Enhancing the resilience of inland fisheries and aquaculture systems to climate change

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Abstract

Some of the most important inland fisheries in the World are found in semi-arid regions. Production systems and livelihoods in arid and semi-arid areas are at risk from future climate variability and change; their fisheries are no exception. This paper reviews the importance of fisheries to livelihoods in 'wetlands in drylands', with a focus on case-studies in Africa. We examine the threats posed by climate change to the traditional 'tri-economy' of fishing, farming and livestock herding. Although both livelihood strategies and local institutions are highly adapted to cope with, and benefit from, climate-induced variability, weaknesses in the wider governance and macro-economic environment mean that the overall adaptive capacity of these regions is low and the farmer-herder-fishers are vulnerable to projected climate change. In order to maintain the important nutritional, economic, cultural and social benefits of fisheries in the face of climate change, planned adaptation at scales from the local to the regional (trans-national) is required. We use the concept of resilience in linked social-ecological systems to examine how such responses may be developed and promoted. Key strategies include facilitating people's geographical and occupational mobility, improving intersectoral water and land-use planning, and promoting forms of aquaculture that help build resilience of farming systems to seasonal and episodic water deficits.

Key words: vulnerability, adaptation, fisherfolk, livelihoods, Lake Chilwa, Malawi

1. Introduction: the contribution of fisheries to development and their vulnerability to climate change

The majority of the world's 200 million fisherfolk (fishers and other fishworkers and their dependents) live in areas that are highly exposed to human-induced climate change, and depend for a major part of their livelihood on resources whose distribution and productivity are known to be influenced by climate variation (Allison et al., 2005). While the climate-sensitivity of major industrial fisheries of shelf-sea and oceanic upwelling zones, such as those for the Peruvian anchoveta, are well known (reviewed in Klyashtorin, 2001), it is the impacts of climate change on the small-scale fisheries of inland and coastal near-shore waters that are perhaps of greatest relevance to concerns with poverty reduction.

In coastal tropical areas, coral reefs and associated ecosystems support the majority of small-scale fisheries. The United Nations Environment Program (UNEP) estimates the annual value of coral reefs at US$100,000-US$600,000 km^{-2}. These ecosystems, occur predominantly in developing countries, and provide important sources of income as well as subsistence nutrition to millions of coastal dwellers (Ahmed et al., 2005). Because of their sensitivity to thermal stress (resulting in coral bleaching and mortality) and CO_2-induced ocean acidification (resulting in reduced coral calcification and enhanced reef erosion), reefs have been specifically identified as vulnerable in the latest IPCC report (Parry et al., 2007).

For inland waters, projected changes in surface water availability are the most obvious threat to fisheries production. There are close relationships between floodplain area, river flow and lake surface area and total fish production, as one might expect (Welcomme, 2001) so the projected decline in surface water availability in many parts of Africa (de Wit and Stankiewicz, 2006), for example, is an obvious threat to fisheries production. Inland waters are of particular importance to the poor due to their accessibility and potential for integration within farming systems.

A key distinction in the fish-producing sector is between capture fisheries (usually just called 'fisheries') and farming of fish, or aquaculture (sometimes called mariculture in the case of marine aquaculture). Globally, aquaculture has expanded at an average annual rate of 8.9% since 1970, making it the fastest growing food production sector. Today, aquaculture provides around half of the fish for human consumption, and must continue to grow because limited — and in many cases declining — capture fisheries will be unable to meet demands from a growing population (FAO, 2007). Based on current per-capita consumption targets and population growth trends, aquaculture is fêted by many as the only means of satisfying the world's growing demand for aquatic food products. Directly and indirectly aquaculture could contribute to the livelihoods and nutrition of many millions of people, acting as an engine for economic growth and a diversification strategy in the face environmental change.

Fisheries and aquaculture contribute to meeting the Millennium Development Goals through employment, provision of nutritious food, generation of revenues for local and national government from licences and taxation on landings, from export revenues, and from various upstream and downstream multipliers (Béné et al., 2007; Heck et al., 2007). For example, fisheries and aquaculture employ over 50 million people worldwide, a quarter of them in aquaculture, and 98% of this total are from developing countries (FAO, 2007). In a global export business worth nearly US$ 80 billion annually, African export earnings from fishery products and services are calculated to be over US$2.7 billion per year, and fisheries sectors in countries such as Namibia, Uganda, Ghana and Senegal contribute over 6% to their national GDPs (FAO, 2007). Fish is also an important and cheap source of protein. It forms at least 50% of the essential animal protein and mineral intake for 400 million people from the poorest African and South Asian Countries (World Bank, 2004; FAO, 2007). Often, fish landing sites are centres of the cash economy in otherwise remote areas; they stimulate the kind of monetisation of the rural economy that is seen by current mainstream development policy makers (e.g. in the form of poverty reduction strategy plans) as the means to reduce rural poverty. In small island states and fishery dependent regions of larger economies, this sector is a significant contributor to the overall economy and society.

The multiple benefits that fisheries contribute to poverty reduction are threatened by climate change that decreases production, affects human health, threatens to damage or destroy physical assets, or all of the above. Fishery and aquaculture benefits are also potentially reduced through the increases in uncertainty that climate change brings. The incentives for long-term management of resources may be reduced and the additional risks of investing in aquaculture development may reduce potential investment by the poorer, more risk-averse sectors of rural society. It is therefore important to understand how climate change might impact the poverty reduction function of fisheries and aquaculture and how this impact might be reduced through appropriate development interventions at policy, programme and project levels. These concerns for climate-induced threats to fisheries take place in the context of widespread overexploitation of fisheries, which reduces the scope for adaptation and increases risks of stock collapse through a combination of climate-related stresses and heavy exploitation pressure. These issues are also compounded by other potential consequences of climate change on natural resources, economies and livelihoods and by a range of pressures on fisheries brought about by broader environmental degradation and demographic change.

2. Scope and objectives

In order to connect the broad theme of fisheries and their vulnerability to climate change with the interests of the readership of this journal, this paper focuses on the implications of climate change for inland fisheries in semi-arid areas. Perhaps surprisingly, some of the world's most fishery-dependent countries are ones where the land-based production systems are classified as arid or semi-arid (Figure 1). While several of these countries are dominated by desert landscapes, they have productive coastal upwelling current systems in their exclusive economic zones that support major fisheries (e.g. Namibia and Angola and the Benguela Current, Mauritania and Morocco and the Canary Current). Others have important inland fisheries in climate-sensitive wetland areas within drylands. In Africa, these include the Niger Inland Delta in Mali, the Sudd, the Kafue Flats in Zambia, Lake Chad, Lake Turkana and numerous smaller lakes and wetlands of the drier parts of the African Rift Valley.

