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Challenges to sustainable management of the lakes of Malawi

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ABSTRACT

This paper reviews the management challenges facing Malawi lakes and analyzes the management responses that have been developed to deal with these challenges. Malawi lakes are under considerable stress due to high population growth and increasing levels of poverty which have led to overexploitation of fishery resources. High rates of soil erosion in the lake catchments are increasing siltation of shallow lakes, deltas and embayments, affecting water quality and fish breeding habitats, thereby degrading fish production potential. This review further shows that past and current management approaches have focused on maximizing sustainable yield and have failed to adequately incorporate socio-ecological factors and broader lake catchment processes into fisheries management plans. This, in turn, led to the top-down development of fisheries laws and technical regulations which were difficult to enforce, increased conflict between resource users and fisheries managers, and failed to control fisheries over-exploitation and the collapse of the chambo (tilapia) and cyprinid fisheries. The paper recommends that the fisheries policy should be reviewed to focus on resilience of fisheries, environment and livelihoods. Policy makers should adopt integrated management planning to address the diverse interest of stakeholders in lake basins, as well as the ecological, socio-economic and external factors threatening sustainability of lake ecosystems and livelihoods of dependent communities.

Introduction

Malawi is endowed with extensive water resources covering about 20% of the country's area (120,000 km^2). The major lakes are Malawi, Chilwa, Chiuta and Malombe the first three of which are internationally shared (Fig. 1). The lakes provide a diversity of ecosystem services and livelihood benefits including food, water for agriculture, recreation, and transportation for commerce and trade to over 13 million people of Malawi, Tanzania and Mozambique (Bootsma and Hecky, 1999). Lake Malawi is a headwater lake for the Zambezi River to which it is connected by the Shire River outlet, and it sustains hydroelectricity generation and irrigation through the Shire River (Hirji et al., 2002). Fishing is the most important economic activity on Malawi lakes. The annual total catch varies widely between 30,000 and 80,000 MT, with landings in most years ranging between 50,000 and 60,000 MT year^{-1}. Since 2003, total fish production has been on the rise due to increasing catches of small zooplantivorous fish such as *usipa* (*Engraulicypris sardella*) and the *utaka* (*Copadichromis* spp.) species group (Russell et al., 2008; GOM, 2008). Fishing and related activities contribute about 4% to the total gross domestic production of Malawi (GOM, 2008; FAO, 2009).

The fisheries sector provides employment opportunities directly to about 60,000 people and indirectly to over 450,000 people in fish processing, distribution and associated trades (GOM, 2009). Lake fisheries are a major source of food and nutritional security for Malawians. Fish supply 60% of animal protein, 40% of the total protein intake, vital vitamins, minerals, micro-nutrients and essential fatty acids to Malawian diets (GOM, 2008; Russell et al., 2008). Hence, fish is a critical ingredient for nutritional security in Malawi, where human diets are dominated by maize and cassava.

Fishing activities also contribute to national economic growth. Fish landings in 2008 had a beach value of MK9.5 billion, equivalent to US $63.8 million (GOM, 2009). Most of the fish caught is locally consumed and this substitutes for fish and animal protein imports. Lake Malawi has over 1000 endemic fish species (Snoeks, 2000) which are of both local and international scientific importance and also act as a source of attraction for tourism. Some fish species (e.g. rock dwelling cichlids — locally called *mbuna*) are exported to the aquarium trade outside the country, thus further contributing towards Malawi's foreign exchange earnings.

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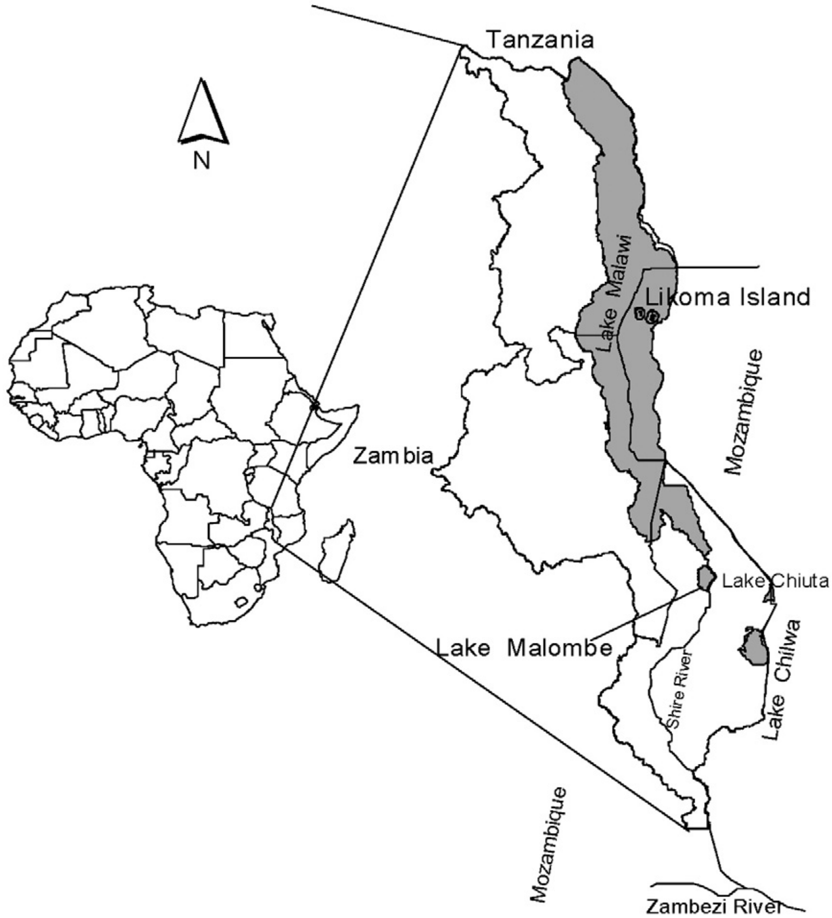

Fig. 1. Location of Malawi's four major lakes.

Malawi lakes and rivers, and the ecosystem services that they provide, are under considerable stress due to high population growth, increasing levels of poverty, environmental degradation and high fish demand (Turner et al., 1995; Mkanda, 2002; Delaney et al., 2007; Hecky et al., 2003). High fish demand has led to localised overexploitation of fish resources. Within the lakes, overexploitation is especially acute for tilapiine and cyprinid fisheries (FAO, 1993; Banda et al., 2005; Turner et al., 1995).

Environmental degradation in lake catchments has increased soil erosion rates and siltation of shallow lakes, increased nutrient loading (Hecky et al., 2003), and reduced the water quality, production and abundance of cyprinids and other fish species which depend on influent rivers for breeding (Mkanda, 2002). Emerging threats to the management of these lakes include climate change (Vollmer et al., 2005) and incipient mineral resource extraction and industrialization, e.g. new coal and uranium mining operations in Karonga and Rumphi districts, located in the northern part of the Lake Malawi catchment.

Because of the long-standing economic importance and value of fisheries in Malawi, lake management has been synonymous with fisheries management. However, recent studies (Hecky et al., 2003; Jamu et al., 2003; Delaney et al., 2007; Otu et al., 2011) indicate that catchment processes and other exogenous factors also exert significant influence on lake aquatic environment and productivity. Therefore, holistic management approaches are required to sustain ecosystem services and livelihood benefits which these lakes provide. In this paper we review the biophysical characteristics of Malawi's major lakes, existing management approaches for Malawi lakes, identify challenges and examine how these can be addressed through integrative planning and management.

Biophysical characteristics of Malawi lakes

Biophysical characteristics of the four largest lakes are presented in Table 1.

Lake Malawi

Lake Malawi covers a surface area of over 29,000 km^2 and drains a catchment area of 100,500 km^2 (Bootsma and Hecky, 2003). It is the largest and most significant water body in terms of fish production in Malawi, usually contributing over 60% of the total annual landings. The lakeshore areas support the livelihoods of about 2 million people and a diverse number of activities including tourism, agriculture, fishing, irrigation and transportation (NSO, 2008).

