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## Review

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# Riparian ecosystem resilience and livelihood strategies under test: lessons from Lake Chilwa in Malawi and other lakes in Africa

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This paper reviews the importance of African lakes and their management challenges. African inland lakes contribute significantly to food security, livelihoods and national economies through direct exploitation of fisheries, water resources for irrigation and hydropower generation. Because of these key contributions, the ecosystem services provided are under significant stress mainly owing to high demand by increasing populations, negative anthropogenic impacts on lake catchments and high levels of poverty which result in unsustainable use. Climate variability exacerbates the stress on these ecosystems. Current research findings show that the lakes cannot sustain further development activities on the scale seen over the past few decades. Millions of people are at risk of losing livelihoods through impacts on livestock and wildlife. The review further shows that the problems facing these lakes are beyond the purview of current management practices. A much better understanding of the interactions and feedbacks between different components of the lake socio-ecological systems is needed to address the complex challenges of managing these ecosystem services. This review suggests that the three small wetlands of Chad, Chilwa and Naivasha provide an opportunity for testing novel ideas that integrate sustainability of natural resource management with livelihoods in order to inform policy on how future land use and climatic variability will affect both food security and the ecosystem services associated with it.

## 1. Introduction

Africa is endowed with at least 677 lakes, large and small; natural and artificial [1]. African lakes are highly productive centres of biodiversity providing ecosystem services and livelihoods, including food, water for domestic use and agriculture, recreation and transportation. These lakes support very important waterfowl and fisheries contributing significantly to national economies and food supply [2–4]. For instance, the fisheries of just 11 lakes in 11 countries of eastern Africa employ over half a million people with perhaps two million engaged in ancillary industries [5]. The key contributions of these lakes and their catchments to food security are undervalued and rarely captured in national budgets [6]. Consequently, national governments allocate very little resources for their management.

Because of the key contributions that African lake ecosystems make to food security and livelihoods of millions of Africans, the ecosystem goods and services they provide are under significant stress mainly owing to high demand by increasing populations, negative anthropogenic impacts on lake catchments and high levels of poverty which result in unsustainable use [2,7–9]. All these factors have serious negative implications for people's livelihoods and biodiversity. These lakes have exhibited periodic, climate-induced, lake level fluctuations, even complete drying out in low-rainfall years [10,11]. As such, productivity of the lake ecosystems has been highly variable resulting in

**Table 1.** Characteristics of Lakes Chad, Chilwa and Naivasha and their livelihood benefits.

	Chad	Chilwa	Naivasha
location	desert	semi-arid lowland savannah	equatorial highland
basin population	37.2 m (2004)	1 472 756 (2008)	650 000 (2009)
lake dynamics	permanent reduction from 25 000 to 500 km <sup>2</sup>	periodic drying over 10–15 year cycles; reduced from 2400 to 1750 km <sup>2</sup>	periodic wet and dry cycles with amplitude of 12 m
lake basin area	967 000 km <sup>2</sup>	8349 km <sup>2</sup>	1700 km <sup>2</sup>
livelihood support	30 m people dependent on agriculture and fisheries	1.5 m people dependent on agriculture and fisheries	>100 000 people employed in vegetable and cut flower industry
value of agriculture and fisheries (US\$ million)	123 (2004)	21 (2012)	613–640 <sup>a</sup> (2007)

<sup>a</sup>Cut flower exports. Other agriculture and fisheries products provide insignificant income.

unstable incomes for riparian communities, thereby increasing vulnerability. For example, fish production in Lake Chad declined from 120 000 tonnes in the 1970s to 60 000–70 000 tonnes to date and Lake Chilwa fish production has declined from an average of 15 000 tonnes per year to 5000 tonnes per year for the same period [12].