The aims of the paper are to raise awareness of the actual and potential importance of fisheries and aquaculture in these dryland contexts; to review how these production systems and their associated livelihoods are affected by, and adapted to, climate variability; and to propose how their resilience might be maintained and enhanced in the face of projected climate change. The paper proceeds by defining key concepts before turning to an analysis of vulnerability, adaptation and resilience of inland fisheries as social-ecological systems. We draw on research on Africa's semi-arid and drought-prone areas. We use Lake Chilwa in southern Malawi as an exemplar of the transient, dynamic interactions between people and ecology that are typical of wetlands in drylands. Lake Chilwa is useful as a case study because there is a substantive historical record of climate variability and some detailed studies of rural livelihoods, resource ecology and institutions for resource governance (Kalk et al., 1979; Allison & Mvula 2002). We draw on this historical record of response to climate variability to infer strategies for 'climate-proofing' the future of high-productivity, climate-sensitive aquatic production systems such as Lake Chilwa, which are found throughout Africa (Allison, 2005). Given this focus on Africa, where aquaculture is not yet a significant contributor to food supplies and economies, and where capture fisheries continue to dominate production, we focus on the vulnerability of capture fisheries to climate change: we have written about the vulnerability of aquaculture systems elsewhere (Handisyde et al., 2006). The paper concludes with a suggested agenda for research and policy responses to the identified vulnerabilities and opportunities for adaptation in the World's 'wetlands in drylands'.

3. Conceptual frameworks for understanding poverty, vulnerability, adaptation and resilience in fisheries

2.1. From vulnerability and adaptation to resilience

Central to discussions of adaptation to climate change are the concepts of vulnerability, adaptive capacity, and resilience. These concepts come from a wide range of intellectual traditions and definitions abound (Birkman, 2006; Janssen & Ostrom, 2006). Lack of consensus on the meaning and interrelations among these concepts is of more than academic interest: as they become integrated into international and national law and policy, vagueness will confound and slow progress towards improved fisheries and livelihoods.

As a starting point, we adopt the working definitions of the Intergovernmental Panel on Climate Change (IPCC, 2001):

"Vulnerability is the extent to which climate change may damage or harm a system; it depends not only on a system's sensitivity, but also its ability to adapt to new climatic conditions"

In IPCC terminology, the degree to which an individual or social group will face a change in climate is their **risk exposure.** In the fisheries context, this might be measured as the expected degree of temperature change, sea level rise, or increase in storm frequency they will face**. Sensitivity** is the degree to which a system will respond to a change in climatic conditions. This could be measured, for example by a proportional change in ecosystem productivity (or household income and/or expenditure) as a result of perturbations in temperature or precipitation. **Adaptive capacity** is the ability of a system to evolve in order to accommodate climate changes or to expand the range of variability with which it can cope (e.g., Jones, 2001).

Vulnerability to climate change is therefore made up of a number of components including exposure to impacts, sensitivity, and the capacity to adapt. Adaptive capacity has diverse elements encompassing the capacity to modify exposure to risks associated with climate change, absorb and recover from losses stemming from climate impacts, and exploit new opportunities that arise in the process of adaptation. Adapting to variability in weather and climate is not in itself adaptation to climate change, although improving adaptations to variability can reduce vulnerability and hence build resilience for dealing with a changing climate.

Adaptation decisions taken by individuals (e.g. to use insurance, relocate away from threats, or change technologies) take place within an institutional context that can facilitate or constrain those decisions. It is clear that individuals and societies will adapt and have been adapting to climate change over the course of human history (Adger et al., 2003). Thus individuals and societies are vulnerable to climate risks and other factors and this vulnerability can act as a driver for adaptive resource management, of the kind already seen in many small-scale fisheries subject to climate-driven and other uncertainties (Allison & Ellis, 2001; Jul-Larson et al., 2003).

The central concept in this emerging paradigm around the governance of such adaptive production and management systems is 'resilience'. Walker et al.'s (2004) definition is widely used: ***resilience*** *is the capacity of a complex system to absorb shocks while still maintaining function, and to reorganize following disturbance*'. We interpret the term 'complex system' in this context to refer to a linked socio-ecological system, which is defined as "*a system that includes societal (human) and ecological (biophysical) subsystems in mutual interaction*" (Gallopin et al 1989). The mutual dependencies of social and ecological processes make such a 'system' non-decomposable. A social-ecological system may be defined at any scale, from a small reservoir fishery to a large river basin.

Picking up elements of all the above definitions and acknowledging the importance of societal learning and adaptation, we suggest the following definition of a resilient aquatic resource production system in the developing world. A resilient small-scale fishery in the developing world is one that '*absorbs shocks and reorganizes itself following stresses and disturbance while still delivering benefits for poverty reduction'*.

A 'fishery' includes both societal and ecological subsystems that are interdependent (see also Charles, 2001). In the context of climate change, 'stresses and disturbances' are the cumulative and acute drivers of change related to climate. Although this definition emphases external processes, we realise that resilience may be threatened by the sum of multiple stressors, both external and internal, and the cumulative effects of one or several of them over time. Most fishery sector analysts regard the harvest itself as the greatest single threat to the resilience of the fishery system (World Bank, 2004; FAO, 2007).

Following from the above definitions, management to maintain resilience should prevent a fishery from failing to deliver benefits by nurturing and preserving ecological and social features that enable it to renew and reorganize itself (Walker et al, 2004). This statement of the objective of management emphasizes different elements of the management problem compared to conventional (and legally binding) fisheries objectives, which emphasise maximising long-run 'sustainable' aggregate yields or economic benefits (e.g. FAO Code of Conduct for Responsible Fisheries, 1995). If the fishery and the socio-ecological system in which it is embedded has tipped over into that new and undesirable configuration and so can not deliver benefits for poverty reduction, then management should seek to apply measures that will move it back to an acceptable configuration.

2.2. Poverty, vulnerability and resilience

The growing consensus in the literature on climate change is that the poor are more vulnerable and less able to adapt (e.g. UN, 2007). In other words, poverty undermines the resilience of social-ecological systems such as fisheries. The relative poverty status of fisherfolk remains largely unknown, but where local and regional case-studies have been undertaken, it is often found that fisherfolks' incomes are higher than those of other rural dwellers (Allison, 2005; Béné et al., 2007). Fishery sector earnings are, however, highly uncertain, often seasonal, and are not evenly distributed within the sector; fishers who own boats and/or fishing gear earn substantially more, in terms of net income, than crew labourers paid a share of the value of the catch.

Income and capital or physical asset ownership are not, however, the only dimensions of poverty. There is an emerging body of literature (reviewed in Allison, 2005; Allison & Horemans, 2005; Béné et al., 2007, Thorpe et al, 2007) that highlights fisherfolks' deprivation in terms of access to services (such as health and education), lack of rights over land and water, limited political representation and widespread social marginalisation, sometimes including active discrimination. Within fishing communities, there are also often marked gender disparities, with women typically occupying lower-margin economic activities and being excluded from decision-making structures at community level.

Fishing livelihoods may be profitable but precarious in conditions where future production is uncertain in the long-term and fluctuates extensively in the short-term, where access rights over resources are insecure, working conditions unsafe and exploitative, and where there is a lack of social and political support for community development and poverty reduction. It is in this 'risk environment' that the added stress of future climate change takes place.

