquifers exceeds natural replenishment.

Environmental impacts

Modification of stream flow

Due to diversion of water for irrigation purposes, there is significant but localised loss of wetlands in some areas (e.g. Burundi) (personal observations). Dams and irrigation channels are not, however, common in affluent rivers (personal observations). Hydroelectric power production on the Rusizi River also has limited impact on Lake Tanganyika.

Pollution of existing supplies

The Lake provides freshwater for drinking and domestic use, but only between 32 and 62% of the population has access to safe water, while 14 to 49% do not have access to sanitation (Table 9) (UNDP 2000, World Bank 1999). This suggests that, within localised settlements, pollution of existing supplies is a significant threat. Increasing land use, particularly in the north, is affecting the quality of river water. The salinity of input from the Rusizi River (0.65‰) may in part influence the slightly elevated salinity of the Lake (0.5‰) (Hughes & Hughes 1992). The very large volume of Lake Tanganyika may provide a temporary buffer against deterioration of water quality (Spigel & Coulter 1996), but there have been several significant fish kills in localised areas, especially in Bujumbura and Kigoma Bays (personal observation, reported in the media). Nevertheless, the observed pollution has not compromised the overall quality of the water supply due to the large size of the reservoir.

Socio-economic impacts

There has probably been a slight reduction in stream flow owing to conversion of wetlands, but it is not possible to obtain quantitative data and there are no known socio-economic or health impacts linked to this issue. The localised pollution that has been observed has not compromised the overall quality of the water supply due to the large size of the reservoir, hence the health impact is generally very small. Freshwater shortage is not significant enough to affect (periodically or continuously) more than a very small proportion of the riparian community, and only in localised areas.
Conclusions and future outlook

Modification of stream flow is not considered a serious problem in Lake Tanganyika Basin. Even though power companies utilise the Rusizi River for hydropower generation, their activities currently have only limited impact on the Lake. More generally, dams and irrigation channels are uncommon. Pollution of existing supplies can be significant in localised areas, but the large volume of Tanganyika acts as a buffer, diluting to insignificant levels the amount of pollutants in the Lake. Consequently, the Lake Basin has relatively few problems with respect to freshwater shortage.

Increased agricultural activities in the catchment, abstraction of water for irrigation, denser settlements with poor sanitation, and possibly damming of the Rusizi River and increased abstraction of water for irrigation, coupled with a trend of decreasing precipitation projected for the region, may result in future freshwater shortage and increased pollution. Due to the Lake’s long residence time, pollution resulting from the effects of human activities and development in its catchment is potentially catastrophic to the Lake’s water quality, economic fish stocks and overall biodiversity (West 2001, Duda 2002). In addition, it is less likely that damage can be reversed once it occurs (Spigel & Coulter 1996). Economic impacts will likely become worse because of increased demand for water for potable use and irrigation. Health impacts will also increase due to lack of sufficient and potable water supplies, and as well to unsanitary conditions in the increasingly settled shoreline. These factors can lead to a host of diseases such as cholera and typhoid.

Pollution

Of many serious environmental threats that Lake Tanganyika faces, the most immediate are excessive loads of sediment and nutrients caused by deforestation and erosion in the watershed, and industrial and urban pollution. The three most important issues of pollution in the Lake and influx rivers are suspended solids, chemical pollution and eutrophication. Increased deforestation and consequently erosion in the catchment has caused an increase in suspended sediment entering the rivers and the Lake (Cohen 1991, Bizimana & Duchafour 1991, Tiercelin & Mondeguer 1991). The dynamics and behaviour of river-borne and run-off sediment entering the Lake are complex and not well understood. It appears, however, that much sediment deposition occurs in the littoral zone, precisely where most of the Lake’s biodiversity is concentrated. Increased sedimentation rates are manifested in the Lake by sediment inundated rocky habitats, common along the Burundi coast, and prograding river deltas, such as the Rusizi River delta. The Rusizi River delta is the major drainage in the northern basin and appears to have prograded by an order of magnitude during the past 20 years (Cohen 1991).

The Lake as a whole has a large nutrient reservoir in the anoxic layer. Relatively strong gradients in concentrations of nutrients and dissolved oxygen approximate a persistent thermocline which divides clear, impoverished surface water layers from reservoirs of nutrients resident within the anoxic hypolimnion (Langenberg et al. 2002). In the pelagic zone at the northern and southern end of the Lake, mean turbidity values (NTU) ranged between 0.3 and 1.4 (mean=0.6 NTU) in August 1995 to July 1996 (Langenberg et al. 2002). The impact of land-derived nutrients is, therefore, constrained to littoral zones within the influence of sediment inputs.

Pollution abatement facilities in the Basin are extremely limited (West 2001). Untreated wastewater discharge, including; industrial waste from large cities (e.g., Buyumbura in Burundi, Uvira in DR Congo, Kigoma in Tanzania and Mpuungu in Zambia); agricultural run-off particularly from Malagarasi and Rusizi catchments due to increase in the use of agro-chemicals concomitant with agricultural expansion; and mining waste containing mercury, are major chemical pollution sources (West 2001). While the condition lake-wide is generally satisfactory, some areas, like Kigoma Bay, show cause for local concern (Chale 2000, Bailey-Watts et al. 2000). Perhaps because of its greater water volume and lower human population density in its watershed, Lake Tanganyika appears to be more resilient to different forms of environmental impact than Lake Victoria (Beeton 2002).

Environmental impacts

Microbiological

Microbiological pollution is an issue, from time to time, on a localised scale, evidenced by water quality issues in Kigoma Bay and cholera outbreaks in Burundi and Zambia (Chale 2000).

Eutrophication

Kigoma Bay, which is about 4 km long, 3 km wide and 25 m deep, is surrounded by Kigoma Town (population 135,000) which draws its domestic water supply from the Bay (West 2001). A comparison of water quality between Kigoma Bay and offshore waters, showed that Kigoma Bay waters were significantly higher in nutrients and less transparent than offshore waters (nitrogen 56 µg/l vs. 36 µg/l; phosphorus 12.55 µg/l vs. 6.47 µg/l) (Chale 2000). A similar trend was found in comparisons with un-impacted nearshore areas, suggesting that nutrient input into the Bay from external sources is considerable. These values are elevated enough to render Kigoma Bay ‘meso-eutrophic’ on the classification of lake productivity levels (West 2001).
Kigoma lacks a wastewater treatment facility; many households have diverted their plumbing to enter the town’s storm drains. These drains thus act as conveyers for domestic effluents to enter the bay, which may ultimately be responsible for the high nitrogen and phosphorus concentrations and enrichment in plant nutrients (West 2001).

Chemical
Of the four riparian countries, Burundi, with the largest population density and the most industries in the Basin, poses the greatest pollution threat. Bujumbura hosts a variety of industries and potential pollution sources within several kilometres of the lakeshore, including a textile-dying plant, a brewery, paint factories, soap factories, battery factories, fuel transport and storage depots, a harbour and a slaughterhouse. Fuel depots, Kigoma’s harbour and electricity-generating facilities, industrialised fishing in Mpuulungu, and cotton and sugar processing plants in DR Congo present other cases of potential industrial pollution. The wastes from these enterprises typically are not treated before they are discharged and ultimately make their way to the Lake. The same is true for domestic waste. Even in highly populated areas, no municipal or household wastewaters are treated before they are discharged.

Run-off of agricultural pesticides may also be an important source of pollution. There is significant use of pesticides in the catchment, other contaminants are also present (water quality studies summarized in Bailey-Watts 2000). Pesticide residues have been detected in molluscs and in the fish that are the main targets of the commercial fishing industry (Foxall et al. 2000, Deelstra et al. 1976), indicating that pesticides have entered the food chain, although the values are within WHO acceptable tolerance ranges. Mercury and other chemicals used in small-scale gold and diamond mining in the catchment represent other potential lake pollutants. Leaks and accidents in the Lake’s cargo/shipping industry, executed by a fleet of ancient vessels, is another potential environmental hazard. Finally, although no production is occurring yet, petroleum exploration has been conducted on the Rusizi Plain and the Kalemie Trough while plans for nickel mining in Burundi are well underway. Table 16 summarises the various types and sources of pollution identified in the Tanganyika catchment.

The impact of these various discharges is poorly understood. While Environmental Impact Assessments (EIAs) have not been conducted, some studies suggest that pollution has altered, in some areas, the composition of phytoplankton communities (Cocquyt et al. 1991).

Suspended solids
Cohen (1991) reports that Landsat image analysis revealed that 40–60% of original forested land in the Lake’s central basin, and almost 100% in the northern basin, had been cleared, as evidenced by headward erosion, stream incision and gully formation, all features associated with deforestation. Much of this land was probably cleared for fuel wood, burned and converted for subsistence agriculture or grazing. Analyses of sedimentation rates from 14C dated cores (Tiercelin & Mondeguer 1991) confirmed the high sediment impact in the northern basin with the southern and central basins receiving <1 500 mm/1 000 years and <500 mm/1 000 years respectively, compared to the northern basin which received about 4 700 mm/1 000 years. Bizimana and Duchafour (1991) have estimated soil erosion rates in the deforested and steep sloping Ntahangwa River catchment in northern Burundi to be between 20 and 100 tonnes/ha/year. More recent studies by Sichingabula (1999) and Kakogozo et al. (2000) show that annual lake-wide sediment input into Lake Tanganyika is enormous (Table 17). In addition, three significant landslides that occurred near Gatororongo show that, especially in the rainy season, significant amounts of sediment (estimated at more than 11 280 tonnes at this site alone) can be introduced into the Lake without transiting through rivers (West 2001).

Excessive sedimentation resulting from high sediment yields from catchments threatens the diversity of nearshore fishes (Cohen et al. 1996). There is evidence of increased turbidity, and large sediment

Table 16 Sources of pollution in the Tanganyika catchment.