The level of biodiversity in the aquatic environment of Lake Malawi is very high. The fishes of Lake Malawi are one of the most

Table 1
Physical features and catchment population of major Malawi Lakes. Lake Malawi data from Bootsma and Hecky (2003).

	Malawi	Chilwa	Malombe	Chiuta
Length (km)	550	50	29	24
Breadth (km)	60	30	17	12
Average depth (m)	264	3	5–7	3
Maximum depth (m)	700	6	17	4
Water area (km^2)	29,500	1836	390	199
Population (million)	2	1.5	0.1	0.4
Outlet	Shire	None	Shire	Lake Amaramba/ Lujenda River

Table 2
The riverine and lacustrine fishes of Lake Malawi adapted from Ribbink (2001).

Family	Genera	Species	% endemism
Anguillidae	1	1	0
Aplocheilidae	1	2	100
Bagridae	2	4	50
Characide	2	2	0
Cichlidae	41	Circa 750	99.5
Claridae	2	17	71
Cyprinidae	5	26	35
Mastacembelida	1	2	100
Mochokoidae	2	3	33
Mormyridae	4	7	0
Protopteridae	1	1	0

remarkably diverse and abundant faunal groups in the world. The number of species and genera in the lake continues to increase with new discoveries and taxonomic revisions (Konings, 1995; Turner, 1996; Ribbink, 2001). There are over 1000 species of fish in the Lake Malawi basin in eleven families (Table 2) (Snoeks, 2000; Ribbink, 2001). The Cichlidae comprising two groups, the tilapiines and haplochromines, is the most common fish family and the only one which attains a high degree of endemicity.

All but four Lake Malawi cichlids are endemic. The tilapiines comprise the genera *Oreochromis* and *Tilapia* which are represented by seven species. The haplochromine cichlids, represented by 39 genera with more than 800 species are the most common fish group in the lake. There are 62 non-cichlid species in ten families occurring in the lake basin, 26 of which are endemic. For the purpose of fisheries management, the Department of Fisheries have grouped the species into 16 commercial fish categories (Table 3).

Of these, relatively few species groups of fish dominate the commercial catches. Commercially important fish species groups include tilapines (chambo (*Oreochromis* spp.), kasawala (juvenile chambo) and other tilapias), haplochromines (Utaka (*Copadicrhomis* spp., mbaba, and chisawasawa), catfish (Kampango (*Bagrus meridionalis*) and Bombe (*Bathyclarias* spp), and Usipa (*Engraulicypris*

Table 3
Commercial fish categories of Lake Malawi, the species comprised and the proportional contribution of the combined landings from Lake Malawi 1976–2009 (JICA, 2005; GOM, 2009).

Species group	Family	Species comprised	Percent of total catch
Chambo	Cichlidae	*Oreochromis* spp. other than *Oreochromis shiranus*	15
Chisawasawa	Cichlidae	Offshore demersal haplochromine cichlid species	6
Kambuzi	Cichlidae	Small demersal inshore haplochromine cichlid species mainly belonging to genus *Lethrinops*.	7
Kampango	Bagridae	*Bagrus meridionalis*	4
Kasawala	Cichlidae	Juvenile chambo	<1
Mbaba	Cichlidae	All haplochromines cichlids other than those incorporated in the chambo, kambuzi, utaka, mcheni and other tilapia groups	<1
Mlamba	Claridae	Clarid catfish including *Clarias gariepinus* and various *Bathyclarias* spp.	3
Mpasa	Cyprinidae	*Opsaridium microlepis*	<1
Mcheni	Cichlidae	*Rhamphocromis* spp.	3
Ndunduma	Cichlidae	Offshore pelagic species belonging to the genus *Diplotaxodon*	<1
Ntchila	Cyprinidae	*Labeo mesops*	<1
Other tilapia	Cichlidae	*Oreochromis shiranus* and *Tilapia rendalli*	1
Sanjika	Cyprinidae	*Opsaridium microcephalus*	<1
Usipa	Cyprinidae	*Engraulicypris sardella*	26
Utaka	Cichlidae	Pelagic small cichlids mainly belonging to the genus *Copadichromis*	28
All other species			6

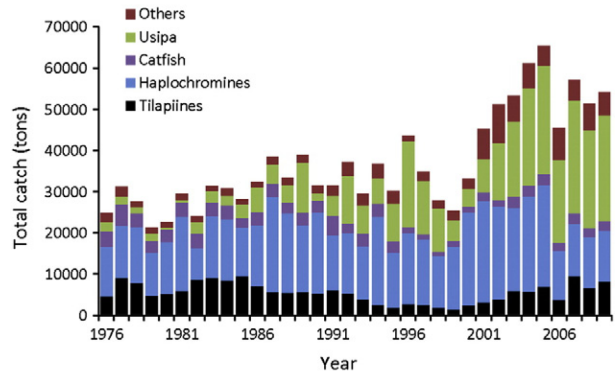

Fig. 2. Total catch by species group in Lake Malawi.

sardella) (Weyl et al., 2005; Russell et al., 2008). These species groups comprise over 80% of the total catch (Fig. 2). Other species include mpasa (*Opsaridium microlepis*), mcheni (*Ramphochromis* spp.), ntchila (*Labeo mesops*) and Matemba (*Barbus* spp.) (Weyl et al., 2005; Russell et al., 2008). There is, however, considerable species diversity within these commercial categories with over 200 fish species being recorded in the Lake Malawi fishery (Banda et al., 2002).

The intensification of artisanal and commercial trawl fishing has resulted in the local extirpation and disappearance of some species resulting in changes in species composition of catches (Tweddle and Turner, 1977; Banda et al., 1996). For example, the *L. mesops* fishery in Lake Malawi collapsed in the early 1970s due to heavy fishing pressure and thereafter the lake fisheries were dominated by the chambo. These fisheries subsequently in the 1980s and catches have since been dominated by haplochromine and usipa. Within the haplochromine species group, larger species such as *Lethrinops stridei* and *L. macracatnthus* were replaced by small cichlids such as *Otopharynx argyrosoma* and *Lethrinops auritus*. This response to heavy fishing or use of illegal methods by multi-species inland fisheries has also been observed in other African inland lakes and is known as the fishing-down process (Welcomme, 1999).

In spite of the collapse of the chambo and *L. mesops* fishery, the total fish catch in Lake Malawi show an increasing trend (Fig. 2). Recent data (GOM, 2009) show that Lake Malawi artisanal fisheries catches increased between the periods 2003 to 2009, while commercial fishery production has been in decline since 1987. The decline is attributed to low chambo catches in the southern part of Lake Malawi, Upper Shire River and Lake Malombe (Fig. 3). Total chambo catches from Malawi lakes reached a historical high of 15,000 MT year^{-1} in the late 1980s but declined to 3000 tonnes year^{-1} at the end of the 1990s (FAO; Banda et al., 2005). The apparent increase in the number of fish captured by the artisanal sub-sector between 1998 and 2009 is mainly due to the increasing proportion of Usipa (*E. sardella*) and Utaka (*Copadichromis*) (Russell et al., 2008) in

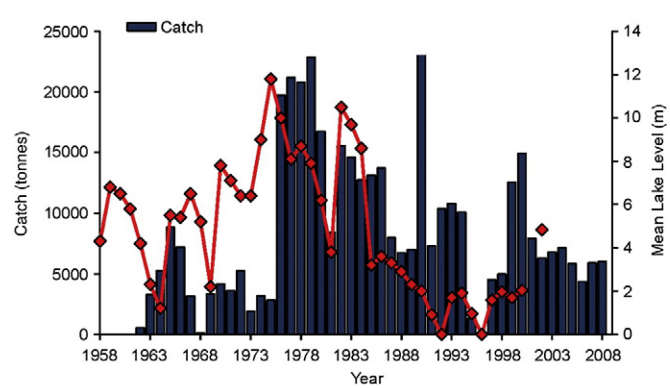

Fig. 3. Total fish production and water levels in Lake Chilwa.

the artisanal catches. However, Chinsinga (2009) contends that the increase could also be attributed to other factors such as deficiencies in data collection.