Negative impacts of anthropogenic activities on lake ecosystems are on the rise owing to human population growth and increasing poverty leading into high demand for services and subsequent unsustainable use of lake ecosystems [8]. These impacts include environmental degradation resulting in siltation, eutrophication especially from agricultural, domestic and industrial sources, possible heavy metal deposition, hypoxia, loss of biodiversity, loss of fish breeding grounds and increased human and livestock disease risks, etc. [2,4]. Consequently, the resilience of these ecosystems and people dependent upon them is at risk of suffering irreversible damage that could negatively affect the well-being of millions of people. These lakes call for properly targeted management systems in order to avoid resource over exploitation and loss of sustainability for the present and future generations [2]. It is, however, difficult to manage these lakes because of inadequate knowledge and understanding of the lake ecosystem dynamics as well as poor multidisciplinary approaches for effective planning. In this review, we demonstrate, through case studies, that lake ecosystems make important contributions to local, national and regional food security and livelihoods of millions of people, and that major challenges face these lake ecosystems and communities who are dependent on them for their livelihoods. We further discuss how multidisciplinary approaches to assessing and mapping ecosystem service supply and demand could be applied to addressing the challenges in order to sustain resilience in a period of rising demand for lake ecosystem services and goods as well as emerging concerns on the negative impacts of climate change.

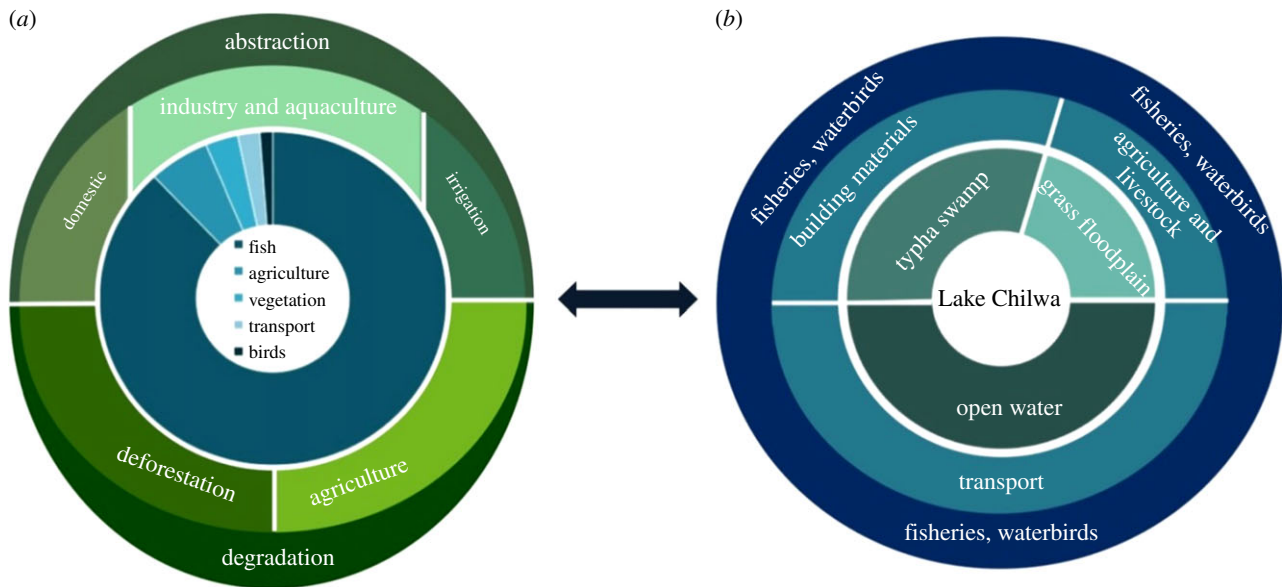
## 2. Ecosystem and livelihood benefits of selected small African lakes

African inland lakes contribute significantly to food security and livelihoods of rural communities and to national economies through direct exploitation of fisheries for food and water resources for irrigation and hydropower generation.

Lakes Chad, Chilwa and Naivasha basins are home to a large number of people who are directly or indirectly dependent on these lakes for their livelihoods (table 1). Lake Naivasha, for example, supports a thriving export-oriented agriculture valued at US\$ 613–640 million which contributes about 7% of Kenya's gross domestic product (GDP) [13]. The lake has also created job opportunities across the value chain in the region of two million people and contributes up to 10% of Kenya's foreign exchange [14]. In Malawi, Lake Chilwa contributes US\$ 21 million [4,15] with fishing alone making up US\$ 18 million [16]. The World Resources Institute [17] estimated that the value of agriculture and fisheries in the Lake Chad basin is in excess of US\$ 750 million. Indirectly, these lakes provide critical welfare functions, which are rarely adequately valued and documented [6,18]. Because of the benefits that these ecosystems provide, inland African lakes and their catchments have become magnets for migration and local centres of high population growth. The Lake Chilwa wetland, for instance, has attracted many dwellers such that the basin is one of the most densely populated wetlands in Africa with 321 persons per km<sup>2</sup> [19,20].