4. Pathways of impact: climate change, inland fisheries & aquaculture

There are multiple and rather complex pathways through which climate change can affect the productivity and distribution of inland fishery resources and the resilience of fisheries and their associated livelihood and economic linkages (Table 1). A major research challenge at present is that even if the changes in climate and biophysical variables were predictable, it is not clear what the relative importance of each individual impact pathway would be and how indirect effects and cross-sectoral responses would affect fisheries.

For river fisheries, downstream impacts from adaptations in other livelihood sectors are a concern. In particular, conflicts exist between agricultural needs and fish productivity, and the effects of reduced flows and floodplains on seasonal spawning.

Impacts of climate change are an additional burden to other poverty drivers such as declining fish stocks, HIV/AIDS, conflict and insecurity, lack of savings, insurance and alternative livelihoods. There may also be increased health risks for the poor. For example, cases of cholera outbreaks in Bangladesh coastal communities were found to increase following El Niño-related flooding. Effects on agriculture and water resources will also potentially reduce water and food security. In combination, projected climate, population and market changes could have major negative effects on local fish supply in regions such as the Mekong Basin or West Africa, where fish is an essential component of peoples' diet (Allison et al., 2005).

In aquaculture, where production processes (such as choice of species, feeding and restocking) are under greater human control, increasing seasonal and annual variability in precipitation and resulting flood and drought extremes are likely to be the most significant drivers of change in inland aquaculture. Reduced annual and dry season rainfall and changes in the duration of the growing season are likely to have implications for aquaculture and create greater potential for conflict with other agricultural, industrial and domestic users in water-scarce areas. These impacts are likely to be felt most strongly by the poorest fish farmers, whose typically smaller ponds retain less water, dry up faster, and are therefore more likely to suffer shortened growing seasons, reduced harvests and a narrower choice of species for culture (Handisyde et al., 2006).

Given the uncertainties and multiple potential pathways linking climate change with fisheries production in biological terms (Table 1), the impact of global warming on the fisheries sector in socio-economic terms is further compounded by the dynamics of human responses. Not only, therefore, is there great uncertainty regarding the extent and speed of climate change and our knowledge of its biophysical impacts on fish stocks, but there is the added uncertainty of understanding how people and economic systems respond to climate-induced variability and change. Before turning to a case study of Lake Chilwa, Malawi, to examine potential adaptive responses to these uncertainties, we introduce two examples from Africa that illustrate in more depth some of the climate-fishery linkages summarised above.

3.1 Climate-fishery linkages in Lake Tanganyika (Burundi, DR Congo, Tanzania and Zambia)

Fisheries for small-pelagic[1] species are important throughout Africa’s inland waters and support both substantial small-scale and ‘industrial’ level fisheries, particularly on the larger Rift Valley Lakes. The pelagic fisheries of Lake Tanganyika have received a great deal of attention from both fisheries development organisations and from the perspective of biodiversity conservation (reviewed in Molsa et al., 1999)

Recent evidence from Lake Tanganyika (Verburg et al., 2003) highlights the ecological consequences of a century of observed regional warming in the lake. They associate warming with a sharpened water density gradient between warmer surface water and cooler deep water (the lake is over 1 km deep in places) which has slowed vertical mixing and reduced primary productivity. Further warming is hypothesised to continue these trends. These findings for Lake Tanganyika are supported by O'Reilly et al. (2003) who show that the rise in surface-water temperature has increased the stability of the water column. This, combined with lower wind

[1] Pelagic fish are those that swim in the mid- and surface waters of large water-bodies, such as the oceans and Africa’s great lakes. In Africa’s lakes, the dominant small pelagic species are sardine-like fishes belonging to the families Clupeidae (the same family as the herring and sardine) and Cyprinidae (the same family as the carp). Those species that live close to the sea-bed or lake-bed are known as demersal fish. The distinction is of course less clear cut in shallow or small water bodies and the terminology is less often used in those contexts. The distinction has practical importance in that different fishing techniques are used to catch pelagic and demersal species.

speeds, has reduced mixing in the lake and primary productivity may have decreased by about 20 per cent accounting for a roughly 30 per cent decrease in fish yields.

3.2 Climate-fishery linkages in Lake Chilwa (Malawi)

Africa's shallow lakes are among the most productive but variable fishery ecosystems in the tropics (Talling & Lemoalle, 1998). Lake Chilwa in Zomba District, Southern Malawi, is typical of this production system (Figure 2). The lake has recently fluctuated around 1850 km^2 in extent, including both open-water and wetland areas; it is less than 3 m deep and is subject to extreme fluctuations, including complete desiccation. In good years, fish catches can be as high as 25,000 tonnes (fishery statistics are rather uncertain and vary between sources) and more than 10,000 people are engaged in fishing activities. There was a major increase in fishing effort around the early 1970s, as the region became better integrated into the market economy. In the past, minor recessions in lake level, sufficient to reduce fishing for one or two years, could be expected every six years or so (see Figure 3). Major recessions which will interfere with fishing in the open lake for 3-5 years could be expected every 60-70 years, with a possibility of an intermediate recession in 30-40 years (Lancaster, 1979). The last drying episode for which data are widely available covered the period from late 1994 to 1996, when fishing ceased altogether. Fishing operations started again in April 1997 (GOM, 1999).

In the last decade, with a series of droughts in Malawi, Lake Chilwa's levels have remained low and the lakes' dwindling waters remain under severe pressure of exploitation, water abstraction and conversion of fringing wetlands for rice cultivation (F. Njaya, Malawi Fisheries Department, personal communication, June 2007).

4. Learning from the past: lessons from adaptations to climate variability in the Lake Chilwa basin, Malawi, 1966-2001.

4.1 Adaptive ecology, livelihoods and institutions

Resource-dependent communities in the developing world have adapted to climate variability throughout history. Studies of livelihoods in small-scale fisheries in both marine and inland waters indicate that migration and livelihood diversification are key adaptive livelihood strategies in fisheries ranging from Arctic Canada to the Equatorial Pacific (reviewed in Allison & Ellis, 2001 and, for African inland waters, by Sarch & Allison, 2000 and Jul-Larsen et al., 2003). But projected climate change poses multiple risks to fishery-dependent communities because of the increased frequency of extreme weather events, the potential for large-scale phase shifts, and from risks that lie outside the realm of present day experience (Adger et al., 2003).

Most inland water ecosystems (with the exception of the African Great Lakes and other ‘ancient lakes’ such as Baikal in Siberia and Biwa in Japan) are young, in geological and evolutionary terms with a flora and fauna well-adapted to change. They are, in a sense, pre-adapted to cope with a degree of human-induced change (Moss, 1992). This resilience is a feature not often emphasised in fisheries analyses, typically pre-occupied with stability as a management objective (Shepherd, 1991). Understanding the responses of ecosystems, people and their institutions (households, communities, cultures) to past climate-driven changes can provide important information to policy makers on existing adaptive strategies that might be built upon to support vulnerable peoples’ livelihoods. For Lake Chilwa in Southern Malawi, instructive comparisons can be made between relatively recent livelihood surveys (Allison and Mvula, 2002) and a multi-disciplinary survey of the Lake Chilwa basin, conducted by researchers at Chancellor College, Univeristy of Malawi during the 1960s (Kalk, 1970; Kalk et al., 1979).