Because of low industrial activity, Lake Malawi is not under immediate threat from many forms of industrial pollution that have impacted large lakes in North America, Europe and elsewhere. Studies by Kidd et al. (2001, 2003) showed low levels of pesticides, metals and other persistent contaminants in lake water, sediments and biota which were unlikely to cause detrimental effects in wildlife. Agricultural activities in the lake catchment have been linked to increased nutrient loading from riverine runoff (Hecky et al., 2003) and also in the form of atmospheric deposition (Hecky et al., 2006). In Lake Victoria changes in nutrient loading led to eutrophication which transformed the fish community and led to loss of biodiversity (Hecky, 1993; Seehausen et al., 2003). Atmospheric deposition of phosphorus at Lake Malawi, and elsewhere in eastern Africa, is nearly an order of magnitude higher than at monitored areas in North America and accounts for nearly 50% of total phosphorus loading. To this current burden of loading will be added nutrient pollution from new industrial and agriculture activities such as cage aquaculture (Gondwe et al., 2011) and mining (coal and uranium), which have been developed in the Lake and its catchment area in the last 10 years. Together these increasing multiple sources of nutrient and sediment loading will pose major challenges to the management of the Lake. Atmospheric deposition from biomass burning in small-scale agriculture and bush fires will perhaps be the biggest challenge because possible sources of atmospherically vectored nutrients may arise from outside the drainage basin (Hecky et al., 2006). The shallow, southern basin of the Lake Malawi, historically the most productive, is already experiencing rapid eutrophication while the deeper northern lake still remains unaffected (Otu et al., 2011).

Major challenges facing the lake include eutrophication due to increasing multiple sources of nutrient loading from economic activities and development projects within the basin, climate change and development of appropriate management strategies that sustain productivity and fish biodiversity.

Lake Chilwa

Lake Chilwa is the second largest lake in Malawi and is located on the Phalombe plain of Malawi and Mozambique (Bossche and Bernacsek, 1990). The catchment area is about 8349 km^2 with 5669 km^2 located in Malawi and 2680 km^2 in Mozambique. The lake, which has no outlet, is shallow (≤6 m), has an open water area of 678 km^2 and is surrounded by 600 km^2 of *Typha* swamps, 390 km^2 of swamps and 580 km^2 of inundated floodplain (van Zwieten and Njaya, 2003). Lake Chilwa is one of the most productive lakes in Africa and fish productivity is driven by water level changes (van Zwieten and Njaya, 2003; Macuiane et al., 2009) (Fig. 4). Fish production averages around 15,000 MT year^{-1} (30% of total Malawi annual fish catch) but in some years annual catch can approach 25,000 MT (van Zwieten and Njaya, 2003; Danida and EAD, 2001).

Lake Chilwa levels fluctuate widely due to seasonal changes in precipitation and evaporation (Danida and EAD, 2001; Macuiane et al., 2009; Njaya et al., 1999) (Fig. 4). Water levels exhibit seasonal cycles of 0.8–1.0 m and annual fluctuations of 2–3 m (Kalk et al., 1979). These fluctuations result in severe water recessions, including complete lake drying (Lancaster, 1979; Agnew and Chipeta, 1979). The frequency of minor and major recessions is about 6 and 25 years respectively, but there is concern that the frequency of these major lake recessions, including total desiccation, may be increasing due to climate change. In response to this fluctuating environment and fish production, communities exploiting the Lake Chilwa fishery have developed adaptive strategies such as mobility and livelihood flexibility (Sarch and Allison, 2000). A detailed account of the natural history and fisheries ecology of Lake Chilwa is provided by Njaya et al. (1999).

Major challenges facing the lake include lake recessions, climate change, environmental degradation and siltation. Lake Chilwa fisheries managers are also faced with the challenge of developing fisheries management measures that maintain the flexibility of lakeshore livelihoods and sustain fisheries production during normal years.

The lake ecosystem is threatened by reduced river discharge and siltation caused by high levels of environmental degradation and deforestation within the lake catchment (Rebelo et al., 2011). New industrial activities in the basin, such as mining for rock phosphate and rare earth metals, and the growing impacts of climate change offer new challenges to the management of Lake Chilwa.

Lake Chilwa is the only lake in Malawi with a comprehensive integrated management plan, was developed in 1999 (Danida and EAD, 2001). The plan is an entry point for addressing the challenges identified above. Unfortunately, this plan has not yet been fully implemented.

Lake Malombe

Lake Malombe is a shallow lake (5–7 m average depth) and lies in the outflow of Lake Malawi. The lake was once covered in dense weed beds and supported a large population of crocodiles which made fishing difficult (Tarbit, 1972). Historical records show that during 1915–1935 much of the lake was farmed due to exceptionally low levels in Lake Malawi which resulted in the loss of outflow to the Shire River (Njaya, 2007; McCracken, 1987). The lake catchment, which includes steep slopes along the adjacent rift escarpment, has undergone rapid deforestation which has resulted in increased runoff and sedimentation (Mwafongo, 1998). Fishing in Lake Malombe started in the early 1960s after the large crocodile population was destroyed (Tweddle et al., 1994). Dense weed beds were subsequently cleared between 1970 and 1980 to facilitate seining (van Zwieten et al., 2003).

The Lake Malombe fishery contributed around 15% of Malawi's total fish landings in the 1980s but this has declined significantly. Total catches have declined from 13,000 MT year^{-1} in the mid 1980s to about 3000 MT year^{-1} (Fig. 4). The chambo species have declined from a peak catch of 8000 MT year^{-1} to less than 200 MT year^{-1} during the same period. Before the chambo collapse in the late 1980s, the lake's fish yield (130 kg ha^{-1} year^{-1}) was among the highest in Africa (Bayley, 1988). Current fish yield is 77 kg ha^{-1} year^{-1} and this is lower than the historical yield of 130 kg ha^{-1} year^{-1} and an estimated potential fish yield of 350 kg ha^{-1} year^{-1} based on current estimates of primary productivity (Guildford et al., 2009). The Lake Malombe fishery has not recovered since the initial decline in the late 1980s. The trends being observed in Lake Malombe are not just a preview of what may happen in other African fisheries if the growth of fishing effort remains unchecked (van Zwieten and Njaya, 2003), but

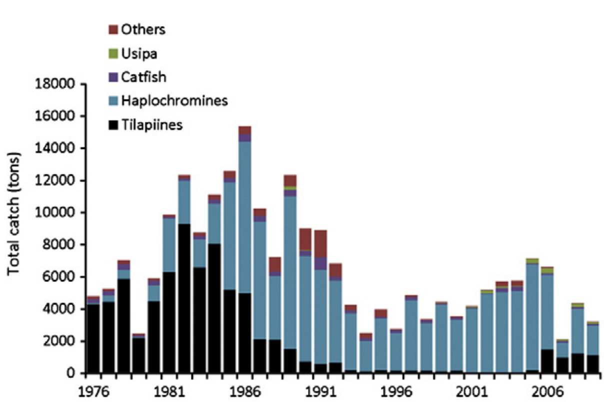

Fig. 4. Total catch by species group in Lake Malombe.

they are already being observed in other systems such as Lake Kariba and Victoria.

In response to the collapse of the fishery, management measures to reverse the trend were instituted; these included limiting access through licensing, gear and mesh size regulations, implementation of a closed season, banning of fine meshed beach seines, and regulating fishing effort through a co-management arrangement (FAO, 1993; Donda, 2001; Hara et al., 2002). The introduction of co-management did not, however, prevent the collapse of the fishery, likely because it was introduced without understanding the social, cultural, economic and institutional factors underlying the exploitation patterns of fish resources in the lake (Hara, 2006).