The ecosystem and livelihood benefits of these lake ecosystems rise and fall in tandem with lake water levels and basin rainfall. Lake water levels are a major driver of fishery productivity [21–23]. High lake levels also increase the area of floodplains that surround these lakes making more land available for floodplain agriculture [17,24]. Flooding is critical for dry and wet season agriculture, fisheries and wildlife, thereby ensuring all year-round agriculture and other livelihood activities. However, high inter- and intra-annual variability impacts food and economic productivity [25,26]. While flooding is an important driver of agriculture and fishery production, it is also disruptive, especially where environmental degradation has reduced ecosystem and social resilience to cope with extreme weather events [27]. The linkages between ecosystem goods and services and the economic and livelihood benefits of these small inland African lakes and the threats they face have been well described and illustrated for Lake Chilwa (figure 1) by Jamu *et al.* [28].

The high productivity of small inland lake ecosystems and their open access management regimes are a major pull factor to migrants and local people seeking social protection mechanisms for food owing to crop failure, livestock disease outbreaks or indeed during periods of employment loss [6,29].



**Figure 1.** (a) The economic benefits derived from the Lake Chilwa wetland (inner circle) and the practices in the catchment (intermediate circle) which are seen as threats (outer circle) to the wetland; (b) the major wetland components (inner circle) and the main livelihood activities which are practiced in each of these (outer circles) [28]. (Online version in colour.)

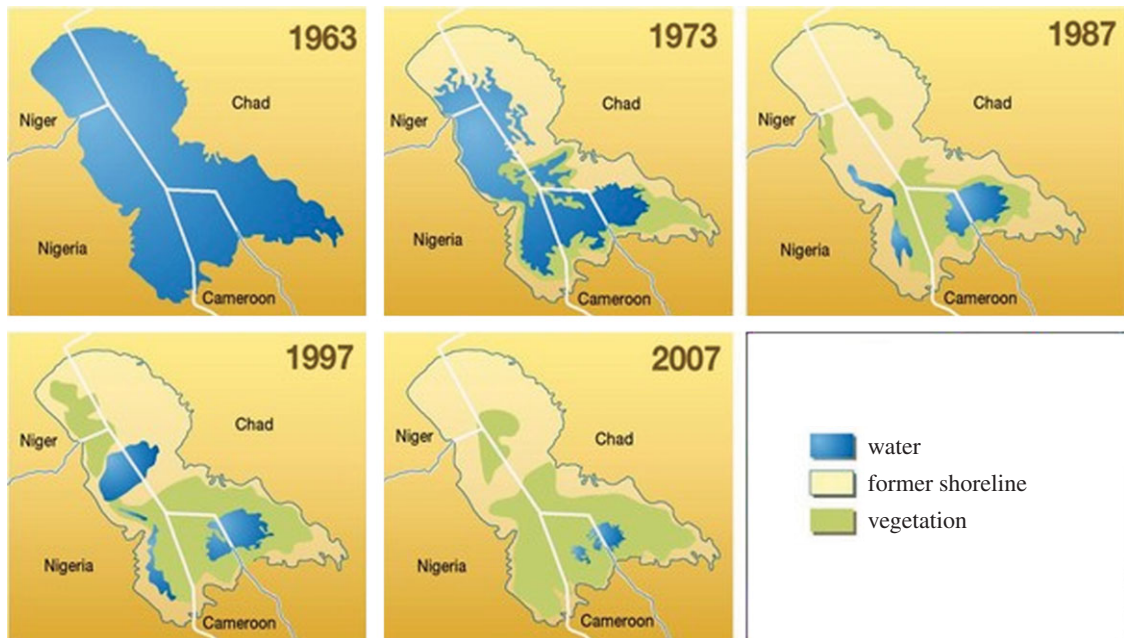
### 3. Why are riparian ecosystem resilience and livelihood strategies under test?