<table>
<thead>
<tr>
<th>Type of pollution</th>
<th>Sources within the catchment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial wastewater</td>
<td>More than 80 industries in Bujumbura, Burundi</td>
</tr>
<tr>
<td>Urban domestic wastewater</td>
<td>Bujumbura, Uriva, Kalemie, Kigoma, Rumonge, Mpuulungu</td>
</tr>
<tr>
<td>Chlorinated hydrocarbons, pesticides</td>
<td>Rusizi Plain, Malagarasi Plain</td>
</tr>
<tr>
<td>Heavy metals</td>
<td>North basin waters from industrial wastes</td>
</tr>
<tr>
<td>Mercury</td>
<td>Malagarasi River</td>
</tr>
<tr>
<td>Ash residues</td>
<td>Cement processing in Kalemie</td>
</tr>
<tr>
<td>Nutrients associated with fertilisers</td>
<td>Rusizi Plain, Malagarasi Plain and other catchments</td>
</tr>
<tr>
<td>Organic wastes, sulphur dioxide</td>
<td>Sugarcane refining plant near Uriva</td>
</tr>
<tr>
<td>Fuel, oil</td>
<td>Ports, harbour and shipping and boats in all four countries</td>
</tr>
</tbody>
</table>

(Source: modified from Patterson & Makin 1998)

Table 17 Some water and sediment discharge rates into Lake Tanganyika.

<table>
<thead>
<tr>
<th>River</th>
<th>Country</th>
<th>Water discharge rate (million m³/year)</th>
<th>Sediment discharge rate (tonnes/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kalimabenge</td>
<td>DR Congo</td>
<td>36.5</td>
<td>25.3</td>
</tr>
<tr>
<td>Kavimira</td>
<td>DR Congo</td>
<td>9.2</td>
<td>18.8</td>
</tr>
<tr>
<td>Mulungwe</td>
<td>DR Congo</td>
<td>34.1</td>
<td>21.3</td>
</tr>
<tr>
<td>Izi</td>
<td>Zambia</td>
<td>44.9</td>
<td>456</td>
</tr>
<tr>
<td>Kalumbo</td>
<td>Zambia</td>
<td>580</td>
<td>14 445</td>
</tr>
<tr>
<td>Luchewe</td>
<td>Zambia</td>
<td>51.4</td>
<td>510</td>
</tr>
<tr>
<td>Lufubu</td>
<td>Zambia</td>
<td>3.1</td>
<td>76 140</td>
</tr>
<tr>
<td>Lunziaa</td>
<td>Zambia</td>
<td>427</td>
<td>9 478</td>
</tr>
</tbody>
</table>

(Source: Sichingabula 1999, Kakogozo et al. 2000)
plumes. Significant stretches of coastline have been transformed from rocky substrates to mixed rocky/sandy substrate or entirely sandy substrates (refer to several studies on sedimentation in Lake Tanganyika summarised in West 2001). Increased water turbidity as a function of sediment load and sediment deposition thwart algal growth, which may have profound effects upon other components of the food web. In studying ostracods across a variety of habitats that were lightly, moderately or highly disturbed by sediment, Cohen et al. (1993b) found that ostracods from highly disturbed environments (both hard and soft substrate) were significantly less diverse than those from the less disturbed environments with differences in species richness in the range of 40–62%. Species richness for deepwater ostracods followed the same general pattern, though the differences were not as great. These data suggest that sediment input may have already had an important role in altering ostracod community structure. Benthic algae productivity studies show that sediment inputs from deforestation probably reduce the amount of available habitat for colonisation, decrease the nutrient value of the food source, and reduce the feeding efficiency of the primary consumers (O’Reilly 1998).

Spills
There have been serious accidental spills, e.g. of DDT in Kigoma harbour (Alabaster 1981) and fuel oil leakages in Mbulungu harbour, although DDT is no longer used except near the shoreline in the Zambian side of the Lake (Cohen et al. 1996). Occasional fish kills suggest that spills exist, but they are not common (personal observation, media reports and local knowledge).

Socio-economic impacts
There are chemical and microbiological pollution impacts in the economic sector, however the score is low overall because few people are actually contaminated, taking preventative measures or seeking medical treatment. In addition, sedimentation and eutrophication have indirect economic impacts that are difficult to quantify. These processes are continuous, and given that the Lake operates as a nearly closed system due to long residence and flushing times, these impacts are cumulative. However, occasional fish kills due to spills have significant, but short-lived, impacts. Sedimentation has a significant effect on the social sector in terms of global biodiversity, but this is not weighted heavily compared to other criteria and therefore the overall evaluation is low in terms of impact.

Conclusions and future outlook
Suspended solids, chemical pollution and eutrophication are the most important sources of pollution in the Lake. Pollution abatement facilities in the Basin are extremely limited. Currently, however, the effects of pollution in Lake Tanganyika seem to be buffered by the enormous size of the reservoir. High sediment loading due to deforestation and erosion in the catchment, particularly in the northern basin where deforestation is almost 100%, has contributed to the rapid growth of the Rusizi River delta over the past 20 years (Cohen 1991). In the lake proper, much of the sediment deposition occurs in the littoral zone where most of the Lake’s biodiversity is concentrated, thus affecting the food web and reducing species diversity (Alin et al. 1999, West 2001). There are various sources of chemical pollution particularly in the northern basin area resulting from industry, agriculture, municipal sources etc., but the impacts of these various discharges is poorly understood.

While the Tanganyika Basin is not nearly as industrialised or populated as other parts of sub-Saharan Africa, pollution is a threat to Lake Tanganyika because the Basin’s population is rapidly increasing and little legislation exists to protect the environment (West 2001). Given the Lake’s fluid medium for transport and that it is a nearly-closed system, with long water residence and flushing times, pollution is potentially catastrophic to the Lake’s water quality, economically important fish stocks and overall biodiversity. Increased agricultural and industrial activities in the catchment, coupled with denser settlements with poor sanitation, will result in further pollution. Petroleum exploration is being undertaken west of the Lake - if oil were discovered and produced in the region, risks of oil spills would arise from well accidents, cross-lake transport and harbour spills (Cohen et al. 1996).

Economic impacts are likely to become worse as sediment blanketing and increased turbidity cause changes in benthic and pelagic biodiversity, affecting the fisheries resources. Health would be affected as a result of an anticipated increase in microbiological and chemical contamination from organic wastes (settlements, agrochemicals). Other social and community impacts would increase due to increased demand for increasingly limited resources.

Habitat and community modification
Human activities in the catchment, especially agriculture and fuel wood gathering, have greatly decreased the original forest cover in the catchment. *Cyperus papyrus*, *Phragmites mauritianus* and *Typha domingensis* dominate the delta swamps (Hughes & Hughes 1992). *Potamogeton* species are the predominant macrophytes around much of the shoreline, with occasional rafts of *Nymphaea caerulea* and *N. capensis* in shallow sheltered bays (Hughes & Hughes 1992). *Phragmites*
mauritianus swamps accompany the Rusizi River (Hughes & Hughes 1992). The Rusizi River has formed a substantial delta at the north end of Lake Tanganyika. Ceratophyllum demersum is abundant in the vicinities of affluent river mouths (Hughes & Hughes 1992). In the deltas of several rivers, Azolla pinnata forms immense floating mats, green or brown in colour, and there are great submerged beds of Myriophyllum spicatum, Najas marina, N. pectinata, Ottelia ulvifolia, Potamogeton pectinatus and P. Schweinfurthii (Hughes & Hughes 1992).

There are extensive wetlands associated with the Rusizi River and its tributaries. Phragmites mauritianus swamps accompany the Rusizi River in a belt up to 3 km wide (Hughes & Hughes 1992). Some reptiles are present including various swamp snakes, as well as several bird species and some small mammals such as otters, mongoosies and water rats (Hughes & Hughes 1992). The floodplains are intensively cultivated, and the wet areas are frequented by domestic cattle in the dry season when large areas of wetland are burned (Hughes & Hughes 1992). The littoral zone of Lake Tanganyika includes sandy, rocky, mixed sandy-rocky and mud substrates. The Lake contains a large fish fauna comprising some 193 species from 13 families; 98% of the cichlids and 57% of the non-cichlid species are endemic (Hughes & Hughes 1992).

### Environmental impacts

#### Loss of ecosystems

Deforestation is essentially complete within the Burundi and northern DR Congo portions of the watershed (Cohen et al. 1993b) and land clearing using uncontrolled large fires is proceeding at an alarming rate further south (Cohen et al. 1996). Intense cultivation of floodplains, grazing by cattle and burning during the dry season (Hughes & Hughes 1992) has led to significant loss of wetland for example in Burundi. Land degradation and deforestation has increased the sediment flux to the Lake and altered habitats, particularly in the littoral zone. Sediment input has transformed extensive stretches of coastline from rocky habitats to mixed sandy and rocky or even wholly sandy habitats (refer to several studies on sedimentation summarised in West 2001). This phenomenon has not been studied quantitatively or rigorously in Lake Tanganyika, but there are two sources of data that underscore the significance of habitat modification. Comparisons between recent biodiversity surveys and lake-wide ecological studies by Belgian expeditions in the 1940s revealed that many sites had been transformed within the past forty years. Also, underwater observations and mapping of littoral substrates (West, unpublished data) has shown that significant stretches of rocky shoreline in Burundi have been transformed to mixed sandy-rocky or wholly sandy substrates since 1986. In some cases more than 1 m of sediment has accumulated at these sites.

### Modification of ecosystems

As a result of the modification of ecosystems particularly by sedimentation and overfishing, the structure of fish communities has changed over time as well as some populations of cichlids and molluscs becoming locally extinct during the past 30 years (West 2001, Lake Tanganyika Research project reports, and personal observation). For example, Alin et al. (1999) have noted that sediment inundation of lacustrine habitats has reduced species richness and density of molluscs, and the species richness of ostracods. The changes in ostracod (Cohen et al. 1993b) and benthic algal (O’Reilly 1998) communities have an impact on ecosystem structure and function, affecting all levels of the aquatic food chain.

### Socio-economic impacts

Loss of ecosystems has indirect links to the economic sector in terms of loss of spawning grounds for fish and severe impacts on the ornamental fishing industry, but perhaps the greatest impact is in terms of loss of global biodiversity. The population structure of the economically important fish stocks has changed, with some difficult to assess impacts on the economic sector.