Studies (van Zwieten et al., 2003; Hara and Jul-Larsen, 2003) were conducted to establish factors responsible for the collapse of the chambo fishery in Lake Malombe. The study by van Zwieten et al. (2003) showed that decreasing water levels due to reduced rainfall and beach seining practices had resulted in the disappearance of submerged vegetation that serves as nursery grounds for the chambo. The studies showed that average annual water levels measured in the Upper Shire at Mangochi, 6 km upstream from its entrance into Lake Malombe, have decreased by around 3.5 m over the period from 1978 to 1999 (Van Zwieten et al., 2003). During the same period, Malawi experienced a decade of declining rainfall which resulted in the drying up of the adjacent Lake Chilwa (Njaya et al., 1999). However, this study failed to explain how environmental changes such as habitat destruction, surface runoff, sediment load and large changes in forest cover around the lake affected lake productivity and fish catch variability.

Detailed analysis on the impact of effort development on the collapse of the Lake Malombe fisheries (van Zwieten et al., 2003), and a sociological analysis by Hara and Jul-Larsen (2003), strongly indicate that the collapse of the Lake Malombe fisheries was due to investment driven growth in fishing effort. Investment driven growth refers to an increase in effort due to an increase in capitalization of the fishery, or improvements in technology. The investment driven results at Lake Malombe are contrary to the population driven growth that has been observed in other Malawi lakes.

It is therefore apparent that Lake Malombe fisheries are facing major challenges, which include a lack of understanding of social, economic and cultural factors governing exploitation of the lake resources, climatic variability, catchment degradation, and over-exploitation due to increased investment in and use of highly efficient fishing gear. The lake is also facing a serious biodiversity threat due to invasion of Asian snails (Genner et al., 2004).

Lake Chiuta

Lake Chiuta is the smallest (199 km^2) of the four major Malawi lakes. It is shallow (4 m maximum depth) and covered with submerged vegetation (FAO, 1993) with about 49 km^2 in Mozambican territory. Geological and biological evidence suggest that Lake Chiuta was connected to the endhoreic Lake Chilwa during higher water stands in the late Pleistocene era when the lakes drained to the Indian Ocean through Lake Amaramba and Lujenda River. The lakes are estimated to have separated within the last 15,000 years (Kalk et al., 1979).

Fish production from an exclusively artisanal fishery averages 2000 MT $year^{-1}$ (GoM, 2005). The lake does not support any significant economic opportunities apart from fishing because of its remote location and poor road access (Njaya et al., 1999). A co-management programme, initiated by the fishers themselves, has been operational since the mid 1990s. Lake Chiuta's co-management programme is reported as an example of a successful co-management programme on African freshwater lakes. Its success has mainly been attributed to the homogeneity of the fishing community, and to the fact that fishers adopted co-management with little government assistance; they organized themselves to protect their fishery from new entrants who were using destructive open water seine nets and polluting the lake (Dawson, 1997; Njaya et al., 1999).

Major challenges to Lake Chiuta include overexploitation of fisheries resources on the Mozambican side of the lake due to lack of harmonization of fisheries management regimes between Malawi and Mozambique, and poor knowledge base of the fishery resources due to inefficient monitoring by the Department of Fisheries (Njaya, 2007).

Review of management of Malawi Lakes

In this section we review lake management approaches that have been applied for Malawi lakes and identify the management challenges that are being faced by authorities and users. We use relevant literature on Malawi lakes reviewed above, augmented by our practical experience and extensive knowledge on the management of Malawi lakes gathered over more than a decade of working with the lakes and policy makers in Malawi.

Fisheries policy and governance systems

The Department of Fisheries is legally mandated to manage and monitor fisheries throughout Malawi through the development and implementation of management plans. These plans are developed based on scientific information on resource status and they also take into consideration the social, cultural and economic factors that affect exploitation and management of lake resources. Management of fisheries in Malawi lakes is guided by the National Fisheries and Aquaculture Policy (GOM, 2001; GoM, 2000), with the objective of managing the fish resources for sustainable utilisation and conservation of aquatic biodiversity to enhance quality of life for fishing communities. The policy aims at maintaining fish stocks at, or above, a level that can produce a maximum sustainable yield (MSY). The main responsibility of the Department of Fisheries, therefore, is to apply appropriate management and control measures that can maintain MSY in all lakes in Malawi. The policy also contains a range of sub-sectoral policies relating to extension, research, participatory fisheries management, fish farming, training, riverine and floodplain fisheries, and marketing. The policy further promotes community participatory fisheries management.

In order to achieve the fisheries policy objective, the Department of Fisheries uses three types of fisheries governance systems to manage lake fisheries: traditional, government-centred and co-management (Munthali, 1994; Njaya, 2007; Hara, 2006). The traditional system is centred on traditional authorities as custodians of fisheries resources. Under this system, fisheries are under the jurisdiction of a single traditional authority, and the right to harvest resources within a specific traditional authority is controlled by the traditional chief or leader. The traditional fisheries management system is heavily dependent on tenurial rights and taboos (Munthali, 1994; GTZ, 2001). The traditional authority has strong rules regarding fishing practices and thus this management system is based on informal rules that are applicable to small-scale fisheries. This system is still used to manage specific fisheries.

The government-centred system focuses on control of fisheries resources by central government and is based on a wide range of conventional regulations and restrictions that are applied to manage resource use. This system dates back to 1940s, when commercial fishing was introduced during colonial rule in Malawi, and is the predominant fisheries management system (Hara, 2006). To facilitate the implementation of this system, the Department of Fisheries has put in place several management tools to ensure that fisheries resources are managed sustainably. These include fisheries laws and regulations as outlined in the Fisheries Act (GOM, 1973).

The Fisheries Act contains fisheries regulations that aim at maximizing fisheries production with reference to MSY through indirect regulation of fishing effort. The Fisheries Act was developed mainly to achieve biologically sustainable exploitation of the chambo (*Oreochromis* spp.) stocks through regulations such as minimum mesh size for gillnets, closed season for seine nets and habitat protection (Hara, 2006). Due to widespread non-compliance to fishing regulations, the government-centered system failed to protect the chambo stocks in Lake Malawi and Malombe, and yield declined from 9000 MT in the mid 70s to less than 2000 MT and 50 MT respectively in 2001.

The need to redress the collapse of the chambo fishery in Lakes Malawi and Malombe in the mid 1990s and the paradigm shift in fisheries management towards user involvement during this period led to the introduction of co-management, also known as participatory fisheries management (FAO, 1993). Co-management was later introduced to Lakes Malombe, Chilwa and Chiuta (Donda, 2001; Njaya, 2007). According to Pinkerton (1989), most co-management agreements between government and fishing interests have arisen out of crises caused by rumoured or real stock depletion, or from political pressure regarding the inability of government to handle specific problems. In Malawi, the crises that led to the introduction of co-management include the collapse of the chambo fishery in Lakes Malawi and Malombe; failure by government agents to control entry of migrant open water seine net fishermen in Lake Chiuta, and the drying up of Lake Chilwa.

Co-management was given legal recognition in the form of a new Fisheries Conservation and Management Act (GoM, 1997b). The Fisheries Policy was also revised to incorporate co-management approaches and other emerging fish production areas such as aquaculture (GoM, 2000). The main focus of the policy, however, remained maximizing sustainable fish supply (GoM, 2000). The Fisheries Conservation and Management Act provides the legal basis for ensuring that input and output controls and technical regulations are enforced to maintain fisheries at MSY. The output controls limit the quantity and quality of fish being landed and legal size limits on fish. Technical measures, which include gear limitations, mesh size restrictions, closed seasons and protected areas, are used to limit over-exploitation of the fishery by placing restrictions on the types, characteristics and mode of operation of the gear used.