Livelihoods research conducted in two lakeshore villages, in 2001 (Allison and Mvula, 2002) revealed that, in order to survive and benefit from fluctuations in the lake level, households adopted one of two major strategies, according to their origins and degree of access to land: they were either migrants, heavily dependent on fishing and fish-trading (contributing >80% of their household incomes) or residents engaged in various mixes of farming, trading, wage-labour, self-employment and fishing, with fishing and fish trading typically making up 30 to 50% of total household income. Both these strategies allowed for a degree of adaptation to the variable environment, but both are under threat from various governance reforms that aim to improve livelihoods, but do not incorporate climate-adaptive responses in their planning. These include various land-tenure reform proposals and the introduction of community-based management that would restrict access by migrants. Household incomes among migrant fisherfolk tended to be higher than those for resident farmer-fishers – a finding replicated in other studies in Eastern and Southern Africa (Allison, 2005). The trade-off between these higher cash incomes may be in increased vulnerability and marginalisation (a ‘Faustian bargain’; Wood, 2003).

4.2 Changes in livelihood options and adaptive strategies since the 1960s

The comparison between livelihood strategies and options in the late 1960s and the early 2000s highlights changes in production options, livelihood strategies and outcomes that point to a likely reduction in the capacity of people living around the lake shore basin – and the regional economy - to adapt to future climate variability and change. The most striking changes to the productive economy of the area are the decline of livestock, the growth in rice production and the apparent change in scale and ownership structure in the fishery. In 1969, there were 34,818 cattle grazing on the Chilwa plain, with most farmer-fishers owning some large livestock. In 1999, official statistics indicate there were less than 3,000 cattle in Zomba district as a whole (Kishindo, 2001 p 33). The current figures for livestock-keeping in lakeshore villages from the livelihoods surveys (averaging 0.43 Cattle Equivalent Units) are amongst the lowest recorded in agricultural surveys in sub-Saharan Africa (Ellis & Freeman, 2004). This decline appears to have been rapid and recent, and is associated with a breakdown in internal security in Malawi following the transition, in 1993, from single-party state under President-for-Life Hastings Banda, to multiparty democracy. During fieldwork in Malawi in 2001-2003, conducted as part of the DFID-funded LADDER research programme[2], we heard of wide-spread livestock theft, including organised cattle raiding. Under these conditions, keeping livestock as part of a security/banking system was no longer tenable (Ellis & Freeman, 2004).

In 1969, rice and cotton production for the whole Chilwa plain were of the order of 1,600 tonnes each. Between 1989 and 1999, rice production from Zomba district alone fluctuated between about 5 and 15,000 tonnes (Kishindo, 2001). After disappearing in the early 1990s, cotton production attained similar levels to that in the 1960s in 2001-2. Fifty to seventy per cent of the land on the Lake Chilwa plain was under crops in 1969; this apparently remained the same for Zomba District in more recent times (Kishindo, 2001). The Lake Chilwa area has been densely populated for at least the last 40 years, but land appears to be still available, partly because the constantly fluctuating lake level periodically changes the area available for cultivation.

Diversified, adaptable and mobile rural livelihoods are characteristic of this unstable production environment. A sample of 528 fishermen interviewed in 1969 showed that most were part-time farmer-fishers, 93 per cent

[2] LADDER stands for 'livelihoods and diversification directions explored by research' (Ugh!) and was a research programme on rural livelihoods and policies in four African countries (Kenya, Malawi, Tanzania and Uganda). It was headed by Professor Frank Ellis, University of East Anglia, U.K., and funded by the UK Department for International Development; ICRISAT was among the research partners and the first author of this paper was a member of the research team.

owned their own boats and 61 per cent gained some income by hiring out their boats when not themselves using them. In 1966, there were also 2,000 migrant fishermen living in the marshes in Kasupe district alone, this from a total of 6,444 fishermen, ancillary workers and their families living within the Lake environs – i.e. on reed rafts, islands and in the wetlands. On Chisi Island (83 km^2) there were 11 villages with 2015 people. Men outnumbered women by 15 to 1 – most of them were migrant fishermen. By 1968, when the lake had dried out (see Figure 3), the population of Chisi Island had fallen to 779 persons. All the temporary migrants had left, and 228 resident men had left to find alternative employment. At Kachulu fish landing (near our 2001 study site at Sauka) population fell from 800 in 1966 to 186 in 1968.

Agnew (1979) and Agnew and Chipeta (1979) summarise the short-term choices of fishermen during the lake-drying period of 1967-68 as: 1) fishing on a very much reduced scale in the remaining swamps, streams and lagoons in the Chilwa catchment, 2) transfer to nearby Lakes Malombe, Malawi or Chiuta, 3) increasing the cultivation of rice, cotton, cassava and vegetables, 4) a switch to commercial handicrafts such as plaiting carpets, 5) spending considerable time trapping birds and digging for rodents, or, 6) seeking employment elsewhere. These responses varied according to income status, asset profiles, ethnicity and time of residence in the area. In the drying episode of 1968, around 200 fishermen migrated to nearby Lake Malombe, and others moved to Lake Malawi. These were among the richest fishermen, whose investment in fishing-related assets meant that they could not simply cease fishing, as could those with less stake in this source of livelihood. Since the introduction of community-based management in Lake Malombe and southern Lake Malawi (Chirwa, 1998, Sholtz et al., 1998,), the option to move fishing operations between lakes is constrained, but this was still a major response to the drought of 1995/6. Conversely, the response by people in Sauka village to the heavy rains and floods of 2000/2001, resulting in low agricultural harvests, was a shift into fishing by lakeshore communities.

The relative wealth differentials between farmers and fisherfolk also seem to have been maintained over the last four decades. Specialist fishing households tended to have higher incomes than farming families in our 2001 survey (Allison and Mvula, 2002). Most of the 1200 fishermen interviewed by Chipeta (in Kalk, 1970) in 1966 were small-scale semi-subsistence fishermen, making their own canoes and using nylon nets, consuming part of the catch and making use of only one relative to help them. Despite this small scale of operation, between 1963 and 1969, fishermen's incomes were several times those of the average small-holder farmer. Fleet ownership structure is not known at present, but the sharp differentiation in income levels between boat/gear owners and others engaged in the fishery (Allison and Mvula, 2002), plus the observation of larger 'plank boat' units, suggests that ownership of fishing assets is now more polarised, with small numbers of wealthier individuals owning two or more boats and several types of fishing gear.