About 70% of all fish species are found in all three sub-basins of Lake Tanganyika (West 2001). While the commercial fishery is based on only six species, the artisanal and subsistence fisheries have over 100 species in their catches and their activities are concentrated in varied habitats along the rocky and sandy shoreline, where biodiversity in the Lake tends to be concentrated (BDP 2003). Habitat modification through sedimentation, nutrient loading, destructive fishing practices and overfishing are leading to reduced fish catches: fish are important to the livelihoods of the numerous artisanal fishers and their dependants in terms of food security and employment. In addition, the loss of biodiversity is of great concern. Possible impacts of biodiversity loss include e.g. loss of traditional food sources, fuel wood energy sources, medicinal plants, and tourism. However, research is required to quantify the rate of loss of biodiversity in the Lake and its catchment, and its impact on the local, regional and global communities.

There are no known health impacts other than reduction in protein sources for the population due to reduced fish yields.

### Conclusions and future outlook

Land use change, land degradation and deforestation in the catchment have had profound impacts that are propagated through the rivers, by the land surface and atmosphere to the lowland wetlands and Lake. Intense cultivation of floodplains, grazing by cattle and biomass burning during the dry season (Hughes & Hughes 1992) has led to significant
loss of wetland e.g. in Burundi. Land degradation and deforestation has increased the sediment flux to the Lake and has dramatically altered habitats, particularly in the littoral zone. Sediment input has transformed extensive stretches of coastline from rocky habitats to mixed sandy and rocky or even wholly sandy habitats. Partly in relation to this, the structure of fish communities has changed over time and some populations of cichlids and molluscs have become locally extinct during the past 30 years.

The pressure on land-based resources is likely to increase with the rapidly increasing population. In addition, a perceived lack of sustainability thinking by farmers cultivating the steep slopes of Lake Tanganyika catchment may have more to do with the present political insecurity than with an inherently short-term view or ignorance of the environmental consequences of a failure to prevent soil erosion (Allison 2002). If this is indeed the case, then rapid population growth and political instability in the region does not augur well for sustainable land management, soil conservation, and biodiversity in the future. The rate of loss of ecosystems and/or their modification will increase as a result of increased sedimentation and reduction in water covered areas, leading to loss of wetland and littoral vegetation, fish spawning grounds, local reduction in species diversity, loss of biodiversity, etc. There is already significant loss of wetlands, local extinction of fishes and changes in population structure of vertebrate and invertebrate organisms in the Lake. Economic impact would become more severe as a result of further ecosystem loss and habitat modification. Subsistence fisheries would be most affected as shallow spawning grounds and fisheries are lost due to sedimentation, reducing the local populations’ capacity to meet basic food needs. This, in turn, would increase health risks and result in the loss of jobs.

Environmental impacts

Overexploitation

Fish production is estimated at 555 130 tonnes per year, while fish catch is at 178 486 tonnes per year: catch per production ratios for the whole Lake remain relatively low (average 0.30), but for *Lates stappersi*, it is extremely high in all countries, being lowest in Tanzania (0.76) and highest in DR Congo (1.12, i.e. clearly unrealistic) (Sarvala et al. 2002). Present fishing pressure in the Lake is very high. According to FAO (2001), the realised catch of planktivorous fish in the whole lake was about 23-28%, and in the most heavily fished Burundi waters it was 43.52% of estimated production. For piscivorous fish in the whole lake the corresponding figure was 61-73%.

The Lake is fished intensively from Bujumbura and other ports in all four countries that border it; the fishing intensity for all species is higher in the southern and northern parts of the Lake than in any other areas (Hughes & Hughes 1992). Several studies (Petit & Kiyuku 1995, Pearce 1995, Coulter 1999) have suggested that commercial fisheries have already drastically reduced the fish stocks, and the impact of ornamental fishing on population and community structure could be considerable as the rare and alien species are extracted in as high a number as possible because of the high mortality rates in shipping (West 2001).

Burundi once hosted a large industrial fishing fleet, but by the early 1990s they could no longer make a living and all the vessels were dormant or had been sold to companies in Congo or Zambia (Petit & Kiyuku 1995). Pearce (1995) calculates that the fishing effort in Zambia had tripled by the early 1990s and catches had been decreasing since 1985. These efforts have apparently affected the community structure of the stocks in Zambia for initially the catch was 50% sardines, 50% *Lates* (Coulter 1970) whereas since 1986 the catch has been 62-94% *Lates stappersi* (West 2001). The fishery has evolved from a six-species

---

**Unsustainable exploitation of fish and other living resources**

Fishing activities on Lake Tanganyika include commercial fishing by both industrial and artisanal fishermen, subsistence fishing, and ornamental fish extraction for export. Commercial fishermen target the sardine and *Lates* species and work further offshore in the pelagic zone. Commercial fishers, both artisanal and industrial, have usually made a significant financial investment in gears and motors to access the pelagic zone. Artisanal fishing relies on canoe-catamarans that use lights to attract fish and deploy lift-nets to collect them. Industrial fishing typically employs 15 m purse seines and a number of smaller vessels to attract the fish and deploy seines. Industrial fishing has been limited to a few areas (Bujumbura, Uvira, Kigoma and Mpulungu) which have access to larger markets. The subsistence fishermen primarily target the sardines and *Lates* species, though in their efforts they catch and utilise many other species. They operate close to shore, from small canoes. Each of Tanganyika’s riparian nations hosts one or more companies which export ornamental fish to markets in Europe, America and Japan. A variety of fish, predominately cichlids, are targeted by divers and snorkellers, captured alive and exported to aquarium enthusiasts abroad. There are six non-cichlid species that are targeted by artisanal and industrial fisheries, and whose potential yield has been estimated at 380 000-460 000 tonnes per year. There is no evidence for decreased stock viability in the Lake.
fishery (two sardines, four Lates spp.) to a single species fishery (Lates stappersi) (West 2001).

**Excessive by-catch and discards**
There is little by-catch or discards; the economically important fish live in the pelagic zone and few other species are present. Inshore fisheries occasionally have cichlid by-catch but these, though they are not targeted, are consumed (from Lake Tanganyika Research project reports, personal observations, reports from Lindley 2000a and b).

**Destructive fishing practices**
Beach seining and fishing with mosquito netting are common (though illegal) (summarised in Lindley 2000a and b). Long-term studies of fisheries statistics for Lake Tanganyika signal that fishing practices have altered the population structure of fish communities, especially for the economically important species. Some studies suggest that, in some areas, pollution has altered the composition of phytoplankton communities. Subsistence fishermen primarily target the sardines and Lates species, though in their efforts they catch and utilise many other species (West 2001). They operate close to shore, from small canoes, using lusenga nets (large, conical scoop nets), bottom-set gill nets, beach seines, basket traps and hand-lines. Often the lusenga nets and beach seines are fitted with small mesh netting, even mosquito netting, which is thought to be especially destructive to stocks, as it catches everything, including juveniles. In addition to disrupting population structure in this way, beach seines are additionally harmful because they drag along the bottom, turning-over the substrate, and thus obliterating food sources and cichlid nests (West 2001).

**Impact on biological and genetic diversity**
Invasive species exist in the Tanganyika Basin, including water hyacinth (Eichornia crassipes), cattail (Typha spp.), and the fish Oreochromis (from West 2000). There is no available data to quantify their impact.

**Socio-economic impacts**
Fishing activities include commercial fishing by both industrial and artisanal fishermen, subsistence fishing, and ornamental fish extraction for export. Overfishing and fishing with destructive methods have led to loss of jobs and livelihoods even at country scale, e.g. the collapse of the Burundi industrial fishing fleet in the early 1990s (West 2001). Sample surveys show that fishers and post-harvest operators are very pessimistic in their appraisals of catch trends over recent years: majorities in all the national sectors take the view that they have been on the decrease (FAO 2001). Fish accounts for 25-40% of total animal protein supply in the Lake Tanganyika Basin (FAO 2001). At the same time, rapid population growth in the Basin has fuelled an ever increasing demand for fish products, so that over the last several decades, the per capita supply has barely kept pace with overall fish production despite increases in the latter (FAO 2001). Thus, local livelihoods are affected as the principal source of protein in the local diet is reduced due to overexploitation and destructive fishing practices. The global species diversity is reduced as a result of overexploitation and destructive fishing practices. Prolonged political unrest in the region (Burundi, DR Congo and Rwanda), has compounded the effects of population growth and drought in increasing the demand for the Lake Tanganyika fisheries products (FAO 2001).

**Conclusions and future outlook**
Fishing activities on Lake Tanganyika include: commercial fishing by both industrial and artisanal fishersmen, subsistence fishing, and ornamental fish extraction for export. Several studies (summarised in West 2001) have suggested that commercial fisheries have already drastically reduced the fish stocks. Increased fishing effort has apparently affected the community structure of the stocks in Zambia, changing the fishery from a six-species fishery to a single species fishery (Lates stappersi). Destructive and illegal fishing practices such as beach seining and fishing with mosquito netting are common. These practices have contributed to an altered population structure of fish communities and degradation of shallow water habitats.