Protected/closed areas

Two types of protected areas, conservation reserves and harvest reserves are used as management tools in Malawi. Conservation reserves are not common in freshwater lakes, but they are a common management tool in marine aquatic environment as they offer a range of protection, from complete prohibitions against removal of any living creature, to other regulations such as seasonal closures or restrictions on the removal of specific species (Hall, 1998). Lake Malawi National Park and the Liwonde National Park, which covers part of Lake Malombe, are the only gazetted freshwater protected areas in Malawi (Munthali, 1994). In Lake Malawi, the protected area includes the headlands and islands themselves, as well as an aquatic zone extending 100 m from the shore. Fishing is prohibited within the park perimeter. Other smaller scale protected areas have been set by local communities as part of co-management arrangements. These protected areas are semi-permanent or temporary, as is the case of fish sanctuaries established in Lake Chilwa affluent rivers during periods of lake recession (Njaya et al., 1999), or semi-permanent, where fishermen put tree logs in the lake to enhance the fishery but also prevent fishing van Zwieten et al. (2011). Protected areas are less effective in conserving natural resources in Malawi because they have failed to gain the support of local people and this has resulted in encroachment into protected areas (Munthali, 1993).

Harvest reserves are either permanent or seasonal closures used in protection of critical life-cycle phases. Small-scale fishers are forbidden to block river mouths with weirs or nets (GOM, 1997a). Large-scale fisheries are licensed to fish in waters >18 m, or not less than one nautical mile from the shoreline (GOM, 1997a). Other smaller scale protected areas have been set by local communities as part of co-management arrangements. A reserve has been established in Nkhota-kota as a permanent enclosure to protect different habitat types of different fish species and their various life stages (GOM, 1997a). Temporary sanctuaries are established in Lake Chilwa affluent rivers during periods of lake recession (Njaya et al., 1999). Protected areas are however less effective in conserving natural resources in Malawi because they have failed to gain the support of local people and this has resulted in encroachment into protected areas (Munthali, 1993; Ribbink, 2001).

Gear limitations

Four technical measures (mesh limitations, gear limitations, closed seasons and closed areas) are used to regulate fisheries exploitation in Malawi lakes. Mesh limitations, which aim to control the size or species of fish caught, are widely applied to all water bodies. The legislation provides a minimum mesh size for all main fishing gear. Gear limitations intending to prohibit certain types of fishing gear also exist in all Malawian water bodies. Destructive fishing methods such as use of poisons and explosives, for example, are prohibited in all natural water bodies. Specific fishing gear such as *nkacha*, an open water seine, is only allowed in Lake Malombe and not on other water bodies. Despite such mesh and gear limitations, there remains a proliferation of illegal fishing gear in the fisheries (Kanyerere et al., 2009). Most of the nets used are illegal i.e. being too small meshed size and larger than the recommended length.

Closed season

Closed seasons and areas prohibit fishing for specific seasons, i.e. breeding season of fish and areas of certain water bodies. Closed seasons are only applicable to small-scale fisheries on Lake Malawi because these fisheries target inshore areas which are breeding sites for chambo. The mechanized commercial fishery is allowed to operate throughout the year because this fishery mainly targets the offshore fishery resources. Fishers observed closed season regulations until 1994, after which fishers chose to ignore such regulations (Hara, 2006); because of the lack of closed season for the commercial mechanized fishery, fishing communities now view the closed season as a socially discriminatory regulation, even when these fisheries may fish in different areas. Reasons for non-compliance to fishing regulations are discussed in more detail below.

Size limits and licensing

Size limits intended to reduce growth over-fishing are equally enforced in both small-scale and large-scale fisheries. Growth over-fishing occurs when too many small fish are being harvested because of excessive effort and too small mesh sizes). The fish are not given the time to grow to the size at which the maximum sustainable yield (MSY) would be obtained from the stock. Minimum landing sizes are only applicable to two high valuable fish species: chambo (*Oreochromis* spp.), and potadromous mpasa (*O. microlepis*), also known as the lake salmon. However, it is difficult to enforce this regulation, and it has never been successfully implemented to regulate fishing effort of these two species.

The licensing system was introduced to limit the number of participants in the fishery (GoM, 2000). The number of licenses available to fish in a particular fishing area is fixed. Licensing was able to limit entry of the large-scale operators in the past based on standing biomass estimates, but weak enforcement capacity currently limits its effectiveness. Limited numbers of licences are prescribed for various fishing zones, but most fishing vessels can and do operate in areas where they are not licensed. Conversely, despite the fact that the licensing system has operated in the large-scale fisheries for more than 30 years, there has never been a sustained attempt to control fishing effort in the artisanal sector through a licensing system. The problem arises from the fact that it is difficult to administer licensing in a dispersed and often mobile fishery fleet. In addition, the licensing fee is too small to act as deterrent for illegal fishing because fishers can afford to pay fines when they are caught fishing without a license. Although licenses are required for small-scale fishing operations, very few fishermen operate with licenses. This regulation is basically a source of revenue for government, as it does not directly limit fishing effort e.g. the number of nets or catch limits.

Managing species versus taxonomic groups

The fish catches from Malawi lakes are divided by species groups into 14 commercial categories. Technical measures for managing the fisheries are then developed for these commercial categories. This approach simplifies regulations and enforcement because managers do not need to develop regulations for each of the 200 species that have been observed in fish catches. Managing fisheries by species or taxonomic groups is based on the premise that the reproductive parameters, ecological and population parameters of the different species within a taxonomic group are the same. In order to justify this approach, population structure and reproductive parameters of individual species within each species groups need to be defined. Turner (2001) used molecular stock structure methods to assess population structure of *Diplotaxodon* and found out that *Diplotaxodon limnothrissa*, a surface pelagic species and *Diplotaxodon macrops*, a more benthic species found near bottom shelf (Turner, 2001) could be managed as a single stock. However, the molecular methods used by Turner (2001) are expensive, require considerable expertise and sophisticated equipment and can only be implemented using externally funded projects. Studies to determine reproductive strategies and population parameters of fish species have only been done on a few species and hence most management decisions for these species groups are made on the basis of rule of thumb (Turner, 2001; Sarch and Allison, 2000). Without quantitative knowledge on reproductive strategies and population stock structure of individual species within a commercial category, there is a risk that some species within a commercial category can be overfished or extirpated with negative consequences on lake fish biodiversity.

The other option available to fisheries managers in Malawi is to manage individual species in fish catches in Malawi lakes. In this case, studies on reproductive strategies and population structure of each individual species within a commercial category would have to be conducted to establish reproductive strategies and population parameters that are required by standard stock assessment models. For Lake Malawi, this is not an easy task due to the huge number of species exploited, the lack of knowledge of fish biology and identification and the diversity and diffuseness of fishing activities (Turner, 2001). In addition, the management of single species would require the use of standard assessment models which have been found inappropriate for multi-species and multi-gear fisheries (Welcomme et al., 2010).

It can therefore be concluded that the current approach of managing fisheries by taxonomic groups is a practical and pragmatic strategy to manage multi-species and multi-gear fisheries under the existing conditions of low institutional capacity, low funding and decentralized fisheries within which the sector operates. However, with this approach, there is need to monitor the status of individual stocks, species composition and ecology of fish communities through simple indicators of heavy fishing pressure such as the reduction of mean size (and age) of fish landed (Welcomme et al., 2010).

Reasons for non-compliance to fishing regulations

Fisheries policy and governance systems, including the technical measures and regulations reviewed above, have largely failed to prevent the over-exploitation and subsequent collapse of the valuable chambo fishery, or to increase fish production from Malawi lakes (Banda et al., 2005; Dobson and Lynch, 2003; Hara, 2006; Sarch and Allison, 2000). The main reasons for these failures include: (i) lack of compliance with fishing regulations, (ii) limited user participation in formulation of regulations and management of fisheries, and (iii) top-down control of fisheries governance, where fisheries objectives in co-management arrangements are still largely set by government officials (Njaya, 2007; Hara et al., 2002).

