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FISHERIES IN THE DRYLANDS OF SUB-SAHARAN AFRICA

"FISH COME WITH THE RAINS"

Building resilience for fisheries-dependent livelihoods to enhance food security and nutrition in the drylands

Cover photograph

Turkana fishers at Longesh Spit, Ferguson’s Gulf, 2010. Photo by Peter Heller (Filmkraft Filmproduktion)

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FISHERIES IN THE DRYLANDS OF SUB-SAHARAN AFRICA

"FISH COME WITH THE RAINS"

Building resilience for fisheries-dependent livelihoods to enhance food security and nutrition in the drylands

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Some of the most important inland fisheries in the world are found in semi-arid regions. This circular documents the general resilience of many fish resources to climatic variability, with a focus on the drylands of sub-Saharan Africa; reviews the importance of fisheries and aquaculture to the livelihoods of drylands communities; discusses future threats to human resilience; and identifies investment opportunities. The knowledge generated by the circular will be used by policy makers and development practitioners to design and implement more effective policies, strategies and programmes that will contribute to reducing the food insecurity and conflicts that currently affect dryland environments in sub-Saharan Africa.

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Abstract

Dryland areas cover more than half of sub-Saharan Africa and are home to nearly 50 percent of its populations, who depend on agriculture (including livestock, crops and fisheries) as their main livelihood strategy. Sporadic and irregular rainfall patterns are the most important environmental driver for these regions and water, in particular surface water, is the primary element of scarcity in drylands. Generally, dryland water bodies are unstable and strongly pulsed ecosystems owing to intermittent and largely unpredictable precipitation. Such systems are characterized by very productive and highly resilient, small opportunistic fish species with "boom and bust" fluctuation adapted to strong environmental disturbances, and are therefore difficult to overfish. As a result of high productivity, they can sustain very high yields in years of good rains, but being largely short-lived they also respond rapidly to environmental changes in hydrological regimes, which means that alternating periods of low productivity are inevitable. The focus of this review is to both document the general resilience of many fish resources to climatic variability − including their underestimation in livelihood importance, particularly in protracted crisis situations − and to enhance the potential supply of fish from dryland areas through improved use of the available water bodies, and in particular small reservoirs. The important role that small water bodies play in supplying essential micronutrients and protein to rural communities has largely been overlooked since the termination of the FAO/ALCOM (Aquaculture for Local Community Development) programme in 1998, although they are more productive on a per unit area basis than the large lakes and reservoirs and, when pooled, constitute a much larger area of water. Most of the fish production, however, is consumed locally and goes unrecorded in official catch statistics. By refocusing attention on the fish productivity of small water bodies and reservoirs in drylands, and in particular by integrating fisheries with developments in water harvesting, irrigation and improved water storage facilities, the potential to increase the role played by fish in the diets of dryland people, and to provide improved livelihood opportunities is great. The overall conclusion is that the potential for increasing fish production in dryland areas is significant, that the resources are highly resilient and productive, but that the general and increased unpredictability of the rainfall required to sustain surface water bodies creates uncertainties in annual production. That must be counteracted by an adaptive and diversified livelihood strategy.

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List of acronyms

AMSL	Average annual water levels in meters
AI	Aridity index
ALCOM	Aquaculture for Local Community Development (programme)
ATTZ	Aquatic terrestrial transition zone
CAADP	Comprehensive Africa Agriculture Development Program (of NEPAD)
CCA	Climate change adaptation
COFI	Committee on Fisheries
DRM	Disaster risk management
DRR	Disaster risk reduction
FAO	Food and Agriculture Organization (of the United Nations)
GDP	Gross domestic product
ICLARM	International Centre for Living Aquatic Resources
IPCC	Intergovernmental Panel on Climate Change
IUU	Illegal, unreported and unregulated (fishing)
MCM	Million cubic metres
MEI	Morpho-edaphic index
NAIP	National Agriculture Investment Plan
NEPAD	New Partnership for Africa's Development
NFFP	NEPAD/FAO Fish Programme
NGO	Non-governmental Organization
PAF	Partnership for African Fisheries
P/B	Production to biomass (ratio)
RFMO	Regional Fisheries Management Organization
RLLF	Relative lake level fluctuation
RLLF-a	Annual relative lake level fluctuation
RLLF-s	Seasonal relative lake level fluctuation
SADC	Southern African Development Community
SMB	Small water body
SSF	Voluntary Guidelines for Securing Small-scale Fisheries in the Context of Food Security and Poverty Eradication
UNCCD	United Nations Convention to Combat Desertification
UNISDR	United Nations International Strategy for Disaster Reduction
VGGT	Voluntary Guidelines on the Responsible Governance of tenure of Land, Fisheries and Forests