Without intervention and legislation, unsustainable exploitation of fish would severely affect fish stocks, the food web and biodiversity of the Lake, with negative ramifications on the local populations and world markets. Declining catches per unit of fishing effort have been noted (e.g. Roest 1992). In addition to impacting biodiversity by altering population and community structures of fish stocks and food webs, overfishing and fishing with destructive methods have negative repercussions on the socio-economic circumstances of riparian communities through loss of jobs and livelihoods. For example, collapse of entire segments of the fishing industry has occurred e.g. the industrial fishing fleet of Burundi in the early 1990s (Vrampas in Cohen et al. 1996). Collapses in the fishing industry are likely to increase in frequency lake-wide. Since fish stocks are already drastically depleted, the industry could face a total collapse in the near future, with severe impacts on the mainstay fisheries economy of the region. Because of the increasing density of settlements close to the Lake, microbiological pollution is expected to increase in these proximal areas. There may be a minor increase in the incidence of bacterial-related gastroenteric disorders in fisheries product consumers due to consumption of fish from these areas. Social conflicts are likely to flare up between commercial and subsistence fishersmen as fishing grounds for the latter are being reduced.
Without intervention and legislation, unsustainable exploitation of fish would severely affect fish stocks, the food web and biodiversity of the Lake, with negative ramifications on the local populations and world markets. Declining catches per unit of fishing effort have been noted (e.g. Roest 1992). In addition to impacting biodiversity by altering population and community structures of fish stocks and food webs, overfishing and fishing with destructive methods have negative repercussions on the socio-economic circumstances of riparian communities through loss of jobs and livelihoods. For example, collapse of entire segments of the fishing industry has occurred e.g. the industrial fishing fleet of Burundi in the early 1990s (Vrampas in Cohen et al. 1996). Collapses in the fishing industry are likely to increase in frequency lakewide. Since fish stocks are already drastically depleted, the industry could face a total collapse in the near future, with severe impacts on the mainstay fisheries economy of the region. Because of the increasing density of settlements close to the Lake, microbiological pollution is expected to increase in these proximal areas. There may be a minor increase in the incidence of bacterial related gastrointestinal disorders in fisheries product consumers due to consumption of fish from these areas. Social conflicts are likely to flare up between commercial and subsistence fishermen as fishing grounds for the latter are being reduced.

Global change

Changes in the hydrological cycle and lake level are intricately intertwined as the water balance of the Lake is dominated by rainfall and evaporation (with river inflow and outflow making minor contributions). Lake Tanganyika enhances rainfall by about 20% compared to that in the catchment (Nicholson & Yin 2002). The lake level is therefore particularly sensitive to climatic and hydrological change. The effects of lake level change, CO₂ source-sink function, etc. remain uninvestigated. Significant ENSO teleconnections have been found, with average air temperature, maximum and minimum air temperature, humidity, rainfall, winds, pressure and radiation, through research conducted by the ENSO Project (1997-2000). The strongest teleconnections were found between monthly air temperature anomalies with the sea surface temperature anomalies in the west equatorial Pacific Ocean. A time lag of 4–6 months generally gave the strongest correlation (ENSO Project 2003). ENSO events over the past approximately 50 years were characterised by an average air temperature increase of +0.26°C while extreme air temperature could reach ±0.8°C during a strong El Niño. During ENSO events, winds decreased but air pressure and radiation increased; this seems to impact mixing of the Lake (ENSO Project 2003).

Besides ENSO, a warming was observed in the recent decades in the air temperature at Lake Tanganyika (≥0.7–0.9°C). This was apparently linked to a water temperature increase and a higher stability of the Lake. Decreased winds and changes in fish catches were observed during the same period for the clupeid fishes and Lates stappersi. Those observations suggest that the Lake is sensitive to other climate variability such as the recent global temperature increase besides ENSO (ENSO Project 2003). It has recently been discovered that local temperature rises, less windy conditions and climate change have dramatically altered the nutrient balance of the Lake (O’Reilly et al. 2003, Verburg et al. 2003): the surface of the Lake is getting warmer, reducing mixing of essential nutrients such as nitrogen and sulphur between the epilimnion and hypolimnion, and thus cutting off fish production. Catch per unit effort of the main pelagic fishes was partially correlated with ENSO for the last 30 years in two stations of Lake Tanganyika, and changes in hydrodynamic and upwelling intensity were presented to explain this (ENSO Project 2003). More wind and lower temperature seem favourable for clupeid fishes (and possibly phytoplankton and zooplankton) while Lates stappersi catches are lower maybe because of lower transparency unfavourable to this visual predator (ENSO Project 2003). The observed decline of primary productivity by about 20% implies that the fish yields have decreased by about 30% over the past 30 years or so (O’Reilly et al. 2003). This suggests that the impact of regional effects of climate change on the aquatic ecosystem functions and services can be larger than that of local anthropogenic activity or overfishing (O’Reilly et al. 2003).

Environmental impacts

Changes in hydrological cycle and lake circulation

Changes in the hydrological cycle are related to changes in rainfall. These are ultimately reflected in lake-level changes as described below. During El Niño events, river discharge and sediment load tends to be high, and the rivers breach their banks in the lower reaches. These floodwaters affect the communities living along the river belts.

Lake-level change

Relatively small changes in rainfall and evaporation may lead to shifting between closed- and open-basin status as has happened in historic times for Lake Tanganyika (Spigel & Coulter 1996). The effects of global climate change in the Tanganyika Basin are reflected mainly in the Lake’s nutrient dynamics (described above) and in increased frequency and intensity of El Niño phenomenon. The El Niño phenomenon in 1997–1998 saw water levels increase, lake-wide, by 2.4 m, but otherwise variability is limited (West, Cohen et al. field observations). Such flooding had a serious impact on low-lying urban riparian centres.
Socio-economic impacts
Economic impacts of El Niño are largest in the agricultural sector, where droughts and floods can significantly affect the GDP of the riparian countries, as they are mainly dependent on the agricultural sector for economic growth and food security. Flooding during El Niño years may also lead to increased incidences of water-borne diseases and may have an impact on low-lying lakeshore centres, e.g. by inundation of settlements and disruption of daily activities.

Conclusions and future outlook
El Niño is a recurrent phenomenon in the region, but due to global change the frequency and perhaps the intensity of the event is likely to increase (IPCC 2001). The current impacts that it has on the communities of the Lake Basin are basically a result of lack of investment in flood control measures, and lack of disaster preparedness by the governments. The social, economic and health impacts of El Niño can be drastically reduced if the afore-mentioned measures are put in place. Malaria and cholera epidemics have occurred to varying degrees in the East African region in the last decade. It is critical to know what to expect in the future in terms of disease trends so that adaptive measures can be put in place. Equally it is important to establish the population’s adaptive capacity in terms of the ability to prevent and treat climate related illnesses.

Although current climate scenarios project small increases in tropical temperatures, small changes in temperature and water balance can dramatically alter water levels, as well as mixing regimes and productivity (IPCC 1996). Further, and more immediate and potentially catastrophic impacts are the changes in nutrient dynamics and mixing regimes within the Lake as a result of increased thermal stability as they affect fisheries production and can completely alter the trophic structure of the food chain (O’Reilly et al. 2003, Verburg et al. 2003, ENSO Project 2003). High temperatures will increase evaporative losses, especially if rainfall also declines (IPCC 1996). Slight decreases in precipitation or increases in either temperature or average wind speeds could convert Lake Tanganyika to a closed basin (Owen et al. 1990, IPCC 1996), cause significant changes in the thermal stability of the Lake’s water mass and mixing dynamics (Hecky & Bugenyi 1992), and change the lake’s water chemistry (Cohen et al. 1996) etc., affecting many aquatic organisms. Global change would affect the riparian communities by perhaps an increase in the frequency of extreme events e.g. El Niño. Severe droughts and floods would adversely impact the socio-economic activities and livelihoods of the inhabitants of the Lake Basin. High economic costs due to impact of droughts are unlikely to decrease. Health impacts of drought, such as malnutrition and deaths are however likely to increase in frequency.

Priority concerns
The GIWA concerns are prioritised as follows:
1. Unsustainable exploitation of fish and other living resources
2. Habitat and community modification
3. Pollution
4. Freshwater shortage
5. Global change

The priority concerns that were selected by the Task team for Lake Tanganyika are Habitat and community modification and Unsustainable exploitation of fish and other living resources. The linkages are shown in Figure 21 and are described below.

Habitat modification arises primarily as a result of all the other four concerns. Unsustainable exploitation of fish and other living resources has been shown to be inextricably linked to habitat modification. This has led to loss of ecosystems and changes in population structure of the wetland areas in the deltaic and floodplain areas of the principal rivers, as well as in the littoral and standing waters of the Lake. Pollution, which in this case is due mainly to suspended sediments that originate from habitat change (land clearance, degradation and increased erosion rates) in the principal river catchments, contributes to habitat modification, which in turn also affects the living resources. Natural habitats and living resources are affected by e.g. limitation of light penetration in the lake water due to increased turbidity and sediment blanketing of benthic organisms. Global change (reducing precipitation and higher temperatures) can result in increased concentrations of pollution in the Lake due to reducing lake level (and volume), but is more important by its influence on freshwater resources through the hydrological cycle.

Figure 21 Linkages between the GIWA concerns in Lake Tanganyika.
Lake Malawi Basin

**Table 18  Scoring table for Lake Malawi.**

| Assessment of GIWA concerns and issues according to scoring criteria (see Methodology chapter) | The arrow indicates the likely direction of future changes. | Lake Malawi | Environmental Impacts | Economic Impacts | Health Impacts | Other community impacts | Overall Score* | Priority *** |
|---|---|---|---|---|---|---|---|---|---|
| No known impacts | 0 | | | | | | | | |
| Slight impacts | 1 | | | | | | | | |
| Moderate impacts | 2 | | | | | | | | |
| Severe impacts | 3 | | | | | | | | |

**Freshwater shortage**

- Modification of stream flow: 2
- Pollution of existing supplies: 2
- Changes in the water table: 0

**Pollution**

- Microbiological pollution: 2
- Eutrophication: 2
- Chemical: 1
- Suspended solids: 3
- Solid waste: 0
- Thermal: 0
- Radionuclide: 0
- Spells: 1

**Habitat and community modification**

- Loss of ecosystems: 2
- Modification of ecosystems: 2

**Unsustainable exploitation of fish**

- Overexploitation: 3
- Excessive by-catch and discards: 0
- Destructive fishing practices: 2
- Decreased viability of stock: 0
- Impact on biological and genetic diversity: 1

**Global change**

- Changes in hydrological cycle: 1
- Sea level change: 1
- Increased UV-B radiation: 0
- Changes in ocean CO2 source/sink function: 0

* This value represents an average weighted score of the environmental issues associated to the concern. For further details see Detailed scoring tables (Annex II).