Hara (2006) has examined the reasons for non-compliance with chambo fishing regulations in the south-east arm of Lake Malawi over two decades, from 1974 to 1994. He found that lack of compliance with fishing regulations was due to resource and budgetary constraints, weak capacity of government personnel to enforce fisheries regulations, the lack of expediency and legitimacy of the fishery management regulations, and the drive for profit. In particular, regulations have usually been formulated and imposed without the participation of fishers; hence most fishers feel that they have no obligations towards fisheries department regulations. Similar observations have been made by Njaya (2007), who reported that fishers are not given a platform to advance their interests in co-management arrangements, leading to low levels of participation and ownership.

The drive for profits as a reason for non-compliance with fishing regulations has largely been ignored in fisheries management discourse in Malawi, as fishing has largely been seen by government agents as a subsistence activity (Ferguson et al., 1993). A review of existing literature on fisheries and fishing communities in Malawi by Sarch and Allison (2000), Allison et al. (2002) and Hara (2006) has shown that fishing in Malawi is a business and livelihood activity for many people in their respective communities. Therefore, fisheries management measures which limit the economic returns of fishermen are resisted, resulting in non-compliance to fishing regulations.

Inadequate enforcement is another factor that has contributed to non-compliance of the regulations. Enforcement of regulations has been difficult due to open access, multi-species of multi-gear of the fisheries and limited resources. This is further exacerbated by numerous landing centres scattered all around the lake, too many fishing crafts as well as people in the fisheries. Lack of financial resources also prevents managers from recruiting the requisite number of inspectorate staff to cover all water bodies. It is apparent from the above analysis that new approaches that de-emphasize conservation of fish resources (i.e. the current fish-centred approach), enhance the legitimacy of fishing regulations and take into consideration the economic and livelihood objectives of fishers are required to improve fisheries management in Malawi.

Management of lake catchments and environment external to fisheries

In this section, we review literature on external drivers affecting the sustainability of Malawi lakes, and the extent to which external drivers have been incorporated in Malawi lake management plans. We focus on how catchment degradation, agricultural and industrial development, climate change, pollutants, and conflicts with other sectors may pose management challenges to these lakes.

Catchment degradation and deforestation

Under pressure from a growing population reliant on subsistence agriculture, Malawi lake catchments are continually being degraded due to deforestation, cultivation of steep slopes and unsustainable agricultural practices (Mkanda, 2002; Jamu et al., 2003). Increased deforestation and the use of unsustainable agricultural practices such as the cultivation of river banks and steep slopes, have increased soil erosion and sediment yield of rivers lake catchment. Soil erosion rates in Malawi lake catchments range from 30 to 100 MT ha^{-1} $year^{-1}$ (Jamu et al., 2003; Mkanda, 2002). Although much of the eroded soil is retained in alluvial deposits within catchment, sediment discharge into Lake Malawi by major rivers range from 0.18 to 3.28 MT ha^{-1} $year^{-1}$ with the highest rates in those steeper catchments with a high proportion of the catchment area cleared for agriculture and altered flow regimes (Hecky et al., 2003). Sedimentation rates in sediment cores recovered from southern Lake Malawi have increased two to three fold since 1970 (Otu et al., 2011). Although the full impacts of increased sediment discharge and runoff are not fully understood, available evidence from Malawi lakes indicate that altered river discharges and high sediment discharge in rivers impacts fish habitat, destroys spawning areas, and affects the feeding and breeding behaviour of fish (Tweddle, 1992; Munthali, 1997). For example, in Lake Chilwa, where recruitment and productivity of *Barbus* spp. is dependent on river discharge, river sediment yield and water levels, altered river discharge rates and high river sediment yield may be responsible for the absence of large cyprinids such as *L. mesops* in degraded river catchments (Delaney et al., 2007). Soil erosion and cultivation of river banks has been associated with declining catches of potadromous *O. microlepis* (Cohen et al., 1993). Similar observations have been made for mpasa in the Lake Malawi catchment (Msiska, 1990). Sediments have also impacted breeding grounds of tilapia in Lake Malawi where sand substrates that are required for chambo breeding are increasingly being silted, thereby reducing breeding areas. Increasing turbidity also reduces the ability of males to see breeding females and disrupts sexual selection (Seehausen et al., 2003). Results from Lake Victoria show that turbidity can also reduce visual reaction distance and can also disrupt predator–prey dynamics (Seehausen et al., 2003), especially among haplochromine fishes which are highly dependent upon sight feeding. High turbidities in Lake Chilwa have been show to sharply reduce food availability in benthic offshore zones, and restrict fishes to pelagic and inshore food resources (Bruton, 1985). Increasing turbidity of Lake Malawi due increasing sediment load could therefore reduce fish productivity due to reduced food availability and disruption of breeding activities.

The effects of catchment degradation and deforestation have been included in the Lake Chilwa wetland and catchment management plan (Danida and EAD, 2001), and are covered implicitly in area fisheries management plans for Lake Malombe, the South-east arm of Lake Malawi and Lake Chiuta (Njaya, personal observation). Environmental drivers have not been considered in the development of fisheries management plans for Lake Malombe and Lake Malawi. van Zwieten et al. (2011) argues that the focus on fishing effort as a main driver of fish stocks has led to the neglect of research by the Fisheries Research Unit on the link between bottom-up environmental processes and stocks. Chinsinga (2009) observed that the lack of capacity in the Department of Fisheries to deal with the range of issues affecting the fisheries sector is partly due to the limited skills scope among its staff because traditionally departmental recruitment has been biased toward fisheries scientists. However, due to local and international trends towards multidisciplinary perspectives on fisheries management issues and problems, there is a need in Malawi to diversify the mix of skill sets of staff in the fisheries sector. Priority areas for institutional capacity development include socio-economics, policy and planning, aquaculture and environmental science.

Agricultural and industrial development

Agricultural and industrial development can lead to increased chemical and organic pollution of lakes, resulting in negative impacts on water quality for fish production and human use. Significant agricultural developments such as tea, sugar and rice plantations have occurred in lake catchment areas due to suitable conditions for growing these crops, as well as the potential for low-cost gravity-fed and motorized irrigation. These plantations use large quantities of fertilizers and pesticides, which can contribute significantly to chemical pollution of the lake. For example, Saka (1999) reported that over 45,851 metric tonnes of fertilizers were used in the Lake Chilwa basin during the 1994/95 season. Pesticide use for storage of major food crops and control of horticultural pests is also widespread (Saka, 1999).

Slash and burn land management practices and other inappropriate soil management practices associated with small-scale farmers release greenhouse gases and nutrients into the atmosphere and aquatic ecosystems. High phosphorus (P) concentrations in dry and wet deposition in Lake Malawi, and other tropical lake airsheds, may be due to biomass burning (Bootsma et al., 1996; Hecky et al., 2006). In Lake Chilwa, *Typha* swamps, thought to be responsible to the high productivity of the lake and vast areas of the wetland, are burnt every year (Mloza-Banda, 1999). The effect of burning on the lake's productivity has not been established, but this practice could contribute towards high N and P loading in the lake. A study conducted by Saka (1999) showed that Lake Chilwa is a sink for residues from agricultural and industrial activities in the catchment areas, and that the concentrations of sulphates, chlorides and metal cations are already above WHO standards for safe drinking water and hence not suitable for human consumption. Fortunately, concentrations of persistent organochlorine pesticides in Lake Malawi are not excessive and may not pose significant hazards to consumers (Kidd et al., 2001).