Small African inland lake ecosystems are under considerable stress owing to unsustainable rates of resource exploitation, inadequate and inappropriate management regimes, degradation of lake catchments and high demand for water, fish and agriculture products [8]. High population growth rates (greater than or equal to 3.2% per annum) have fuelled demand for food, non-food agricultural products and energy. This, in turn, has contributed to overfishing, deforestation of lake catchments owing to firewood and charcoal production extensification, and intensification of agriculture as communities increase agriculture land to improve production and also as a response to low yields and small land holding sizes [4].

Lake Naivasha is a shallow (maximum depth at 8 m) freshwater lake in the Eastern Africa rift valley which has been disrupted by alien species invasions, particularly crayfish, *Procambarus clarkii*, and riparian vegetation degradation [30]. High silt and nutrient loads entering the lake especially during wet seasons, owing to lake-wide *Cyperus papyrus* degradation following lake-level decline from agri-industrial abstraction, have made the lake eutrophic [30,31]. The water demand for commercial flower production has grown over the past 10 years, and there is increasing abstraction of water estimated at  $3\text{--}5 \times 10^6 \text{ m}^3$  per month [32] to meet demands for a fivefold increase in population within 5 km of the lakeshore [13]. Increased water abstraction has reduced the wetland area by 23% over 25 years [33]. The lake was said to be half of its former size with the water level being three vertical metres lower than it should be naturally [30]. Owing to increased population and fertilizer use by agriculture, the lake ecosystem is experiencing high levels of nutrient inputs [17,34], pollution which can result in reduced biodiversity. However, some authors argue that chances of severe pollution from agrochemicals are minimal, because the water flow is generally away from the lake [26,35], and pollution control measures are high [36]. Nevertheless, it has been reported that fish

biodiversity and bird populations have declined over the past years [37,38]. Unlike other case studies reviewed below, Lake Naivasha has been resilient to high water abstraction owing to groundwater recharge from aquifers [24] whose capacity is, however, under threat owing to degradation of headwater forests [30]. There is little natural vegetation left in the lake catchment as over 30% of the land cover consists of maize, vegetables and scattered exotic tree species reaching down to stream level [31,37]. The Lake Naivasha ecosystem faces an array of threats (table 2) to its ecological stability and functioning.

Lake Chilwa is another classical example of an ecosystem which is undergoing considerable stress and whose capacity to recover from extreme events is declining over time. The lake is a shallow, endorheic tropical lake averaging 3 m in depth, peaking at 5 m [39]. It is not yet known whether the lake has any underground outlets. Six perennial rivers, whose catchment areas form the Lake Chilwa Basin, feed into the lake carrying a volume of water equivalent to  $1472 \text{ mm}^3$  annually [40]. The total catchment area is  $8349 \text{ km}^2$  of which 32% is in Mozambique. The wetland area has reduced from over 2400 to  $1750 \text{ km}^2$  as a result of subsistence agriculture [41,42] and is subjected to extreme fluctuations including complete desiccation [4,43,44]. Lake Chilwa has dried up completely on nine occasions in the past 100 years (1903, 1913–1916, 1922, 1934, 1943–1944, 1967, 1973, 1975, 1995–1996) [39,44]. It is not surprising that surface water bodies in the catchment including the lake itself are prone to drying up during prolonged dry spells as the wetland water budget shows a net loss owing to evapotranspiration [40,45]. The lake has, however, demonstrated resilience in the past as it has managed to recover within 2 years after a partial or full desiccation [46]. This has mainly been due to good rainfall following the recession, rapid recharge of water tables in forested headwater areas and management of river pools which maintained remnant fish populations which were able to populate the lake after refilling [47]. Groundwater resources in the catchment area remain virtually unexploited as only 1 mm of the base flow is abstracted [45].