**Environmental impacts**

**Modification of stream flow**

Catchment disturbance through land clearance has resulted in greatly increased sediment loads and run-off (Calder et al. 1995), and diversion of water for irrigation in some rivers has resulted in reduced flow (Government of Malawi 1998). This is a significant issue due to its basin-wide pervasiveness and long-term impact on other aquatic aspects such as fisheries and habitat modification. Cattle grazing and agricultural activities (sugar and cotton growing under irrigation) are common in the marginal areas of the Shire swamps in the lower part of the course of the Shire River that supports one of Malawi’s most important fisheries (Hughes & Hughes 1992). For example, the Dwanga River is completely closed off during the dry season and diverted to sugar cane fields; the River was originally an important locality for potamodromous fish runs, these spawning runs have now ceased completely with the annual diversion (Tweddle 1992).

**Pollution of existing supplies**

A survey of the water resources of Malawi concluded in 1980 that industrial pollutants and partly treated wastes from sewage had reduced the quality of water in many streams too far below acceptable levels (UNEP-IETC 2003). Today, with the rapidly rising population, lack of sanitation infrastructure, lack of sewage treatment facilities, increased numbers of informal settlements, rampant deforestation, etc., the situation must be far worse. The principal rivers, used to abstract potable water, carry suspended loads exceeding WHO guidelines in the range of 100 mg/l to over 400 mg/l (Kasweswe-Mafongo 2003).
The very large volume of Lake Malawi may provide a temporary buffer against deterioration of water quality (Spigel & Coulter 1996) but pollution of existing supplies in rivers and localised shoreline areas does occur. This problem is particularly associated with the western shoreline of Lake Malawi which is densely populated, and where the largely rural population relies on surface waters from the rivers and lake for domestic consumption without any treatment (Government of Malawi 1998).

**Socio-economic impacts**

The high silt load in surface water run-off has recently led to significant problems in downstream water quality, such as increased suspended solids, organic matter pollution and water treatment costs, decreased hydroelectric power generation capacity, water flow problems and siltation of ports (Government of Malawi 1998). This has most likely been associated with increased costs of human health protection, but there is no data to evaluate this.

The largely rural population is involved in continuously utilising untreated water, resulting in adverse health impacts that are localised and confined largely to densely populated settlements (Government of Malawi 1998). Up to 53% of the population use water sources that are classified as unsafe, and 34% of the population have no access to flush toilets nor traditional pit latrines (UNEP-IETC 2003). As a result, the people suffer from common ailments such as diarrhoea and malaria; these diseases are common in coastal communities (UNEP-IETC 2003). It has been noted that there has been an increased incidence of bilharzia (schistosomiasis) in the last two decades, and outbreaks of cholera are common near the lakeshore in the rainy season (Bootsma, pers. comm.).

Loss of human drinking water supplies, loss of recreational use, reduction in future use options and transboundary implications are the identified social and community impacts brought about by pollution of water. The possibility of contracting schistosomiasis in Lake Malawi and the negative travel advisories abroad in relation to this disease have deterred tourists from visiting the Lake's attractions (Bootsma, pers. comm.).

**Conclusions and future outlook**

Freshwater shortage has only slight impact in Lake Malawi, but a much greater impact on the rivers that flow into the Lake in terms of available water for consumption, domestic and livestock use, and irrigation of crops. Catchment disturbance through land clearance has resulted in greatly increased sediment loads (Tweeddale 1992), and diversion of water for irrigation in some rivers has resulted in reduced flows. Most of the rivers are now polluted and are unsafe for use as potable water; this is prevalent mostly in rivers that flow through urban settlements and along the largely unplanned coastal settlements that lack proper sanitation infrastructure. The various forms of pollution have had diverse impacts: siltation threatens the production capacity of the hydroelectric power plant and operations of irrigation systems; reduced water quality and quantity has increased the costs of water treatment and water supply, respectively; and agricultural productivity is facing a decline due to soil loss and inadequate water supply for irrigation. It has been suggested that pesticide pollution in the rivers and the Lake itself may have played a role in the decline of the Ntchila (*Labeo mesops*) population (Government of Malawi 1998).

Increased agricultural activities and land degradation in the catchment will result in increased suspended solids being transported to the rivers and lake. Pollution of both surface and groundwater resources due to excessive use of agro-chemicals in catchment areas is likely to increase (Government of Malawi 1998). The very large volume of Lake Malawi may provide a temporary buffer against deterioration of water quality (Spigel & Coulter 1996), but its long residence time makes it more vulnerable to damage from the effects of human activities and development in its catchment. Because of the rapid population growth, high level of poverty, e.g. 46% of Malawi’s population are currently facing severe poverty (Government of Malawi 1998), and high dependence on subsistence rain-fed agriculture and to a lesser extent irrigation, demand for the water resources, whose quantity and quality are increasingly being diminished by abstraction and pollution, will increase. Since the riparian countries are very poor, they will not be able to meet the associated rising costs of water treatment, sanitation and sewerage infrastructure. Nor will they be able to introduce the necessary sustainable land management practices that will ensure sustainability of the quality and quantity of freshwater resources.

**Pollution**

Most of the pollutants in Lake Malawi come from the Malawi watershed which is by far the most densely populated. Tanzania and Mozambique watershed areas are lightly populated particularly because most of the lakeshore on the eastern and northern side is inaccessible due to the steep topography. Microbiological, chemical and spill pollution are largely local in extent. On the other hand, eutrophication and suspended solids are much more widespread due to increased run-off and erosion from the degraded and deforested watershed areas and large-scale biomass burning during the dry seasons that convey...
nutrient elements to the Lake via the atmosphere (Bootsma & Hecky 1999). As early as 1960, the high population density of Malawi had led to extensive alteration of the natural vegetation of the catchment (Eccles 1984).

Environmental impacts

Microbiological

Microbiological pollution is an issue, at various localities, but there are few reports that document its severity, particularly in Tanzania and Mozambique. The bacteriological quality of major rivers in Malawi is poor due to effluent discharges, with the worst quality being found in rivers that flow through the cities of Blantyre, Lilongwe, Zomba and Mzuzu (Government of Malawi 1998). Most rivers contain faecal coliforms exceeding 500 per 100 ml in the dry season: the faecal coliforms are largely from unplanned settlements and improper waste disposal (Kasweswe-Mafongo 2003). Counts as high as 20,000 faecal coliforms per 100 ml have been observed in Linthipe River downstream of the sewage plant during periods when the plant has broken down (Government of Malawi 1998). In low-income areas of the above cities, pit latrines are usually constructed without consideration to their potential for water resource pollution. Poor sanitation in the more densely populated areas around the Lake can potentially result in serious disease transmission problems, particularly via lake fish. For example, the practice of drying fish directly on beaches that are also used as untreated effluent disposal points can lead to outbreaks of cholera as outlined above.

Eutrophication

There are three major sources of nutrient inputs to Lake Malawi; land-based discharge, atmospheric deposition, and upwelling return (Lam et al. 2002). The nutrient and sediment loading to the Lake from its rivers is likely to have increased by 50% within the past few decades with a few rivers such as the Linthipe, Songwe and Dwanga accounting for much of that increase (World Bank 2003). The likely factors influencing increased sediment deposition (Calder et al. 1995) and nutrient input (Bootsma & Hecky 1999) in the southern catchments are deforestation, increased agriculture, erosion and biomass burning. The environmental degradation is driven by the need to sustain the growing population.

The prominence of the blue-green algae Planktolyngbya tallingi in the southern region of the Lake (where it has replaced the previously dominant Planktolyngbya nyassensis) and the reported occurrence of Cylindrospermopsis raciborskii, a filamentous blue-green algae which is often a climax species in highly eutrophic situations and which has toxic forms are indicative of increasing eutrophication (Bootsma & Hecky 1999). The increased nutrient inputs (including phosphorus which is likely to be influencing changes in plankton composition) are from both the atmosphere and rivers resulting from deforestation, increased agricultural erosion and burning (Bootsma & Hecky 1999). They are not linked to fertiliser application, but are the result of nutrient mobilisation in terrestrial biomass and soils.

The water hyacinth is now encroaching into Lake Malawi from a variety of sources including its infested Shire River outlet and rivers, such as Bua and Linthipe, that drain the watershed (UNEP-IETC 2003). Some pockets along the Lake already show signs of infestation, e.g. at Chembe, Cape Maclear, where clusters of hyacinth were observed in 1996 (UNEP-IETC 2003).

Chemical

Chemical pollution from urban domestic and industrial sources, and from fertilisers, herbicides and pesticides used in agriculture has been increasing (Coulter & Mubamba 1993). Mercury in fish is a potential health hazard for humans, while organochlorines are unlikely to have any health impacts (Bootsma & Hecky 1999). Very heavy application of copper fungicides is reported near Nbozi, in the Tanzanian portion of the watershed (Alabaster 1981).

Suspended solids

Changing patterns of land use and erosion resulting from forest clearance (Calder et al. 1995) for agriculture to sustain the growing population in the southern catchments are the likely factors influencing increased sediment deposition in southern Lake Malawi (Bootsma & Hecky 1999). The inshore quality of water along Lake Malawi depends on the effect of river effluent, some of which has high sediment loads (UNEP-IETC 2003). River catchments with very high deforestation rates have led to increased turbidity and river discharges high in suspended solids. The increasing soil loss poses the greatest threat to sustainable agricultural production and negatively impacts on water quality (Kasweswe-Mafongo 2003). High sediment loads smother nearshore rocky habitats, reducing algal growth and habitat diversity, which in turn reduce fish abundance and, possibly, diversity. The sediment decreases water clarity and light penetration, further reducing benthic algal growth (which is the food base for the species-rich nearshore cichlid communities), and may reduce species diversity by preventing females from recognising con-specific males. Phytoplankton, and other pelagic or benthic organisms, will be affected by increased turbidity. In addition, many of the fish retain the habit of spawning in the inflowing rivers, and thus high sedimentation and turbidity may reduce fish stocks in the Lake.

Spills

There are no reported spills in the Lake, but these are likely to occur from time to time in the maritime transport industry.
Socio-economic impacts
Pollution has led to increased costs of human health protection, water treatment, preventive medicine and loss in fisheries.