1. Introduction and rationale

The role and importance of fish in securing food and nutrition for humans, particularly in developing countries, has frequently been overlooked. Fisheries and aquaculture are often arbitrarily separated from other parts of the food and agricultural system in food security studies, debates and policy-making (HLPE, 2014). Furthermore, nourishment is no longer only a question of calorie availability and access: food security should be broadened to also include alimentary/nutritional aspects. There is now robust evidence that a lack of essential micronutrients, such as zinc and vitamin A, affects hundreds of millions of malnourished people around the world (IPCC, 2013). In this regard, the importance of fish, and in particular small fish, for sustainable and healthy livelihoods in Africa, as well as their strong relationship with climate-driven water dynamics and their role during times of crisis and disasters, are generally undervalued and little understood. This is because most small fish are consumed locally and, as such, go unrecorded in catch statistics (Kolding *et al*., 2016).

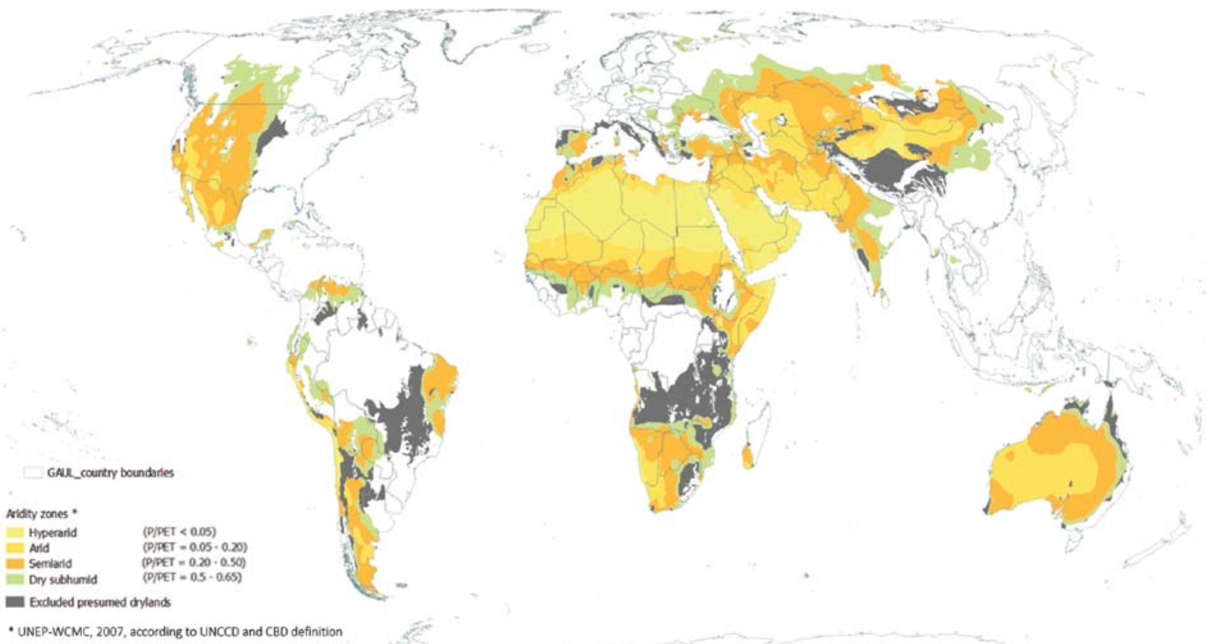
This dilemma is particularly prominent in the so-called drylands, where the focus has traditionally been almost exclusively on terrestrial crops and animal husbandry. However, given the widespread distribution of drylands in sub-Saharan Africa, and the extent of fish production and regional trade on the continent, all fisheries in sub-Saharan Africa do, or have the potential to, contribute to the livelihoods of people in the drylands; either directly to those fishers and fish farmers working in dryland areas, or as a vital source of food for drylands populations. This paper takes a continent-wide perspective to address the current and future contribution of fisheries and aquaculture to drylands livelihoods and resilience.

Box 1: FAO's definition of resilience

"The ability to prevent disasters and crises as well as to anticipate, absorb, accommodate or recover and adapt from them in a timely, efficient and sustainable manner. This includes protecting, restoring and improving livelihoods systems in the face of threats that impact agriculture, food security and nutrition, and food safety."