Until recently there has been very little industrialization in the catchments of Lake Malawi, Malombe, Chilwa and Chiuta. Industries have been limited to agricultural plantations for tea, coffee and sugar and associated agro-processing plants. However the recent commissioning of a uranium mine in the northern part of Lake Malawi and planned open cast mines for uranium, rare earth metals, cement manufacturing, phosphate mining, large scale cotton plantations and the Malawi Greenbelt initiative which seeks to develop 1 million hectares of irrigable land (Namakhoma, 2009) in the Lake Malawi and Chilwa catchments are likely to increase chemical pollution for these two lakes.

Increasing industrialization and agricultural development can also promote rapid population growth in lake catchments, thereby increasing resource use conflicts, deforestation, and fisheries overexploitation. It has been shown that the high human population density in the Lake Victoria catchment has led to eutrophication of the lake (Hecky, 1993; Verschuren et al., 2002). Similar consequences are likely to occur in Malawi lakes due to rapid industrialization and high population growth rates, and are already affecting the shallower southern end of Lake Malawi (Otu et al., 2011). Population growth rates in Lakeshore districts between 1998 and 2008 ranged from 2.4 to 3.5% per annum and total population in lakeshore districts increased by 25–40% during the same period (NSO, 2008). Population growth rates in lakeshore districts may increase further as new industries such as uranium and rare earth mineral mining, agroprocessing plants linked to the greenbelt initiative attract labour and businesses into the lake catchments.

Climate change

Malawi lake fisheries are vulnerable to climate change impacts (Allison et al., 2009). There are indications that the great lakes of Africa, including Lake Malawi, are warming, and the full consequences are as yet undefined (Vollmer et al., 2005). The impacts of climate change on deep tropical lakes are not well understood. However, research results for another deep African rift lake, Lake Tanganyika, suggest that warming climate has reduced internal nutrient loading and primary production (Verburg et al., 2003). This study further suggests that increased warming rates during the coming century may continue to slow mixing and further reduce productivity in Lake Tanganyika and other deep tropical lakes. A similar effect on internal nutrient loading from deep water in Lake Malawi might be expected but may be offset, at least in the short term, by increases in external loading from rivers and the atmosphere (Otu et al., 2011). Conversely, this could also mask the evolving problems in the catchments which are increasingly adding nutrients to Lake Malawi.

Results obtained from the General Circulation Models suggest that temperature will increase in the Lake Chilwa Basin by 2.6–4.72 °C, with carbon dioxide doubling by the year 2075 (Chavula, 1999). In addition to warming temperatures, smaller lakes such as Chilwa and Malombe have exhibited fluctuating but declining water levels. In Lake Malombe, rainfall and runoff have been shown to contribute to lake productivity (van Zwieten et al., 2003). Decreasing water levels in the same lake have also been linked to disappearance of vegetation and reduction in breeding areas for fish. Lake Chilwa water levels fluctuate in response to rainfall and drought, and these fluctuations have a significant effect on stock levels (van Zwieten and Njaya, 2003; Njaya et al., 1999). For example, analysis of long term data (Fig. 4) from Lake Chilwa shows that fish yield is correlated ($r = 0.47$; $p = 0.003$) to lake level. High lake levels generally increases fish production by enhancing nutrient recycling in swampy areas of the lake, increasing lake volume and maintaining the swamp vegetation that fish depend on for breeding and refugia (Moss, 1979; Ryder, 1982). In shallow lakes such as Chilwa and Malombe, the climatic and hydrological fluctuations are mirrored by changes in fishing activity and catches (Allison et al., 2002). In response to this unpredictable environment related to high variability in the water supply to these lakes, communities have developed diversified, adaptable and mobile livelihoods. These include transfer to nearby Lakes and beaches in search of better fish catches, investing in petty trading and agriculture, bird trapping and weaving of commercial handicrafts such as carpets and baskets (Agnew and Chipeta, 1979; Allison et al., 2002).

Warming temperatures and increased severity and frequency of floods and drought will further amplify these fluctuations and reduce the capacity of fishing communities to adapt to climate change. Therefore, lake and fisheries management would need to incorporate strategies that reduce the impacts of climate change on livelihoods and improve the capacity of communities and economies to adapt to climate change. These strategies include reducing the poverty of fishing communities through diversification of livelihood options, strengthening livelihoods, economies and environmental governance (Allison et al., 2009).

Managers could use existing participatory methodologies such as the Climate Vulnerability and Capacity Assessment (CVCA) methodology (Dazé et al., 2009) to identify practical strategies for increasing the adaptation of fisher communities to climate change. Through the use of local knowledge and scientific data, the methodology assists managers, policy makers and development practitioners to build people's understanding about climate risks and adaptation strategies and provides a framework for dialogue within communities and between communities and other stakeholders which in turn leads to identification of practical strategies that facilitate community-based adaptation to climate change.

Improving management of Malawi lakes

From the foregoing review it is evident that the challenges facing lake management in Malawi are due to the failure of existing fisheries management approaches, the inadequate consideration of the linkages between catchment processes and aquatic environments and fish productivity, and poor incorporation of external drivers such as climate change, population growth and industrialization into management plans.

Fisheries management

Specific issues that need to be addressed are related to the policy environment, existing legal framework, inability or at least inertia of government institutions to learn and adapt, and a lack of implementing mechanisms for different strategies and plans. The existing fisheries policy needs to be reviewed so that it focuses more on key issues affecting the sector and not on departmental functions. In addition, the policy needs to be more specific and provide clear guidance on policy objectives of fisheries management in Malawi. This entails a review of the policy objective of maximizing sustainable yield and corresponding fishing regulations focus. Andrew et al. (2007) contends that rather than focusing on maximizing sustainable yield, fisheries policies should aim at making the fisheries more resilient. They further propose that under resilient management, the fisheries policy goal should focus on preventing the fishery from failing to deliver benefits by nurturing and preserving ecological, social and institutional attributes that enable it to renew and reorganize itself. Benefits in this case refer to the ecosystem goods and services derived from the fishery. This approach requires acceptance and utilization of indicators for resilience and sustainability rather than focusing solely on MSY.

Framework for diagnosis and adaptive management of fisheries for resilience

Evans and Andrew (2009) have developed a participatory diagnosis and adaptive management (PDAM) framework for small-scale fisheries in developing countries. This framework is aimed at assisting fisheries managers and policy makers to manage fisheries for resilience and improve the ability of small-scale fisheries (SSF) in the developing world to cope with and adapt to both external drivers and internal sources of uncertainty. The framework can further assist managers in outlining the scope of the management problem, identifying stakeholders and mobilizing a management constituency, constructing realistic and desired future projections, and defining indicators for necessary adaptive management.

The PDAM framework has been used in the Solomon Islands and in Malawi to develop indicators and thresholds for adaptive management and to define the status of fishery resources with the view of constructing desired and future projections for the fishery. In the Solomon Islands, fishermen were assisted in using the PDAM framework to develop indicators of resilience management and to identify thresholds below which the fishery could be considered to have gone into undesirable configurations. In Malawi, the framework was used by a group of fisheries scientists, ecologists and socio-economists to diagnose the Lake Malawi fishery. Results s obtained in Malawi are presented in Table 2. The Malawi stakeholder group selected variables which were linked to macro (national) or ecosystem level indicators. In the Solomon Islands where the PDAM framework was piloted, fisher group selected variables that were linked to micro (household) level indicators (N. Andrew, pers. Comm.). This difference in focus may simply be the result of which stakeholder groups are involved with the PDAM, an aspect that needs to be further explored (Table 4).

van Zwieten et al. (2011) used a similar participatory approach to identify a list of practical indicators for evaluating the fish community and fisheries of Lake Malawi and Lake Malombe. The process of selecting indicators involved fisheries researchers from the Malawi Department of Fisheries. The list of indicators was chosen to reveal patterns on the level of ecosystem drivers (indicators of ecosystem drivers), fish community and exploitation states (indicators of fishery resources), and exploitation pressures (indicators of direct human pressures on fisheries resources). The list of indicators that scored high included catch, catch per unit effort and nominal effort, while indicators related to socio-economics and with objectives of

Table 4
Proposed indicators, variables, thresholds for a resilient fishery and the current status of Lake Malawi fisheries analyzed using the Participatory Diagnosis and Management (PDAM) framework. The thresholds define the desired state and contributions of the fishery to livelihoods, production and biodiversity.