Microbiological pollution is widespread in the Basin’s rivers, particularly in those that pass through urban settlements, but is more localised along the lake shore where it results from poor sanitation infrastructure and unhygienic handling of fish, leading to increased incidence of water-borne diseases, particularly in densely populated settlements (Government of Malawi 1998, UNEP-IETC 2003). Pollution leads to increased risks to human health. In addition, loss of traditional protein sources (decline in fisheries) would increase the vulnerability of the people living in this area to food or essential nutrient shortages (Government of Malawi 1998, Kasweswe-Mafongo 2003).

Pollution has to some degree led to loss of potable water supplies, loss of tourism or recreational values, loss of aesthetic values, change in fisheries value, loss of wildlife sanctuaries, and avoidance of amenities and products due to perception of the effects of contamination (Government of Malawi 1998, Kasweswe-Mafongo 2003).

Conclusions and future outlook
The problem of eutrophication and increased suspended solids is widespread and is related to deforestation, agriculture, erosion and biomass burning in the catchment (Calder et al. 1995, Bootsma & Hecky 1999). This is leading, for example, to changes in phytoplankton communities particularly in the southern region of the Lake (Bootsma & Hecky 1999). There is also reported occurrence of Cylindrospermopsis raciborskii, a filamentous blue-green algae, which is often a climax species in highly eutrophic situations (Bootsma & Hecky 1999). The water hyacinth is now encroaching Lake Malawi from a variety of sources including its infested Shire outlet and rivers that drain the watershed (UNEP-IETC 2003). There are no reported spills in the Lake, but this is likely to occur from time to time in the maritime transport industry. Pollution (as defined in this section) is perhaps the greatest threat to Lake Malawi (Tweedle 1992). Eutrophication, pesticides, alteration of biological communities and possible consequences of petroleum extraction are of concern to the Lake Malawi Basin (Hecky & Bugenyi 1992).

Pollution will continue to increase as the human population grows and natural landscapes are converted for agriculture, habitation and transportation (Beeton 2002). Suspended solids and eutrophication are the primary pollution issues in Lake Malawi. Soil is declining in fertility due to soil erosion and degradation, and is evidenced by increased rates of soil loss, declining yields from unfertilised crops, declining responses to fertiliser application, and impaired watershed performance (World Bank 2003). While the concentration of solutes and particulates in rainwater near Lake Malawi are not particularly high relative to industrial regions or some other parts of Africa, higher than average ammonium-cation ratios, nitrate-anion ratios, and potassium concentrations suggest that burning is having a significant effect on atmospheric chemistry around the Lake (Bootsma & Hecky 1999). Although the direct effect of the deposition of these solutes on the Lake may not be deleterious, the burning and soil exposure that these observations reflect may potentially result in detrimental impacts on the Lake, such as siltation, accelerated flux of nutrients from soil to the Lake, and a decreased and more variable water supply from rivers (Bootsma & Hecky 1999). Phosphorus loading resulting from catchment disturbance could have some of the following consequences: reduced water clarity, resulting in a shallower benthic trophogenic zone; and a shoaling of the oxic-anoxic boundary and reduction of available fish habitat (Bootsma & Hecky 1999).

Soil conservation measures will need to be urgently implemented in order to protect both the rivers and lake, and to preserve or improve upon current agricultural productivity in the catchment. Because of its high contribution to total river infl ow to Lake Malawi, land management within the Tanzania catchment area has a significant impact upon the level of nutrients, sediments and other land-based pollution entering the Lake. It is clear that further land clearance in the more mountainous northern areas will have relatively greater negative impacts on the Lake due to steeper slopes and higher rainfall (World Bank 2003). Pressure on the Lake is expected to increase as a direct result of declining agricultural productivity (World Bank 2003) and increasing pollution of rivers, etc., and this has the potential effect of adversely affecting fisheries, the lake ecosystems and water quality.

Habitat and community modification
There is a high rate of deforestation within the catchment. The total land areas under cultivation in the northern and central regions of Malawi were estimated to be 17% and 22% respectively in 1964-1965; these increased to 22% in the north and 41% in the central region by 1978 (Eccles 1984). Together, these two regions form almost 64% of the land catchment and 49% of the total catchment of the Lake, so it is evident that a large proportion of the natural Brachystegia-Julbernardia woodland has been cleared.
The fast-flowing upper reaches of the numerous rivers that drain into Lake Malawi support unique communities of animals and plants that are not found elsewhere in the system (Jackson et al. 1963, Tweddle & Skelton 1993). Small deltas with freshwater swamps occur at the mouths of some streams entering the Lake on the Tanzania shore. Larger swamps include: the Linthipe River delta, 22 km long and 15 km wide, mainly swampland; the Karonga Lakeshore Plain, much of which is under cultivation, along the northwest shore at the Malawi side; Nikhotakota Lakeshore Lowlands, a strip extending for 125 km along the western shore of Lake Malawi, containing a number of seasonally flooded areas; and Salima Lakeshore Plain, a very wet plain about 90 km long, with large marshes and the swampy delta of Linthipe River (Hughes & Hughes 1992). Water-level changes as a result of abstraction or natural fluctuations in the hydrological balance can have marked impacts on fish catches because the floodplains act as very productive nursery areas (Ribbink 2001). The Shire swamps in the lower part of the course of the Shire River support one of Malawi’s most important fisheries. Cattle grazing and agricultural activities (sugar and cotton growing under irrigation) are also common in the marginal areas (Hughes & Hughes 1992).

The only area which currently protects the cichlid fishes is the 94 km² Lake Malawi National Park in the southern part of the Lake, declared by UNESCO as a World Heritage Site in 1982, but the continuous nature of the lake environment leaves this part vulnerable to large-scale changes in the Lake and its basin (Figure 22) (World Bank 2003).

**Environmental impacts**

**Loss of ecosystems**

The widespread deforestation within the catchment to pave way for agriculture and settlements has resulted in loss of some floral and faunal ecosystems. In addition, the rich genetic pool of flora and fauna in protected areas such as national parks, game and forest reserves is diminishing due to habitat destruction and poaching (Kasweswe-Mafongo 2003). Habitat degradation of rivers and overfishing threaten riverine and potamodromous fish species (Chapman et al. 1992, Tweddle 1992, Ribbink 2001). In the Bua River, the largest river to enter the Lake from the Malawi side, fishes e.g. *Opsaridium microlepsis* have now been largely eliminated from Malawian waters through a combination of siltation and fishing pressure (Cohen et al. 1996). They are still common in lightly populated areas of the Mozambiquan coast, but even there spawning grounds are beginning to show signs of serious deterioration (Massinga 1990). Within the Lake itself, it appears that some of the “key” fish stocks are declining. In the area south of Boadzulu Island, an area of intensive demersal trawling, many of the larger cichlid species have declined with some species becoming locally extinct. More generally, the fish community compositions are changing within the Lake as a result of overfishing.

**Modification of ecosystems**

Available evidence indicates that the most seriously threatened fish species are the riverine and potamodromous species as a result of both habitat degradation of rivers and overfishing (Tweddle 1992, Ribbink 2001). The Bua River, for example, is important since it supports huge breeding runs of the migrating cyprinid fish *Opsaridium microlepsis*, which is endemic to Lake Malawi and is one of the major commercial species in its northern and central parts (Hughes & Hughes 1992). These fishes have now been largely eliminated from Malawian waters through a combination of siltation and fishing pressure (Cohen et al. 1996). They are still common in lightly populated areas of the Mozambiquan coast, but even there spawning grounds are beginning to show signs of serious deterioration (Massinga 1990). Within the Lake itself, it appears that some of the “key” fish stocks are declining. In the area south of Boadzulu Island, an area of intensive demersal trawling, many of the larger cichlid species have declined with some species becoming locally extinct. More generally, the fish community compositions are changing within the Lake as a result of overfishing.

**Socio-economic impacts**

In Malawi, 85% of the population is below the absolute poverty line: the major source of income for the population is agricultural production at subsistence level, and this is increasingly threatened by soil degradation (ADB 1997). It is estimated that 230 000 (ATF 1997) to 290 000 people (World Bank 2003) are employed directly or indirectly in the fishing industries, and these jobs are now being threatened by declining fish stocks (ATF 1997). The declining fish yields (Mapila 1998, Ribbink 2001), partly resulting from habitat change, has contributed to increased effort per catch unit. Given that the number of fishermen in the Lake is increasing against this decline in fish yields, the effective income per individual in the fisheries industry has declined. Fish is a primary source of protein in the area, so habitat change that results in lower fish yields leads to declines in nutritional status of the population.
Widespread poverty within the population plays a significant role in environmental degradation (ATF 1997). More than 90% of energy requirements are met from biomass supplies, and national wood consumption stands at double the sustainable production (WWF 2003). Reduced capacity to meet the basic human need for food and fuel affects the welfare of the family unit. Loss of species in Lake Malawi is a serious problem caused by a combination of high population growth, rampant poverty and other economic factors (ATF 1997). The harvest of large quantities of fish has altered the ecological balance in the Lake, reducing the number and species of fish and affecting other wildlife such as birds which feed on fish (ATF 1997). Loss of alternative income has affected the family units’ ability to afford e.g. education and health services. This has been compounded by disruption of living patterns due to commercial fisheries opening up wider markets and fostering increased demand for fish, resulting in increased fish prices. This has forced the local people to modify their cultural ways in order to find alternative food sources (ATF 1997). Reduction of the diversity of the genetic pool reduces the available materials for extraction of medicines, for agriculture and research (Kasweswe-Mafongo 2003). Human conflicts (e.g. between subsistence and commercial fishermen) are likely to increase due to competition for diminishing resources, and loss of habitats leads to intergenerational inequities. Because of the endemicity of the Lake’s cichlid fishes and rich speciation in haplochromines, the global community has only one chance at effective management of this unique resource (World Bank 2003).