The goal of this report is: *to improve understanding of the importance of fisheries and aquaculture to the livelihoods of communities in the drylands of sub-Saharan Africa; to discuss future threats and opportunities to human resilience; and identify potential investment opportunities in the fisheries and aquaculture sector that will strengthen the resilience of the sector in drylands and enhance food security and nutrition*.

FIGURE 1
Distribution of drylands in the world

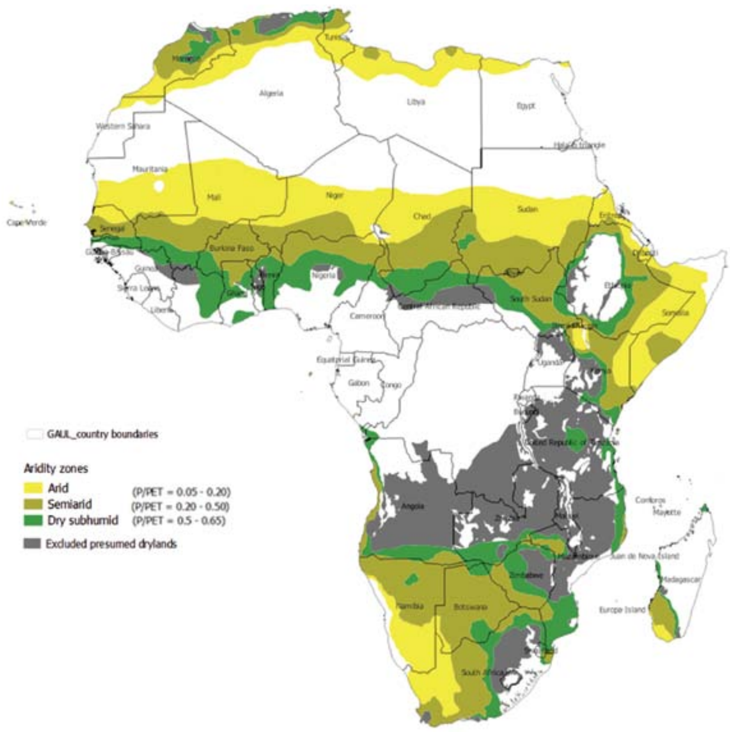


Source: Adapted from UNEP-WCMC, 2007, in accordance with UNCCD and CBD and updated in 2014

Drylands, as defined by the United Nations Convention to Combat Desertification (UNCCD), are regions with an aridity index[1] (AI) of between 0.05 and 0.65. Drylands are further divided into four subtypes (zones): hyper-arid (deserts), arid, semi-arid and dry subhumid, with AIs of 0.00–0.05; 0.05–0.20; 0.20–0.50; and 0.50–0.65, respectively (Figure 1). The UNCCD excludes hyper-arid zones from its definition of drylands. FAO (2000) has defined drylands as those areas with a length of growing period of 1 to 179 days; this includes regions classified climatically as arid, semi-arid and dry subhumid.

Sub-Saharan Africa is undergoing significant challenges brought about by a number of environmental and socio-economic disruptions (such as human-made and natural disasters, conflicts, terrorism and human and animal diseases) and pressures from population growth, degradation of aquatic resources and environment, climate change, etc. These often have their most profound effects in the more harsh and unfavourable environments such as the drylands that make up nearly 55 percent of sub-Saharan Africa, as shown in Figure 2. Drylands cover 13 million km^2 and are inhabited by 390 million people, or roughly 48 percent of the sub-Saharan regional population, most of whom depend on agriculture (including livestock, crops and fisheries) as their main livelihood strategy.

FIGURE 2
The drylands of Africa



Source: Adapted from UNEP-WCMC, 2007, in accordance with UNCCD and CBD and updated in 2014

This report focuses mainly on the drylands of the Sahel, Horn of Africa and southern Africa. The countries are shown in Figure 2. Some are countries that are predominantly made up of drylands, such as South Sudan, Chad, Niger, Mali and Botswana, while others have important dryland areas which occupy part of the country, such as Kenya, Ghana and Namibia. Dryland areas are often among the most precarious in terms of their ability to support sustainable and equitable livelihoods at acceptable levels. With increasing population growth, recurrent droughts and other pressures, the people who live in these drylands experience challenges that often result in declining health, poor nutrition, food shortages, physical asset loss, income reduction, unemployment, displacement and further marginalization, loss of access rights, migration and conflict. Poverty is heavily concentrated in drylands: about 75 percent of Africa's poor people are found in countries in which at least one quarter of the population lives in dryland zones. For many, the pressures and challenges are getting worse. Among the most vulnerable are pastoralists and smallholder farmers in dry areas, whose susceptibility is expected to exacerbate with climate change (HLPE, 2012).