Domain	Indicator	Variable	Thresholds	Current status
People livelihood	Income generation	% fish processed	Value added = 70%	60%
	Household nutrition	Consumption per capita	Access to protein = 7 kg p^{-1} $year^{-1}$	5.8 kg p^{-1} $year^{-1}$ (crisis level)
	Economic security	Sector employment	Stable employment = 500,000	300,000 (crisis level)
Natural system	Nearshore stock	Chambo catch	Landing above = 7000 t $year^{-1}$	300 t $year^{-1}$ (crisis level)
	Ecosystem integrity	Biodiversity	loss of species = 0	0 (stable)
	Sustainable exploitation of deep water stock	Biomass of *Diplotaxodon*	Natural biomass preserved = 66%	100% (Meets needs and stable)

maintaining and conserving resources scored low. The low score for socio-economics, habitat and tropho-dynamic indicators was attributed to the composition of the group, which mainly involved researchers and did not include other stakeholders such as fishermen.

These examples suggest that PDAM framework can be useful in assessing small-scale fisheries to determine the scope of fisheries management problems, and in developing indicators for resilient management of small-scale fisheries in Malawi. The three examples given strongly suggest that different stakeholder groups can develop different sets of indicators and fisheries management objectives for the same fishery. Hence, a participatory process with all fisheries stakeholders is required to identify a more diverse set of indicators that includes social and livelihood indicators, as well as biological and physical environment indicators. Indeed, Evans and Andrew (2009) observe that selecting the small number of indicators required to track management progress is as much a political process as a technical one, and requires a clearly defined and empowered group of stakeholders to reach durable decisions about management objectives and the indicators used to track performance. The value of participatory processes in developing fisheries management plans has also been demonstrated by Smith (1998) who showed that traditional fish handling practices and local knowledge can provide the basis for effective monitoring programs for small-scale fisheries in Lake Malawi. When combined with the Climate Vulnerability and Capacity Assessment methodology described earlier, the PDAM framework can also be a useful tool for incorporating climate change adaptation strategies into fisheries management plans.

The PDAM framework can also assist fisheries managers in Malawi to develop fisheries management regimes that allow managers to adapt and learn. The inability of the Department of Fisheries to learn and adapt its management based on changes in fisheries exploitation and the socio-economic environment within which the fishers operate has been identified as one of the key challenges for sustainable management of fisheries in Malawi. For example, Hara (2006) observed that analysis of the investment decisions of gear owners and the technical innovations of gear owners could have provided valuable insights to the Department of Fisheries on the dynamic changes in fishing effort and the status of chambo stocks. For this learning and adaptation to take place, fisheries management in Malawi lakes needs to focus more on the people and the socio-economic and political institutions driving fisheries exploitation. Hara (2006) recommends that specific mechanisms need to be put in place to involve beneficiaries in the identification, formulation, development and implementation of policies and legislations for managing fisheries resources.

In addition to reviewing the fisheries policy as stated earlier, existing legislative regulations which are based on maximizing sustainable yield need to be revised because they are not comprehensive enough for effective management and conservation of the small-scale fisheries, and may not be well-aligned with a revised policy objective of managing fisheries for resilience (Andrew et al., 2007). It has also been observed that the (rarely enforced) regulatory measures are technical measures restricting the efficiency of the fishing gear through minimum mesh size, and are not standardised. For example, mesh size legislation is rather complex because different fishing gear targeting different fish stocks have different mesh size requirement. Enforcement of such regulations is problematic due to inadequate resources and weak management. Parsons (1995) argued that fisheries regulations such as area closures and mesh size restrictions are not useful as primary methods of management (such as limited entry control, catch quotas and technical regulations), and are not likely to meet either the biological or economic objectives of a fishery. Therefore, by focusing on resilience and developing a key set of indicators that are cost effective, practical and specific, the need for expensive and labour intensive data collection methods that are necessary to assess the status of stocks under the MSY management regime will be reduced.

Improving implementation mechanisms

Analysis of existing strategies, plans and on-going projects indicates that too often good strategies and plans devised by the Department of Fisheries are never implemented. For example, a number of strategies meant to implement the Fisheries Policy and Act have been conceived, but most of them, such as Chambo Restoration Strategic Plan (CRSP), have not had effective implementation strategies. The existing weak human capacity, both in terms of number and skills, and limited ability to mobilise financial resources to support key strategic actions compounds the situation further. Development of an effective implementation plan that also includes the establishment of human resource development, finance systems and development of sustainable funding mechanisms will facilitate the implementation of strategies.

Developing integrated lake basin management planning

Challenges related to sedimentation, pollution, and losses of aquatic biodiversity are better addressed through integrated lake basin planning and management (Kalk et al., 1979). There is need to integrate land, water, forestry, fisheries and wildlife practice and policy, and to coordinate the use of a range of policy and legislative instruments to achieve integrated management goals. Integration is important because most existing threats to lake management, such as pollution, siltation/sedimentation, cultivation and grazing, occur outside of the lake ecosystem and are driven by external factors. In Malawi this is linked to high population growth rates and poverty, which drive communities to convert forest land into agriculture. Because of poverty and current land tenure regimes (Mkanda, 2002), farmers are unable to invest in sustainable agricultural and land management practices. Integrated planning and management of lake basins is also critical in dealing with potential threats from emerging industrialization in Lake Malawi catchments, especially mining (contaminants, soil erosion from open cast mines, sewage etc.) and large-scale commercial agriculture (increased use of pesticides and fertilizers). Impacts of climate change on lake ecosystems, livelihoods, agriculture and natural resource use within lake basins would also be better addressed through integrated cross-sectoral planning.

Improving biodiversity conservation

Biodiversity conservation has not been accorded high attention and where conservation plans have been implemented, the focus has been on conserving scientifically important species such as the mbuna, which are also the focus of the aquarium export trade. The fisheries policy focuses on preventing exotic species introductions (especially exotic fishes) to the Lake Malawi catchment as a strategy for conserving Lake Malawi's rich fish biodiversity. Other insidious and non-charismatic biodiversity threats such as the camouflaged invasion of the Asian snail in Lake Malombe (Genner et al., 2004), declining populations of the potadromous *O. microlepis* and the commercial extinction of *L. mesops* and the impacts of climate change, fishing methods and siltation on fish biodiversity have been given low priority. Since these threats have greater potential to damage lake biodiversity, the fisheries policy needs to be revised to include explicit policy direction on management of lake biodiversity. At an operational level, biodiversity conservation and climate change adaptation mechanisms are at the heart of resilience management and should be mainstreamed in fisheries department operations and management processes.

Summary and conclusions

Management of Malawi lakes has, to date, focused on fisheries resources. Fisheries policies and regulations have been developed with the view of conserving fisheries resources and without considering the capacity of the Fisheries Department to enforce regulations. The impacts of degradation of agricultural and forest landscapes, climate change and the people using lake resources has also received inadequate attention. This has resulted in the collapse of fish stocks in Malombe, overexploitation of fish resources, reduced populations of migratory fish species in major rivers, and other biodiversity impacts such as the invasion of Asian snails in Lake Malombe. It is recommended that integrated lake management planning should be adopted to ensure that agriculture, industry, water, forestry, fisheries and wildlife sectors and other cross-cutting issues such as climate change and gender are properly addressed in management plans. Fisheries management objectives need to be reviewed to focus on the long-term resilience of the ecosystem, fisheries resources and livelihoods of people utilizing the resource. In order for this to happen, government needs to provide adequate resources to ensure effective monitoring, enforcement of regulations and participatory development and implementation of integrated lake management plans.

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