Conclusions and future outlook
The Lake Malawi Basin has numerous swamps/wetlands that are important in terms of plant species diversity and nursing grounds for fish. Conversion of these swamps/wetlands for cultivation and cattle grazing, as well as the use of their waters for irrigation, has adverse impacts on their biodiversity. Increased sedimentation resulting from land degradation and deforestation in the catchment is also changing riverine and lacustrine habitats that again impacts on biodiversity. Overfishing and destructive fishing practices, acting in concert with human-induced wetland conversion and increased sedimentation, has grave impacts on the fish stocks and species diversity, particularly in the wetlands and littoral zones of the Lake. For example, the cyprinid fish *Opsaridium microlepsis*, which is endemic to Lake Malawi and is one of the major commercial species in its northern and central regions (Hughes & Hughes 1992) has now been largely eliminated from Malawian waters through a combination of siltation and fishing pressure (Cohen et al. 1996). In addition, water level changes in the floodplains can have marked impacts on fish catches because the floodplains act as very productive nursery areas (Ribbink 2001).

Figure 22  Lake shore of Lake Malawi near Money Bay in Lake Malawi National Park.
(Photo: Corbis)
Water hyacinth has been introduced into the rivers of the Basin and through them has entered the Lake. It is currently not a problem as the Lake does not have sufficient nutrients to sustain it, but may become so with increased eutrophication. The rate of loss of ecosystems and/or their modification will increase as result of changes (reduction) in the surface area currently under water, human activities in the catchment and aquatic system as a whole. Changes in salinity due to decreasing water levels and increasing temperatures will also affect the current ecosystem and could result in changes in community structure and species composition, though this is very unlikely in the near future. Economic impact would become more severe as a result of further ecosystem loss and habitat modification. Subsistence fisheries would be most affected, as shallow aquatic areas are lost to land, reducing the local populations capacity to meet basic food needs. This, in turn, would increase health risks. The prospect of enhanced lake deterioration would also increase as populations migrate to areas which still retain their ecosystem integrity in search for unpolluted fish food, water, agricultural land and fuel wood resources.

Unsustainable exploitation of fish and other living resources

Malawi has about 800 different species of fish (Ribbink 2001). Many of these fishes are colourful and highly sought after by the aquarium trade. The inshore distribution of these fishes and their inquisitive behaviour make them attractive to view and adds immeasurably to the tourism potential of the Lake.

By the 1930s, commercial fisheries had begun in Malawi (Ribbink 2001), and in the 1940s the first concerns over overfishing were raised (Ricardo-Bertram et al. 1942). The growth of the artisanal fishery was accompanied by the development of a mechanised fishery which started in 1943 with the introduction of open plank boats with engines. Fishing pressure increased in the 1960s when artificial twines replaced natural fibres, plank boats with outboard engines became popular and the first demersal trawlers were introduced (Tarbit 1971). Since then, the number of small, open vessels has increased progressively, with a growth of more than 80% since 1980 in Malawi, to almost 9 400, of which 1 700 are plank boats (Malawi Fisheries Department, cited in Ribbink 2001). In Mozambique and Tanzania, the remoteness of the Lake from regions of high population density meant that the scale and intensity of fishing never reached a level comparable to that in Malawi (Ribbink 2001). Nevertheless, fishing pressures grew along the lakeshore in both countries, despite the relatively low population densities (Booth 2000). In Malawi, the artisanal fishery land 80–90% of the catches, while in Tanzania and Mozambique, the artisanal fisheries account for all landings (Ribbink 2001).

All the fishes in the Lake are edible, consequently, by-catch is not wasted as all fish that are caught are eaten, whether targeted or not (Ribbink 2001). There is no evidence of decreased viability of stock through increased incidence of fish contamination and disease.

Environmental impacts

Overexploitation

Fish production in Malawi rose dramatically from annual catches of 20 000 tonnes in 1965 to 84 000 tonnes in the 1970s and has declined since then to give fluctuating yields, sometimes dropping to 60 000 tonnes per year (Mapila 1998). In Mozambique, there was a decline in fishing effort due to the civil war but since then there has been an increase in fishing activity. In Tanzania, the fishery has shown steady growth. An increase in the number of boats and in fishing effort has resulted in a decline in catches (Ribbink 2001). The soft substratum-associated fish communities have been more heavily impacted than the rocky fish-associated communities in the shallower parts of the Lake. Overfishing does not occur throughout the Lake, and the deep pelagic waters of the Lake are probably under-exploited. However, deep water demersal communities (50-100 m depth) are harvested by offshore trawlers in particular and have shown changes in species composition and standing stock, but nearshore, shallow demersal communities are under the greatest pressure (Ribbink 2001). The cichlid fish communities of the inshore regions are the richest, most diverse, most stenotopic, and hence the most vulnerable to fishing pressure, yet it is these vulnerable communities that are subjected to the greatest fishing effort; the artisanal fishery land about 85% of the catch and is restricted to the nearshore habitats (Ribbink 2001). There are indications that local overfishing has taken place because Catch Per Unit Effort (CPUE) and standing stocks have decreased (Ribbink 2001). In the artisanal and commercial fisheries, species composition of catches has changed, with the larger fishes disappearing from the catches (Ribbink 2001). Partly as a result of overfishing, the most seriously threatened fish species are the riverine and potamodromous species, some of which have now been eliminated (Tweddle 1992, Cohen et al. 1996, Ribbink 2001).

Destructive fishing practices

Although no studies have been done, anecdotal comments on fishing in the littoral belt suggest that seine netting has reduced substantially the vegetated regions, and hence the amount of habitat for use as nurseries and for species that are adapted to living among macrophytes (Ribbink 2001).
Impact on biological and genetic diversity

There is no evidence of deliberate or accidental introductions of alien stocks or genetically modified species (Cohen et al. 1996). However, there have been many unintentional species translocations within the Lake, mostly by the aquarium trade industry. The translocations disrupt existing nearshore species, and may result in the extinction of species at certain locations, and/or homogenisation of the gene pool and loss of genetic diversity (Bootsma, pers. comm.).

Socio-economic impacts

Fisheries is an important economic sector, supporting thousands of permanent inhabitants who are largely dependent upon fish for their livelihood (Ribbink 2001). The commercial fisheries from Lake Malawi are currently estimated to contribute 1–2% to GDP and provides employment, directly or indirectly, to up to 290 000 people (World Bank 2003). The ornamental fishery provides foreign exchange, and employment to several hundred people (Ribbink 2001). The per capita consumption of fish fell in Malawi from 12.3 kg in 1972 to 7 kg in 1991 (Mapila 1992), and is believed to have continued to fall, suggesting that supply cannot keep up with demand (Ribbink 2001). Overexploitation and destructive fishing methods would lead to reduced economic returns, loss of employment and livelihood, and reduced earnings in one area by destruction of juveniles in another (migrating populations).

Fish is particularly important to the people during times of drought (Mapila 1992) as it combats malnutrition when crops fail. Unsustainable exploitation can therefore lead to malnutrition due to loss of protein sources for human consumption. In Malawi, for example, fish from the Lake and rivers provides about 70% of animal protein consumption in the country (Nyambose 1997, World Bank 2003). The poor who rely on fish for their daily needs lose out as fish stocks decline, and demand and prices increase (Nyambose 1997). However, it is not too severe due to the existence of protein options.

The Lake is one of the world’s major biodiversity hotspots. The ornamental fishery stimulates the interest in the biodiversity of the Lake and focuses international attention on the Lake, which is of benefit to promoting donor interest and the tourism industry (Ribbink 2001). On the other hand, trawlers sometimes fish inshore, creating conflict between them and the artisanal fishermen. With the introduction of commercial large-scale fishing, the lakeshore people are finding it difficult to continue their traditional way of life: in some cases, living patterns have been dismantled and cultural practices have been modified in order to find alternative sources of food (Nyambose 1997). Intergenerational equity issues also arise due to the environmental degradation and loss of biodiversity.

Conclusions and future outlook

The Lake Malawi fish community has been adversely impacted by increased exploitation of inshore fishes resulting in declining catches and loss of biodiversity (Turner 1994). Overfishing does not occur throughout Lake Malawi, and the deep pelagic waters of the Lake are probably under-exploited (Ribbink 2001). However, deepwater demersal communities (between 50–100 m depth) are harvested by offshore trawlers in particular and have shown changes in species composition and standing stock, but nearshore, shallow demersal communities are under the greatest pressure (Ribbink 2001). At the southern end of the Lake, fishing has resulted in reduced fish size, smaller catches, and possibly reduced biodiversity. The potamodromous fishes are subjected to heavy fishing pressure when adults congregate on their spawning runs up river; simultaneously, degradation of rivers negatively affects breeding success and recruitment, so that populations of several species are in decline and many are threatened (Tweedle 1992, Ribbink 2001). As in Lake Tanganyika, the impact of ornamental fishing on population and community structure could be considerable as the rare and alien species are extracted in as high a number as possible because of the high mortality rates in shipping. Declining fish yields and CPUE, as well as disappearance of certain fishes from the catches (while the number of people involved in fishing continues to grow), suggests that present levels of exploitation are not sustainable, at least in some parts of the Lake (Ribbink 2001).

The fisheries sector is likely to become more important to the GDP of the region as more people turn from agriculture (which is now exhibiting declining productivity as a result of land degradation) to fisheries. In addition, the rapidly increasing population will fuel increased fishing effort through sheer numbers alone as the people try to sustain their livelihoods. Under immediate threat are the riverine, potamodromous and littoral zone fisheries. If the Mtwara Development Corridor is successful in its initiatives, this will open up the remote lakeshore areas of Mozambique and Tanzania, and will probably also lead to increased fishing pressure from the two countries. Currently, the deep pelagic waters of the Lake are probably under-exploited (Ribbink 2001), but as the fish stocks dwindle in the littoral and shallower areas, these deep pelagic waters will probably become the new fishing grounds that will be accessible to the large commercial trawlers. In relation to this, there is the prospect of the collapse of artisanal fisheries with dire consequences for the hundreds of thousands of people who are dependent on them for income and food. Negative spin-offs from this would be increased levels of poverty, malnutrition, and social conflicts (e.g. between artisanal and commercial fishermen as is currently the case). Declining fish stocks may accentuate the use of destructive fishing practices which would, in turn, accelerate the elimination of
fish through direct (overfishing) and indirect (destruction of habitat, changes in the food chain, etc.) impacts.