**Figure 2.** Lake Chad water levels from 1963 to 2007. This collection of maps has been sourced from a series of satellite images provided by NASA Goddard Space Flight Center (<http://maps.grida.no/go/graphic/lake-chad-almost-gone>; image credit: Philippe Rekacewicz). (Online version in colour.)

**Table 2.** Environmental concerns and adaptive responses in Lakes Chad, Chilwa and Naivasha (SMEs, small and medium enterprises; MAB, Man and Biosphere).

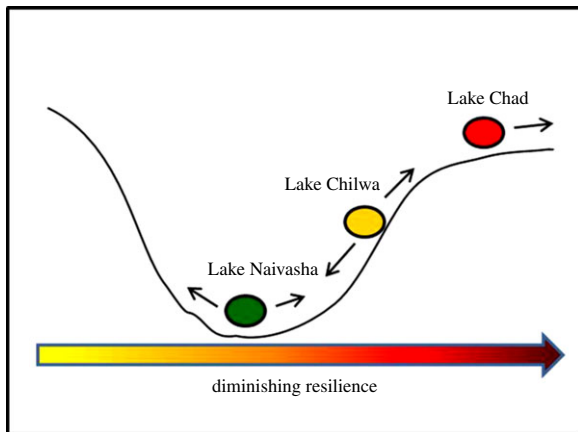
	Chad	Chilwa	Naivasha
main environmental concerns	reduced river flow; climate variability; habitat and community modification; unsustainable natural resource exploitation; siltation	deforestation; wetland degradation; increasing climatic variability; reduced river flows; high population growth; siltation	deforestation, overgrazing due to high population growth; water abstraction; organic pollution from agrochemicals; siltation
institutional framework	Lake Chad Basin Commission	district councils, no basin-wide authority	Lake Naivasha Management Implementation Committee
international treaties	—	Ramsar site; UNESCO MAB reserve	Ramsar site
adaptation measures	efficient irrigation technologies; inter-basin water transfer	afforestation; efficient irrigation technologies; development of SMEs; commodity value-addition	efficient irrigation technologies; payment for ecosystem services

Lake Chilwa supports the livelihood of over 1.5 million people in the basin through agriculture and natural resource goods and services. Low water levels have negative implications on people's livelihoods through loss of income and employment, reduced fish supply, increased conflicts from competition for resources and increased exploitation of birds [46,48]. Receding water exposes land to crop farming and livestock grazing which negatively impacts wetland vegetation and associated biodiversity [48]. Crowding of fishing villages which remain with adequate water levels for fishing has also resulted in poor sanitation [49].

During the periods of ecosystem stress as a result of lake-level fluctuations and desiccation, the riparian communities have, however, responded positively, or recovered from the crises. Kalk *et al.* [39] and reviews by Agnew [50] and Agnew & Chipeta [51] provide insights into livelihood responses to fishery fluctuation between 1967 and 1973 during a time of transition from quasi-subsistence to a partial cash economy in the Lake Chilwa wetland. Of course, the responses varied with income status, assets profile, ethnicity

and residence time in the area. The drying of the lake reduces the productivity of the fishery, forcing fishermen to migrate, resulting in loss of business and livelihood, whereas women and children are left with minimal resources for food. These effects will be compounded by population increase, low agricultural production and water scarcity because of climate change [20]. Human populations in sub-Saharan Africa are projected to grow as food security declines [20].

Lake Chad, situated on the edges of the Sahara Desert, is a basin drainage water body that is a vital source of freshwater and other natural resources for people, livestock and wildlife. The lake has dramatically shrunk in size (figure 2) owing to climate change and extractions such that it is now one-twentieth of the size it was over 40 years ago [52,53]. A series of devastating droughts hitting the Lake Chad region over the past few decades have caused a marked variability in the hydrological regimes of the rivers that feed the lake, as well as rainfall regimes in the region. This has led to continuing decline in local access to water, crop failures, livestock deaths, collapsed fisheries and wetlands



**Figure 3.** Ecological states of three small African lakes. (Online version in colour.)

services, etc. The socio-economic consequences of the impacts include food insecurity and declining physical, mental and social well-being of the populace [54].