Dryland areas often have weak institutional support, limited infrastructure, low levels of financial market development, and often few commercial opportunities for growth. As a consequence, dryland communities have had to learn to live with the precarious nature of their livelihoods. Their ability to cope with shocks and pressures, especially by undertaking frequent migrations, are well documented (e.g. Swallow, 1994; McPeak and Barrett, 2001). However, in recent years, with increasing settlement and growing territorial conflicts, these challenges have become more frequent and more severe, pushing many people to the edge of their capacity to respond. While the situation in Africa is reaching critical levels in some areas – with frequent droughts or floods, depleted natural resources and damaged habitats – the potential for

1. Aridity index is the ratio of mean annual precipitation to mean annual potential evapotranspiration (P/PET).

improvement is substantial if the right policies, priorities and investments are made over the coming years. This report outlines the current knowledge of fisheries and aquaculture in relation to the drylands of sub-Saharan Africa; describes the variability and vulnerability of these sectors; suggests how resilience can be strengthened; and proposes options for investment so as to help achieve that potential.

The report is intended primarily for the governments of countries in sub-Saharan Africa, as well as their regional, international and civil society partners, relevant private sector actors and the development community.

2. Drylands and the (potential) role of fisheries and aquaculture production

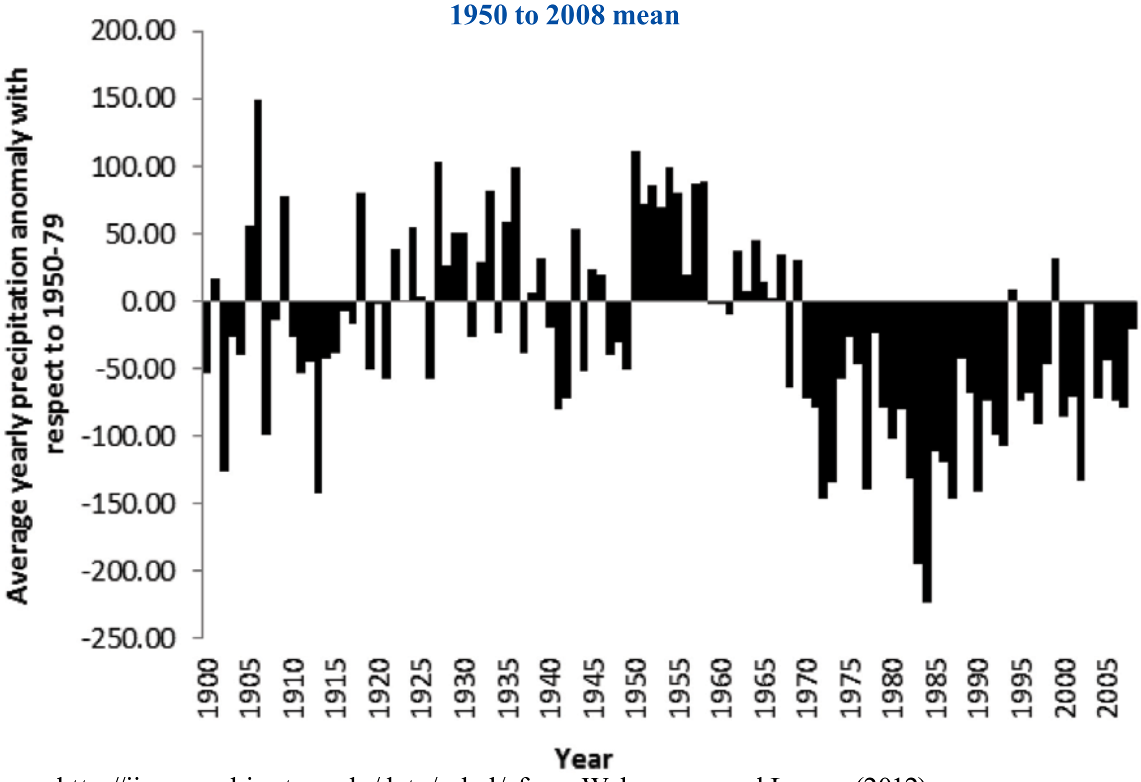
Fish provides the main source of animal protein for some 200 million people on the African continent (Heck *et al*., 2007). Fisheries also provide a direct source of livelihoods to over 10 million Africans, while five to ten times that number engage in fisheries as a secondary activity for food security in rural areas. Fish depend on available open surface water and inland fisheries are normally associated with wetlands. Water, and in particular surface water, is the primary element of scarcity in drylands (Kapatuė *et al*., 2013) and dryland fisheries and aquaculture may therefore sound like a paradox. How can a lack of regular water supply be meaningfully connected with fish and fisheries? To fully understand this dynamic relationship, we must first understand the climatic and hydrological characteristics of drylands and then how these attributes affect fish production.