4.3. Is it appropriate to 'manage' fishing activity on Lake Chilwa for sustainability?

Although the fisheries of Lake Chilwa offer an economically unstable environment, determined by the seasonal and long-term fluctuations in lake level, at high production periods, the fisheries contribute readily-earned cash to the wider rural economy. In good years, Lake Chilwa supplies almost half the total fish production in Malawi. Management that constrains access to fish in productive periods constrains income-generating opportunities, denies people access to subsistence and, arguably, serves no resource conservation purpose in a lake where the biomass and production of the resource are determined by climate-driven lake-level variations and where the sustainable yield concept (based on an equilibrium-model) is therefore obviously untenable. And yet, despite wide-spread acceptance that fisheries management, in its traditional guise of stock conservation measures, is inappropriate, there have been recent measures to introduce fishery regulations to stabilise yields and conserve stocks. This goes counter to Kalk's (1979) suggestion that uncertainty about lake levels suggests that development effort be focused on agriculture, rather than the management of fisheries.

The repercussions of recession in Lake Chilwa waters and consequent decline of fishing are much wider than on fishing alone. The whole of the Chilwa plains and lake must be seen as an economic network. Not only are there links between fishing and various ancillary services, but also complementary flows of income between fishing and farming. The "integrated small-scale economy of farming, fishing and cattle-rearing" of the 1960s (Kalk, 1979) has now changed to one in which cattle-rearing has all but disappeared as a saving and livelihood option, potentially decreasing the resilience of the overall livelihood system.

Sectoral concerns for the sustainability of individual natural resource systems have prevailed, even when it is known that notions of resource sustainability are questionable. "The Chilwa fishes are clearly well fitted to persist in the unpredictable Chilwa ecosystem, provided the refugium of swamps and streams is maintained", according to Moss, (1979) who also cautions that more dangerous than overfishing were threats to the swamps through reclamation for agriculture or perhaps as irrigation reservoirs, siltation through changes in catchment land-management, and pesticides. It is these threats that have led to recent interest in environmental management in the Chilwa wetland, and its designation as a Ramsar[3] site (EAD, 2000).

4.4 Managing Lake Chilwa for resilience – problems and solutions.

The Environmental Affairs Department (EAD) report reiterates the perceived resilience of the system. However, in an analysis of fisheries issues (EAD, 2000, Table 5.2), the report highlights "ignorance, poverty, corruption, migratory fishermen and lack of resources" as barriers to sustainable utilization of fishery resources, and recommends the implementation of "community-based natural resource management for the benefit of the local people". There is clearly some difficulty in accepting that migration may be a legitimate and sustainable strategy adopted by 'local people' to maximize benefits from a fluctuating resource, a factor that needs to be taken into account in the design of any community-based management scheme. Around Lake Chilwa, there are large-scale shifts from fishing to farming, pastoralism and other occupations when the lake dries out (and back to fishing when it refills).

Such strategies highlight the importance of enhancing or maintaining the flexibility of lake-shore livelihoods rather than constraining it with fixed fisheries access arrangements. Adapting successfully to future climate change may depend on reversing some of the current policy directions and supporting adaptive strategies that have withstood at least 40 years of change. In fisheries where exploitation has little demonstrable impact on fish stocks, and productivity is closely linked with climate, it is not useful to talk about sustainable yields, or limited access to limit fishing effort.

Neither are community-based or co-managed territorial use rights, in the form of geographically fixed territories, useful for fisheries management in areas where lake or floodplain levels are highly variable, or where fishers have to track mobile pelagic resources to sustain their catch rates. Malawi's fisheries have been undergoing a transition from state-based management to an arrangement known as 'co-management', where communities themselves (loosely defined as geographical entities) manage access to fisheries and enforce fishery regulations, in partnership with local and national government (Allison et al, 2002). The model conceived for these local institutions is one based on the concept of fixed sustainable yields, this time

[3] A Ramsar site is designated under the Ramsar Convention (1973) as a wetland of Global Importance. Lake Chilwa was designated on the basis of its importance as a site for migratory wetland bird species. Ramsar site management aims to integrate conservation and human development needs.

operationalised by attempting to grant fixed communities stable access to a geographically defined area of water. This is obviously problematic when water-levels fluctuate and fishermen move (Allison & Mvula, 2002). Other problems have also arisen. These include: power struggles between migrant and resident fishers, and between local elites and the poor; the use of new fishing regulations as a political weapon to exclude access by other ethnic groups; and a decline in the potentially beneficial role of the state in regulating the use of destructive fishing methods (Hara et al, 2002).

Common property institutions that have evolved mechanisms such as reciprocal access agreements between migrants, may be considered more appropriate than these new territory-based approaches as a way of implementing any effort-limitations deemed necessary. Formal recognition, in national policy and legislation, of the legitimacy of opportunistic livelihood strategies, coupled with active removal of barriers to mobility and livelihood diversification would seem to be appropriate policy responses at national or district level. Active support for livelihood diversification (not the same as providing incentives for people to diversify out of fishing altogether) is another management option.

The apparently greater importance of climate, relative to fishing, in driving the dynamics of fish stocks in many of Africa's inland waters also suggests that effort should be redirected at protecting wetland functions and broader ecosystem integrity and away from trying to manage fish stocks for sustainability. Management needs to lose its preoccupation with stability and gain an increased appreciation of resilience.

Aquaculture may also provide opportunities for improving water productivity in areas of worsening water scarcity. Schemes that integrate pond aquaculture with traditional crops in Malawi have successfully reduced farmers' vulnerability to drought, provided a source of high-quality protein to supplement crops, and boosted overall production and profit (Jamu and Chimatiro, 2004). In terms of water use efficiency, systems that reuse water from aquaculture compare very favorably with terrestrial crop and livestock production. When water requirements for feed production are considered, fish production in some intensive aquaculture systems is a more productive use of water than cattle production. Cattle require approximately seven kilograms of grain to gain a kilogram of live weight, whereas fish need only two kilograms (USAID, 2007).

Greater understanding of how people cope with, and adapt to, fisheries with extreme natural variations would assist in developing adaptation strategies to the additional impacts of future climate change. The relative risk of climate change on fisheries sectors also need to be understood in the context of impacts on other natural resource sectors and on other hazards that result in high levels of poverty, including food insecurity, epidemic disease, conflict, political marginalisation, inequity and poor governance

5. Looking to the future: planned adaptation to climate change in Africa's wetlands-in-drylands.

When considering the complexity and scale-dependence of climate change (interpreted broadly to include variability), adaptations may be viewed as either strategic or tactical. Although uncertainty rises as the scale of inference reduces, many projections are sufficiently probable that national and regional policy can be developed. Strategic adaptation refers to changes we can be confident society must make. We can plan for these now, and the research needed to underpin such policy can make specific reference to climate change policy and drivers. In other instances, particularly at local scales, the impact of climate change is much harder to divine and will, in many instances, simply exacerbate vulnerabilities to other stressors and reduce further the range of policy options open to governments. At this scale, it is much harder to predict what will happen, and more difficult to isolate climate change from other causes of change in ecologies and societies. Adaptations at smaller scales must therefore be more tactical or reactive. In the context of small scale fisheries and aquaculture, adaptations must focus on building institutions and rules of management that will increase the capacity of ecosystems and people to accommodate unpredictable change. Flexible and reactive institutions will offer the best chances of minimizing the effects of irreversible change. Examples of these from Lake Chilwa are given in the previous section. Note that thresholds and non-linearity are not confined to smaller scales, global processes are also capable of surprise, but policy is more likely to be set earlier at these larger scales.