#### 4. Climatic variability

The provision of a wide range of ecosystem services is strongly influenced by climatic variability over decadal or longer timescales [55]. The stocks and flow of ecosystem services and goods in these small lake ecosystems of Africa have fluctuated dramatically from year to year in resonance with climate variability. This dynamic reduces the quality and quantity of ecosystem services and goods leading to food insecurity and reduced economic opportunities which, in turn, forces communities to turn to natural resources as a source of food and livelihood [56]. The inability of the communities with limited resource-based economies to adapt favourably to climate variability within weak social and institutional structures completes the vicious cycle. For example, Alison *et al.* [3] identified several African countries including Malawi where climate change impacts on fisheries will have significant social and economic impacts owing to the combined effects of global warming, the relative importance of fisheries to national economies and diets and limited social capital to adapt to potential impacts and opportunities.

#### 5. Challenges of managing African lakes

Food security in these lake communities relies heavily on the flow of ecosystem services and it will continue to be a critical issue owing to the volatile and unpredictable nature of food chains. During extreme climate events, such as drought, loss of employment or other shocks, rural communities are often forced to turn to stocks and service flows from natural environments to meet their nutritional needs [56]. Such extremes have often led to a collapse of natural ecosystem and livelihood resilience [57]. Many complex systems have critical thresholds at which the system shifts abruptly into another state [58] which may be too costly to reverse. From the foregoing analysis, Lakes Chad, Chilwa and Naivasha are in qualitatively different states of losing resilience (figure 3). Lake Chad is a ghost of its former self [52] which may have already passed a 'critical threshold' to provide adequate ecosystem services. In the Lake Chad region, scarcity of resources has already degenerated into large-scale conflicts [54].

Lake Naivasha has retained resilience mainly owing to groundwater recharge from aquifers. The Lake Chilwa ecosystem completes a trio of African lake ecosystems in a downward spiral into diminished capacities for providing ecosystem goods and services in the face of human intervention. Unsustainable resource exploitation, climatic variability and increasing demographic pressure have conspired to suck the life out of these ecosystems. A similar fate also faces other African lakes such as Lake Victoria. The capacity of these lake ecosystems to supply the necessary services is linked to their integrity [9]. The survival of these lakes and their resources will depend on multi-sectoral, integrated resource management efforts based on good scientific data and local knowledge.

The challenge as stated by Carpenter *et al.* [59] remains in integrating the sustainability of natural resource management with livelihoods so as to inform policy how future land use and climate change will affect both food security and the ecosystem services associated with it. Ecosystem-based approaches to managing the lake environments are key to sustaining the ecosystem services and livelihood benefits provided by these lakes. Catchment processes and other exogenous factors exert influence on lake environments and productivity [60,61]. Moreover, flows of ecosystem services and goods are shaped by complex dynamic systems that operate over multiple temporal and spatial scales and often exhibit stochastic behaviour, changing both in a seasonal cycle and in response to extreme events [61]. This complexity makes it difficult to resolve an appropriate course of collective action to pursue sustainable livelihoods in the absence of an information management system. Further, it also poses challenges for the selection of appropriate scale (population, community, ecosystem or landscape) for targeting interventions aimed at mediating impacts that arise from over-exploitation of ecosystem goods and services.

Indeed, nonlinearity of the underlying natural systems (e.g. droughts) or socio-economic systems (e.g. commodity price collapses) can cause tipping points in stocks of ecosystem services, as can more gradual socio-economic, political or demographic changes among the beneficiaries of those ecosystem services [61]. In addition, inadequate institutionalized 'safety nets', limited access to fertile lands, resources and secure income in most developing countries, including Malawi, Kenya and Chad, often forces the rural poor to prioritize their short-term needs over long-term sustainability [62]. This is compounded by poor linkages between knowledge generation and policy level resulting in a lack of a sustainable development concept of rational natural resource use in programmes and interventions. Consequently, daily decisions for poor rural communities are driven by coping strategies involving trade-offs of different ecosystem services. For example, forest clearance to grow agricultural crops reduces the availability of forest products for subsistence or generating income. Agricultural production can also indirectly reduce the availability of other ecosystem services. Typically, increased irrigation and deforestation in the Lake Chilwa catchment has reduced suitable fish breeding habitat in the lake [48].