2.1 Hydrological conditions in drylands

Drylands are subject to large year-to-year variations in precipitation, with prolonged dry periods interspersed with wetter years. Figure 3 illustrates years of above and below average rainfall in the Sahel region, which

FIGURE 3

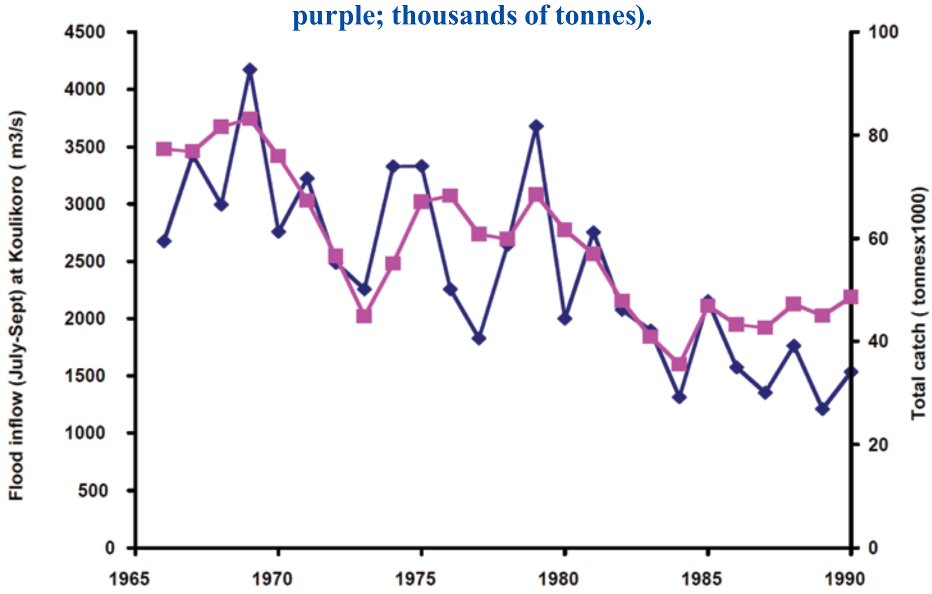
Years of above and below average rainfall in the Sahel region based on deviations from 1950 to 2008 mean



Source: http://jisao.washington.edu/data/sahel/, from Welcomme and Lymer (2012) encompasses major waterbodies such as the Nile, Niger, Senegal, Chari and Logone Rivers, the Sudd wetlands in southern Sudan and Lake Chad. The general drying out of the climate in the Sahel since about 1970 and the increased abstraction of water for irrigation means that many notable hydrological features are disappearing (Welcomme and Lymer, 2012). This is most clearly observed in the desiccation of Lake Chad which has contracted by 80 percent in the last 40 years (Lemoalle *et al*., 2012). The decreased rainfall in the Sahel over the past four decades, and its effect on the major water bodies, is directly reflected in the fisheries yields (Figure 4).