Developed partly from our selective review of climate change impacts and responses to past climate variability in the Lake Chilwa case study, and partly from broader literature review and policy analysis, we propose a set of principles that combine the strategic and tactical elements of adaptation to provide a coherent basis upon which to build resilient small-scale fisheries and aquatic resource production systems for the World's 'wetlands in drylands'. Recalling our definition (Section 2), a resilient fishery is one that continues to deliver benefits to the poor, either directly in the form of livelihoods, or indirectly in the form of contributions to wider development processes, food and nutritional security. ‘Climate proofing’ the fishery systems of inland waters in African and other drylands could, therefore, incorporate the following principles and elements:

Enabling diverse and flexible livelihood strategies. Livelihoods that combine activities that vary in their climate-response and sensitivity will be more adaptable to climate change. These can be supported in policy through removal of barriers to geographical mobility (such as requirements to be a full-time resident to access a fishery) and disincentives to diversification (such as commodity-based taxes on traded goods)

Supporting flexible, adaptive institutions. Co-management approaches to fisheries can benefit local communities by giving them more control over their resources. However, if new institutions for management are not based on an understanding of livelihoods and of current coping strategies, and do not explicitly account for the ecology of the natural system, they can increase communities’ vulnerabilities to climate variability. Traditional institutions (rules, customs, taboos) in climate-sensitive environments, such as Lake Chilwa, have tended to be flexible, to accommodate the impacts of climate variability. Examples may include the integration of land and water resource tenure, access ‘filters’ rather than barriers to access to common property resources by the poor in times of crisis or scarcity, and maintenance of reciprocal resource access arrangements as a social insurance mechanism (Allison and Ellis, 2001).

Technological innovation. In aquaculture, technological innovations similar to those in agriculture can be pursued. There are species that are tolerant of brackish water that can cope with salinisation, for example. A shift towards aquaculture based on recirculation systems can help reduce water requirements and to insulate farming operations from the external environment to some degree, although these tend to be intensive (and expensive) systems suited for luxury markets and highly capitalised investors. Selective fish breeding, though in its infancy compared to winged and four-legged livestock, can contribute to developing fish that have different thermal optima, growth characteristics, feed conversion efficiencies, disease tolerances and so on. Because the industry is in its infancy, these breeding programmes would be taking place anyway, and may not impose too much extra burden on the sector. Fisheries and fisherfolk can also switch fishing gear, species and marketing chains to accommodate different available species, and production processes are flexible in the fishery sector. The economic and social costs of technological adaptation to climate change may therefore not be so great. A further category of technological innovation is multi-sectoral in nature. The rising number of reservoirs being built in response to water resource demands from agriculture, power generation, flood control and domestic water supply are creating opportunities for new fisheries (as well as destroying existing ones). Both technological and institutional innovations are possible in these new water bodies and a variety of fishery strategies such as ranching (stocking the water body with cultured juvenile fish), cage aquaculture and communal ownership arrangements are developing to exploit the productive potential of these water bodies and add value to these water-resource developments.

Developing risk reduction initiatives. Risk reduction initiatives seek to address vulnerabilities through early warning systems, timely seasonal weather forecasts, market information systems and disaster recovery programmes. Famine early warning systems (FEWS) are one example of such a system. Information and communication technologies are being widely utilised in fisheries and appropriate information services will find a ready market and existing means of dissemination (Cranston & Holmes, 2007). The value of proactive risk reduction initiatives in fisheries is illustrated by Red Cross programmes in Vietnam, where assistance to coastal communities to replant depleted mangrove swamps has improved physical protection from storms. This has reduced the cost of maintaining coastal defences (dykes) and saved lives and property during typhoon seasons. Mangrove restoration has also improved fisheries livelihoods through the harvesting of crabs, shrimps and molluscs (WDR, 2001). In inland waters, similar benefits may be achieved through focus on maintaining areas of natural wetland vegetation (e.g. reed swamp) which acts as refuge for fish populations during drought periods. These refuges are threatened by intensification of horticulture and rice-cultivation around wetland areas – a problem highlighted in the Chilwa case-study.

Local and National planned adaptation. National Adaptation Programmes of Action (NAPAs) are being funded by the World Bank/ United Nations Environment Programme Global Environment Facility to address the urgent national needs of least developed countries (LDCs) for adapting to the adverse impacts of climate change. Coastal and fishery sector management plans are often only partly considered, frequently due to lack of appropriate knowledge on the sector. Bangladesh, for example, has drafted a NAPA and held a National Stakeholder Consultation Workshop to discuss it (UNDP, 2007). The adaptation options for fisheries focuses on aquaculture, but does not consider options for mitigating adverse effects of river floods or droughts on river fisheries, which are currently more important in supporting Bangladeshi rural livelihoods than fish farming (UNDP, 2007).

Mitigating future impacts. The scope for working with the small-scale inland fisheries sector to mitigate future climate change through CO_2 emission reduction or carbon sequestration is negligible. The scope for mitigation in the sector as a whole is only marginally more significant; the world's marine fishing fleets are estimated to burn 1.2% of global annual fuel-oil use (Tyedmers et al., 2005). The few possibilities for mitigation are outlined in FAO SFLP (2007).

Policy responses. Reducing the vulnerability of fishing communities as a whole can help address poverty and resource degradation, and enhance adaptive capacity to a range of shocks, including those resulting from climate variability and extreme events. A range of policy impact strategies and pathways relevant to small-scale fisheries in drylands can be identified (modified from FAO SFLP, 2007):

Ministries and other national-level and international stakeholders responsible for fisheries management can conduct climate-change risk assessments and allow for the costs of adaptation and the potential changes in economic contributions from the fishery sector under likely climate scenarios in their sectoral planning. They can support initiatives to reduce fishing effort in overexploited fisheries as lightly-fished stocks are likely to be more resilient to climate change impacts than heavily-fished ones. High level policy support can also assist in building institutions that can consider, and respond to, climate change threats along with other pressures such as overfishing, pollution and changing hydrological conditions. Similarly, it is important to link with disaster management and risk reduction planning, especially concerning water resource governance and agricultural development. Engagement in adaptation planning, including promotion of fisheries related climate issues in PRSPs and National Adaptation Programmes of Action can help to address longer-term trends or potential large-scale shifts in resources or ecosystems. Finally, providing legal and policy support to existing adaptive livelihood strategies and management institutions can help maintain resilience, as can addressing other issues contributing to the vulnerability of fishery sector communities such as access to markets and services, political representation and improved governance.

NGOs and community-based organizations can also help to identify the current and future risks, potential impacts and resilience/recovery mechanisms within communities, and engage communities together with governmental and non-governmental agents in preparedness planning by communicating to policy makers the importance of fisheries for poverty reduction and the risks of climate change, building the resilience of coastal and other fisheries communities by supporting community-level institutional development and vulnerability reduction programmes and by supporting risk reduction initiatives within fishing communities, including conservation of wetlands, development of forecasting and early warning systems, preparation measures and recovery processes.