Global change

Within the region, changes in the distribution of rainfall take place in response to the movement of the Inter-Tropical Convergence Zone (ITCZ) and associated belts of distribution. Climate change and variability are caused amongst others by long-term trends in the movement and characteristics of the ITCZ, shifts in the global circulation pattern, deforestation, rates of evapotranspiration, global greenhouse gas emissions and changes in the hydrological system (Government of Malawi 1998). The Lake itself exerts a considerable modifying effect on the weather and climate in its vicinity (Eccles 1984). Average rainfall around the Lake varies regionally, the general trend being less rain at the south of the Lake and more at the north end (Bootsm & Hecky 1999). Using more than two decades of data (1954–1980), Kidd (1983) calculated mean annual rainfall in the south (south of the Dwanga watershed) to be 996 mm, that in the central area to be 1 110 mm, and that in the north and northeastern area (Songwe to Ruhuhu watersheds) to be 1 542 mm. The estimated average annual rainfall directly on the Lake is estimated to be 1 414 mm (Kidd 1983). Global warming will lead to higher temperatures: the rate of warming is estimated to be between 0.2 and 0.5°C per decade for Africa (Hulme et al. 2001), and rainfall in southern Africa is projected to decline by 2050 by about 10% (IPCC 2001).

The hydrological cycle in the region is closely linked to ENSO cycles (cf. Nicholson 1996). However, as opposed to eastern Africa, El Niño in this region is associated with drought rather than excess rainfall. The correlation between El Niño and inter-annual variations in southern Africa is highly significant, but it is not a simple relationship. Not every El Niño event brings low rainfall, and in some years extremely low annual rainfall is not clearly linked to El Niño events (Clay et al. 2003). Much less well understood oceanic-atmospheric interactions in the Indian Ocean and Southern Atlantic are now recognised as important influences on rainfall patterns (Clay et al. 2003).

Agriculture accounts for between one-third to slightly over one-half of the GDP of the riparian countries (see Table 10). Most of the agricultural activities are at subsistence level, and depend directly on rainfall. The region’s electricity is dependent largely on hydroelectric power production from the Shire Valley hydroelectric power plant, which in turn depends on flow from Lake Malawi. Inland fisheries and navigation are often dependent on the hydrological regime in lakes and rivers. A reliable supply of good quality water is required for human consumption, industry and irrigation (Calder et al. 1995). In the drought of 1991/1992, the Shire Valley hydroelectric system came close to power restrictions due to insufficient water flow (Clay et al. 2003). Because most rural people depend on agriculture for subsistence, unreliability of rainfall causes loss of income, and increased general vulnerability to food security (Government of Malawi 1998). The effects of sea-level change, radiation, carbon dioxide source-sink function, and temperature change, remain uninvestigated in the Lake Malawi Basin.

Environmental impacts

Changes in hydrological cycle and lake circulation

There has been an increase in the frequency of droughts in recent years (Ribbink 2001). The droughts of 1991/1992, 1994/1995 and 1997/1998 were all associated with ENSO (Clay et al. 2003), but the recent disastrous floods in Mozambique and the role which the extremely high rainfall in Malawi in 2000/2001 played in the crisis in 2002 have highlighted the risks associated with high rainfall (Clay et al. 2003). Periods of below-average or erratic rainfall were less extreme and less general in their impacts in the 1970s and 1980s than in the 1990s (Clay et al. 2003). High outflows in the Shire River were recorded in 1980 when the discharge (963 m³/s) was over twice as high as the mean discharge (395 m³/s), and the highest annual outflows of 825 m³/s and 820 m³/s occurred in 1979–1980 and 1980–1981 respectively, during an unusually wet period (Government of Malawi 1998).

Lake-level change

Lake Malawi is similar to Lake Victoria and Lake Tanganyika in that relatively small changes in rainfall and evaporation may lead to shifting between open- and closed-basin status as has happened in historical times (Beadle 1981, Owen et al. 1990, Spigel & Coulter 1996). Lake Malawi had a lowstand between 1500 and 1850 (²¹⁰Pb dates) (Owen et al. 1990) and in 1915 when outflow via the Shire River ceased; outflow resumed in 1935 after the lake level had risen 6 m (Beadle 1981). Lake Malawi, as the other east African lakes, also responds dramatically to El Niño events, but also to anomalous warming of the Western Equatorial Ocean, such as that which led to the high rainfall event that occurred in 1997–1998 and resulted in a water level rise in the Lake of 1.8 m (Birkett et al. 1999).

Other high rainfall periods are recorded in the early 1960s and late 1970s. A modelling study of Lake Malawi shows that rainfall variation is sufficient to explain the lake-level changes on annual and seasonal resolution over the past century (1896 to 1967) irrespective of changes in land use, evaporative demand or in the hydraulic regime of the Lake (Calder et al. 1995). However, because of a 13% decrease in forest cover from 1967 to 1990 as a result of human activities, the run-off increased,
and consequently the lake level was 1 m higher than it would otherwise have been during the drought of 1992 (Calder et al. 1995).

**Socio-economic impacts**

Impacts of increased frequency and intensity of drought are felt mostly in agriculture and in other sectors reliant on water, such as hydroelectric power generation. In southern Africa, including Lake Malawi Basin, agricultural performance is optimal with annual rainfall between 95% and 120% of long-term mean total rainfall – excesses or deficits will negatively impact on agricultural production such as the 1991/92 drought that resulted in a 60% decline in maize production (Clay et al. 2003). The economic cost of this drought in the southern African region was estimated as follows: 1 billion USD in cereal losses at import parity prices and 500 million USD in actual logistical costs of importing cereal into affected southern African countries (Clay et al. 2003). Economic costs of excess rainfall through damage to infrastructure and agriculture can also be quite extensive: in the past, floods have destroyed hotel and harbour installations, destroyed crops, and cut off communications. The degradation of catchment areas and marginal lands as a result of population pressure and inappropriate agricultural activities, has led to the reduction of base flows and increased incidences of flood disasters during heavy storms. The flood peak levels in 1976 and 1978 caused considerable difficulties to lakeshore dwellers, hotels and harbour installations (Drayton & Crossley cited in Eccles 1984). The floods of 1979 and 1980 inundated large areas of productive land, rendering many villages uninhabitable, caused the temporary closure of some hotels, threatened communications and overtopped jetties at major ports (Drayton & Crossley cited in Eccles 1984). This has resulted in temporary displacement of large populations, loss of food resources, and has been a major impediment to communications.

**Conclusions and future outlook**

A complex interaction between an array of climate parameters (ITCZ, shifts in the global circulation pattern, deforestation, rate of evapotranspiration, global greenhouse gas emissions and changes in the hydrological system) affect the climate of the region. The Lake itself also exerts a strong modifying influence on the regional climate. The hydrological cycle is closely linked to ENSO cycles. Drought is normally but not always associated with the ENSO, whose frequency and intensity has been observed to be increasing, probably as a result of global warming. However, the increased frequency of drought that has been observed in southern Africa, e.g., in the 1990s, cannot be conclusively linked to ENSO (and global warming), as there are other causes that are not necessarily linked to ENSO, such as oceanic-atmospheric cycles in the Indian Ocean and Southern Atlantic, that significantly affect the climate of the region (Clay et al. 2003). Changes in the rainfall patterns have had adverse economic impacts on the agricultural sector, and on infrastructure, housing and communications (Drayton & Crossley cited in Eccles 1984, Clay et al. 2003). Reductions in rainfall also threaten the production of electrical power from the Shire Valley hydroelectric power plant. Rural communities are the most vulnerable to changes in precipitation as they rely largely on subsistence agriculture for food security and income generation. Global warming will lead to higher temperatures at a rate of 0.2–0.5°C per decade in Africa (Hulme et al. 2001), while rainfall in southern Africa is projected to decline by about 10% over the next 50 years (IPCC 2001). The projected decline in rainfall relative to today does not appear to be a great threat to the region, but there may be associated increased variability and changes in the distribution of precipitation. These are issues which need further, and urgent, investigation.

As has been observed in Lake Tanganyika (O'Reilly et al. 2003, Verburg et al. 2003), warming temperatures in the region will cause greater heating in surface waters than in deep waters in the meromictic Rift Valley Lakes, and this could reduce vertical exchange of deep waters with surface waters and reduced loading from the higher nutrient concentrations in those deep waters. Vollmer et al. (2002) have documented a recent reduction in the ventilation of the deep water of Lake Malawi which has also reduced nutrient loading from the hypolimnion (Bootsma & Hecky 1999). Reduced nutrient loading could lead to lower biological production in the Lake Malawi, as in Lake Tanganyika (cf. O'Reilly et al. 2003). The possibility of a return to historically low levels is of great concern in relation to: the maintenance and planning of future hydropower development on the rivers draining into the Lake (Calder et al. 1995); disruption of electrical power supply from the Shire Valley hydroelectric powerplant; and; changes in the littoral and deltaic habitats and its effects on fisheries. Knowledge of the changes in the hydrological regime, which may result from climate change or land use change, is therefore necessary for the planning of future developments (Calder et al. 1995).

**Priority concerns**

The Task team prioritised the GIWA concerns as follows:

1. Unsustainable exploitation of fish and other living resources
2. Habitat and community modification
3. Pollution
4. Freshwater shortage
5. Global change
The concerns that are recommended for further analysis are:
Unsustainable exploitation of fish and other living resources and Habitat and community modification.

The linkages between the GIWA concerns are illustrated in Figure 23 below. All fishes, but particularly the riverine, the potamodromous and the stenotopic lacustrine species are vulnerable to changes in water quality (pollution), freshwater shortage and habitat degradation. Pollution and unsustainable exploitation of living resources are linked primarily via the effect of sediment blanketing and turbidity on fish resources. Habitat modification and unsustainable exploitation of living resources are significantly linked as degradation of habitat would also lead to declines in fish stocks and species loss.

Figure 23  Linkages between GIWA concerns in Lake Malawi.