#### 6. Programmatic responses

In response to the pressures facing the three lakes, a number of initiatives have been put in place (table 2). For instance, the Lake Chad Basin Commission (LCBC) is an

intergovernmental body created in 1964 to coordinate hydro-activities within the Lake Chad basin. Within the limits of its mandate, LCBC has delivered dividends in small-scale agriculture, preparation of an integrated lake management plan and vision 2025. The vision identifies the causes of the status of the wetland and spells out the strategies for reversing degradation by 2025 [52].

Similarly, the Lake Naivasha management plan implemented by the Naivasha Riparian Owners Association and Water Resource User Associations calls for proper governance arrangements and partnerships [63]. A comprehensive Lake Chilwa Management plan developed in 2001 to serve as a blueprint for establishment of a basin authority is yet to be implemented [28,64]. Meanwhile, councils in the riparian districts of Machinga, Phalombe and Zomba manage Lake Chilwa through a joint committee. Various measures have been instituted, including irrigation technologies, afforestation programmes, etc., in attempts to reduce the vulnerability of communities to the vagaries of nature. Despite these efforts, the challenge remains to ensure that the wetlands continue to provide the ecosystem services that support livelihoods for future generations, while at the same time conserving the biological diversity and ecosystem health. This is in tandem with the Ramsar 'wise-use' principle to which both Lakes Chilwa and Naivasha subscribe as Ramsar wetlands of international importance.

The small wetlands of Chad, Chilwa and Naivasha provide an opportunity for testing novel ideas that integrate the sustainability of natural resource management with livelihoods in order to inform policy on how future land use and climatic variability will affect both food security and the ecosystem services associated with it. Within the Lake Chilwa basin, there are currently two initiatives that may address some of the wetland management challenges highlighted. The Attaining Sustainable Services from Ecosystems through Trade-off Scenarios project is a multidisciplinary study coordinated by the University of Southampton in the Lake Chilwa basin from 2012 to 2016. A key focus of the research is to examine the linkages between ecosystem services and impacts on nutritional and socio-economic status and maternal and child health outcomes using a suite of complexity tools and innovative models. The Lake Chilwa Basin Climate Change Adaptation Programme, which commenced in 2010, is another 5 year multidisciplinary research and development initiative being implemented by three institutions, namely the University of Malawi (through LEAD SEA), WorldFish and the Forestry Research

Institute of Malawi with funding from the Royal Kingdom of Norway. The goal of the programme is to secure the livelihoods of the 1.5 million people in the Lake Chilwa Basin and enhance the resilience of the natural resource base.

Carpenter *et al.* [59] suggested that we need a much better understanding of the interactions and feedbacks between the different components of the socio-ecological system if we are to address the challenges of managing ecosystem services in the face of the complex challenges global society is now facing. The integrated philosophy in the two projects in the Lake Chilwa basin does offer some hope for addressing the sustainability of natural resource management, ecosystem service provision and livelihoods. There will be research evidence from these studies that may provide ideas for managing other wetlands facing similar challenges.

## 7. Concluding remarks

Small African inland lakes contribute significantly to food security and the livelihoods of rural communities and to national economies through direct exploitation of fisheries for food and water resources for irrigation, and hydropower generation. The high productivity of these ecosystems and their open access management regimes are a major pull factor to migrants and local people seeking social protection mechanisms for food owing to crop failure, livestock disease outbreaks or indeed during periods of employment loss. As a result, the ecosystem services they provide are under significant stress, mainly owing to the high demand of increasing populations, negative anthropogenic impacts on lake catchments, high levels of poverty which result in unsustainable resource use and climatic variability. A number of initiatives have been promoted in attempts to sustainably manage these important wetlands but these lake ecosystems, as well as other African lakes, continue to face serious threats to their stability and functioning revolving around unsustainable resource exploitation both within the open water lakes and their catchments. The lakes may not sustain further development activities on the scale seen over the past few decades. There is, however, scope for applying new approaches that integrate sustainability of natural resource management with livelihoods in order to inform policy on how future land use and climatic variability will affect both food security and the ecosystem services associated with it.

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