Adaptation planners, donor organizations and economic analysts can take a lead in assessing to overall range, combination, likelihood and potential impacts of climate related effects in fishery contexts. This may include assessing risks of future fish stock variation and likelihood of resource collapse and producing sectoral and food security plans accordingly; assessing specific cross-sectoral factors which will increase or decrease impacts and adaptation potential in fishing communities; and promoting the incorporation of fisheries issues within National Adaptation Programmes of Action (NAPAs) for the Least Developed Countries (LDCs).

6. Conclusions

Climate-proofing fisheries is especially important when those fisheries occur in the world's tropical and sub-tropical drylands, where livelihoods can be precarious and highly exposed to climate-related risks. Although the uncertainties around estimating future climate change impacts on fisheries are high, responding to future climate change threats is largely compatible with wider attempts to reduce rural poverty and vulnerability and the additional costs are therefore likely to be modest. There is a growing consensus among fishery sector agencies that strengthening governance and reducing fisherfolk's vulnerability are both mutually reinforcing and synergistic with building capacity to adapt to climate change (e.g. FAO SFLP, 2007).

There is also a consensus that many of the threats faced by fisheries are external to the sector, so that a process of engagement with interest-groups in other sectors is required if progress is to be made on reducing poverty in fishing-dependent communities and improving resource governance so that the sector's contribution to wider poverty reduction is maintained or enhanced (Andrew et al., 2007). The fate of the world's fisheries and aquaculture is linked to external processes – water governance, climate change, river/lake-basin/land use planning, pollution and habitat conversion or destruction. Past attempts to achieve cross-sectoral integration through river-basin planning, coastal zone management or watershed and lake-basin management, have often foundered through lack of a common conceptual framework, and through identification of sectoral interests as being invariably in conflict, so that the need for 'trade-offs' comes to dominate at the expense of the potential synergies. In this paper, we have proposed the application of a resilience-based approach, elements of which will be familiar to students of dryland ecology and management as it draws on elements of 'new rangeland ecology' and related studies of environmental change and adaptation in drylands (e.g. Behnke et al., 1993; Scoones, 1995).

In sum, we believe fish production to be important to climate change adaptation beyond the sector – in this case to the livelihoods and agricultural production systems of hundreds of thousands of people living in Africa's 'wetlands in drylands'. The interface with water governance is key and our programmes are currently focusing on rights, non-consumptive uses, valuation and interactions with infrastructure development. Although we have long recognised that aquaculture should be considered alongside broader agricultural policy, we have recently been attempting to draw policy attention to the linkages between capture fisheries and agricultural policy development. The future of fisheries will be shaped by cross-sectoral solutions to current problems.

With respect to climate change, we believe this paper has demonstrated that a key to understanding and adapting to climate change lies in studying high-variability systems. Furthermore, fisheries as common pool resources are of particular importance as they are both more vulnerable to inadequate management and more useful to the poorest people and therefore have more impact on the poor if they are threatened (Beck and Nesmith, 2001).

Recent analysis of global climate models show that, even if the concentrations of greenhouse gases in the atmosphere had been stabilized in the year 2000, we are already committed to further global warming of about another half degree and additional sea level rise caused by thermal expansion by the end of the 21st Century (Wigley, 2005; Meehl et al., 2005). This means that, whatever progress is made over the coming decades in climate change mitigation, it will be necessary to plan and adapt for impacts of unstoppable change. It seems appropriate to give prominence in the response to global climate change to those people whose lives depend so directly on the warming, rising or receding waters that the coming century will bring.

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Figure 1. Index of national economic dependency on fisheries. The index comprises the unweighted sum of the fishery production (tonnes per year), fishery consumption (Kg per capita per year), employment in fisheries (as a proportion of total labour force) and contribution to exports (as a proportion of value of total exports). The index is divided into quartiles with the darkest shading representing the quartile of countries most dependent on fishing in the sample of 139 nations for which data were available. (See Allison et al 2005 for details of data sources and methods)

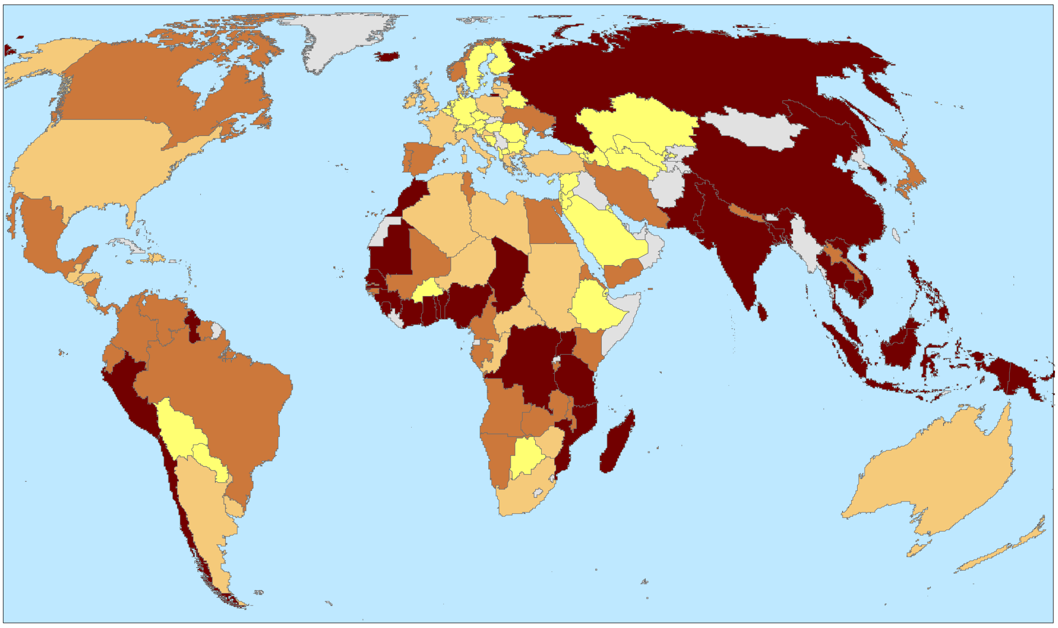


Figure 2. Lake Chilwa, Southern Malawi, showing the boundaries of Zomba District and the location of two fishing villages and associated fish landing sites surveyed in 2001 (Allison & Mvula, 2002)

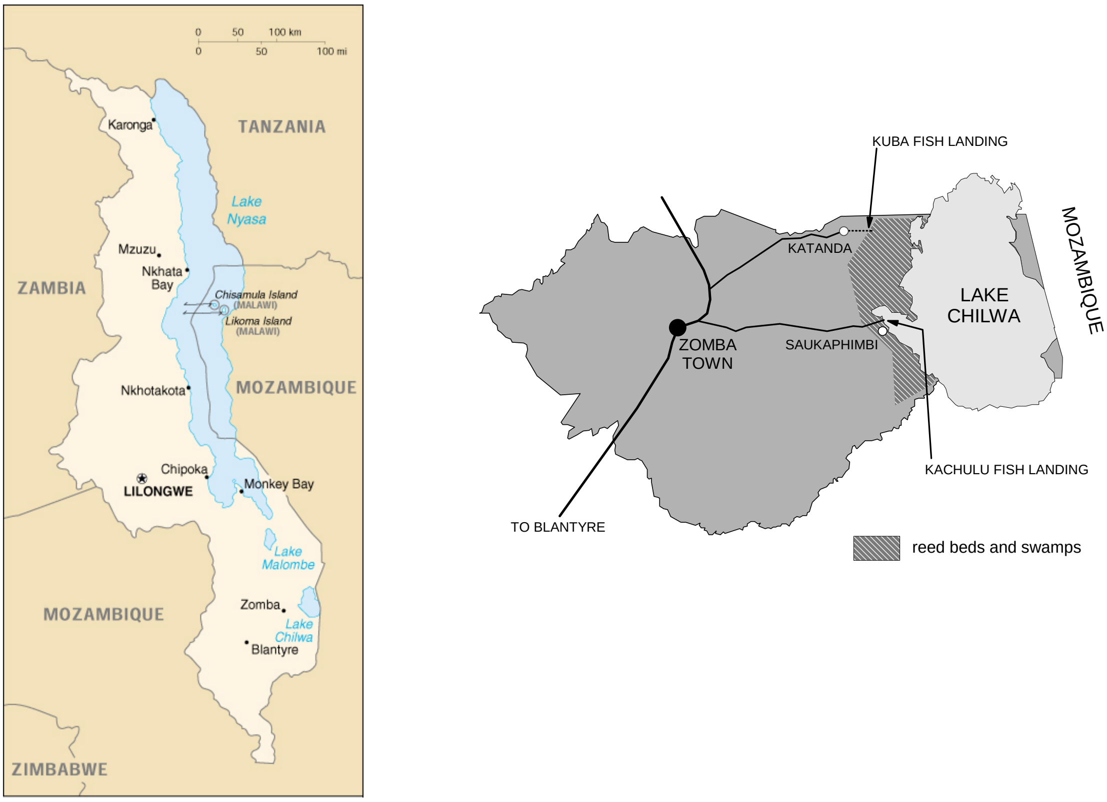
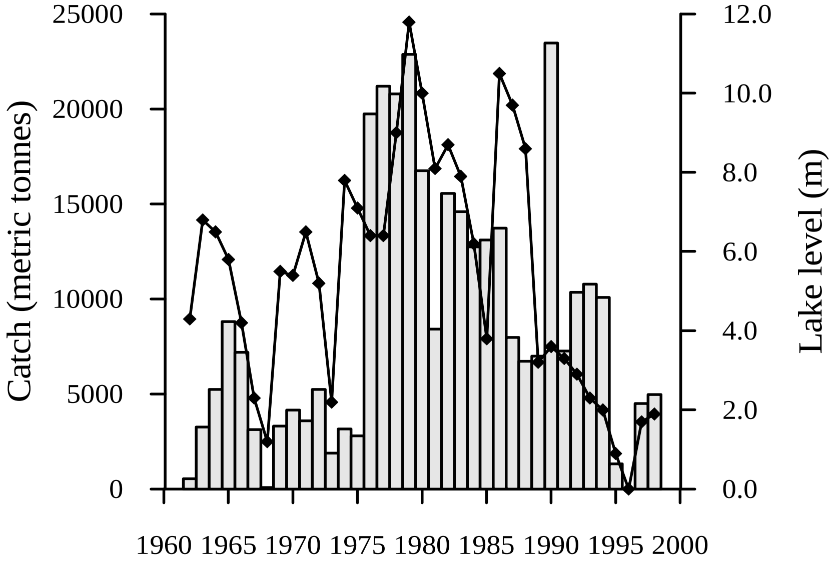


Figure 3. Catch fluctuations (shaded bars) and lake level variations in the shallow Lake Chilwa, Malawi 1962-1998



Note that the lake gauging system was changed in 1989 and the lake level measurements from this period onwards may not be directly comparable with those in previous years, and have a lower apparent amplitude of fluctuation

Table 1. Examples of climate impact pathways on inland fisheries (Modified from Allison et al, 2005 and FAO SFLP, 2007)

Type of changes	Climatic variable	Impacts	Potential outcomes for fisheries
	Surface warming of rivers and lakes	Warm water species replacing cold water species Shifts in distribution of plankton, insect larvae and other key food resources for fish	Shifts in ***distribution*** of important food fish Reduction in ***biodiversity*** through loss of sensitive species in inland waters
	Changes in precipitation	Altered river flows, lake levels, flood and drought frequencies Rivers affected by snow melt have earlier and faster spring flows	Changes in fish ***diversity*** and ***production*** Changes in timing and extent of fish ***production***
	Changes in cloud cover and wind speed	Changes in thermal stratification, affecting nutrient recycling Changes in light penetration and photosynthetic efficiency	Reduction in ecosystem productivity and fish ***production*** where stratification strengthens (reduced windspeed) Changes in ecosystem structure and function potentially impacting fish ***production***
	Sea level rise	Backing up of rivers Flooding and salinisation of river deltas, coastal lagoons and wetlands Loss of coastal fish breeding and nursery habitats	Increased ***flooding of riparian settlements*** Reduced ***production*** of coastal and brackish-water fisheries and aquaculture Declines in ***biodiversity*** and ***provision of ecosystem services***
		Changes in sex ratios Altered time of spawning Altered time of migrations Altered time of peak abundance	Possible impacts on timing and levels of ***productivity*** across fresh-water systems
		Increased invasive species, diseases and algal blooms	Reduced ***production*** of target species in fresh water systems
		Changes in fish recruitment success	Abundance of juvenile fish affected and therefore ***production***
	Reduced water flows and increased droughts	Changes in lake water levels Changes in dry season water flows in rivers Reduced water quality (less dilution of pollutants, eutrophication)	Reduced lake ***production*** and ***productivity*** Reduced river ***productivity*** ***Fish kills***, ***loss of sensitive species*** reduced ***production***
	Reduced surface water availability	Increased water abstraction for agriculture and other uses Increased use of built-structures (dams, weirs, flood barriers etc)	Reduced water availability for aquaculture and fisheries leading to loss of ***production*** Disruption to life-cycles, ***reduction in biomass and possible extinction*** of high-value migratory fish species ***Displacement of fishing communities***

	Changing levels of precipitation	Where rainfall decreases, reduced opportunities for farming, fishing and aquaculture as part of rural livelihood systems	***Reduced diversity of rural livelihoods***; greater risks in agriculture; greater reliance on non-farm income
	More droughts or floods	Damage to productive assets (fish ponds, weirs, rice fields etc) and homes.	
	Less predictable rain/dry seasons	Decreased ability to plan livelihood activities – e.g. farming and fishing seasonality	