FIGURE 4

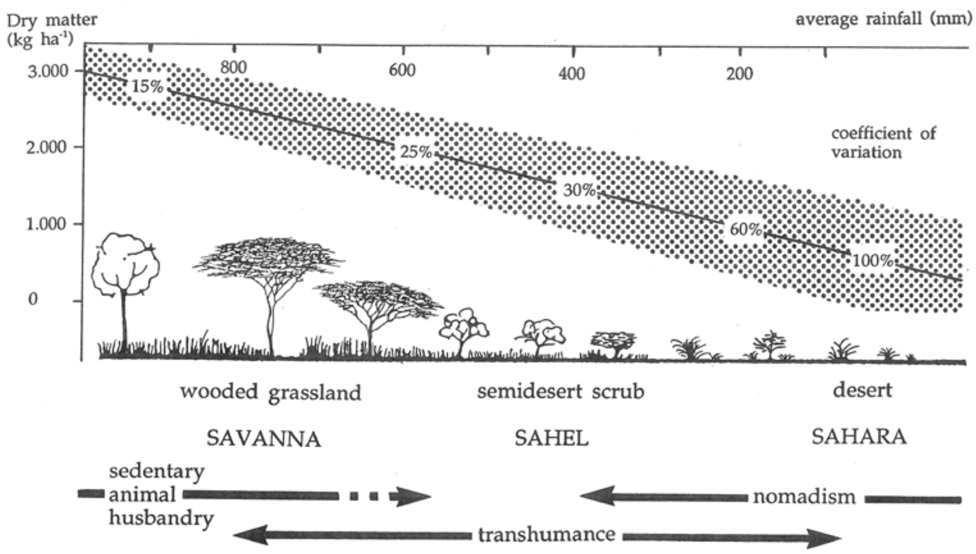
Relation between flood river inflow in the inner delta of the River Niger as measured at Koulikoro, Mali (diamonds, blue; m^3/s from July to September) and annual catch (squares, purple; thousands of tonnes).



Source: Lemoalle (2008); data from Laë and Mahé (2002)

FIGURE 5

Relationship between average rainfall (mm/year), primary production (kg/ha) and the variability of rainfall across the Sahel (coefficient of variation (dotted area) is 100 times the standard deviation divided by the mean). Also shown are the three main ecological zones illustrated in Figure 1 (arid: Sahara; semi-arid: Sahel; and dry subhumid: savanna) and the corresponding location of the three main human livelihood strategies adapted to variable rainfall patterns: sedentary, transhumance and nomadism



Source: Vetaas and Kolding (1991)

In addition to long-term climatic changes, most drylands are best understood as ecological gradients owing to uneven levels of precipitation across different sub-type boundaries (Figures 1 and 2). However, more important than the difference in precipitation, is the gradual change in the predictability of the rainfall pattern. This is because the decrease in average precipitation along dryland sub-types is positively correlated with an increase in variability in time and space (Figure 5).

This means that the irregularity of water, the most important ecological constraint, has increased from the moist part to the dry part of the precipitation gradient. In the driest areas the main problem is not so much the aridity itself, but that the rainfall is highly unpredictable in time and space (Vetaas and Kolding 1991; Baijot *et al*., 1997). These environmental conditions are reflected in all other parameters correlated with water availability, such as vegetation patterns, biological production (including fish) and people's lives and livelihoods. Of all the climatic factors, the daily and interannual variations in precipitation are the most crucial for rain-fed and irrigated agricultural production (FAO, 2008a). The gradients in rainfall and vegetation also drive the three main traditional livelihood strategies in drylands: nomadism in the driest part; transhumance (seasonal movement of people with their livestock between fixed summer and winter pastures) in the middle part; and sedentary animal husbandry and farming in the subhumid areas (Figure 5). The main differences between these three traditional livelihood strategies are the mobility, the size of the area needed for sustenance and the relative number of animals per person, which are all directly correlated with the aridity. Generally, farmers in dry subhumid areas rely on their crops as the staple food and are mostly interested in animals for supplementary meat

Box 2: Fluctuations of Lake Chad

A classification of three main states of the lake was proposed by Tilho (1928) and recently an additional state was added by IRD (2013):

1. **The large Lake Chad**: holds 25 000 km^2 of open water with a limited coastal sand dune archipelago, a water surface altitude level of 282.5 m and occasional slight overflow towards the northeast through the Bahr El Ghazal. This large Lake Chad state was approached only for short periods during the last century.

2. **The normal-intermediate Lake Chad**: is a single body of water covering about 20 000 km^2, at an intermediate altitude level of 281 to 282 m, with an archipelago of some 2 000 dune islands and some limited marshy vegetation on the shores. This normal intermediate state occurred from the 1960s to the 1970s and then a shift from normal to small Lake Chad occurred in 1973 to 1975.

3. **The small Lake Chad**: is made up of different separated bodies with a permanent open water pool in the southern part of about 1 700 km^2 (at a maximum altitude of about 280 m) facing the River Chari delta. The other water bodies are mostly permanent or seasonal marshes ranging from 2 000 to 14 000 km^2 covering the northern basin of the lake and parts of its southern basin. The input from the small River Yobe (about 0.5 km^3/year), feeding directly the northern basin at the border between Nigeria and Niger, is just sufficient to maintain a marsh area around its estuary. The lake has been functioning as a small Lake Chad since 1975.

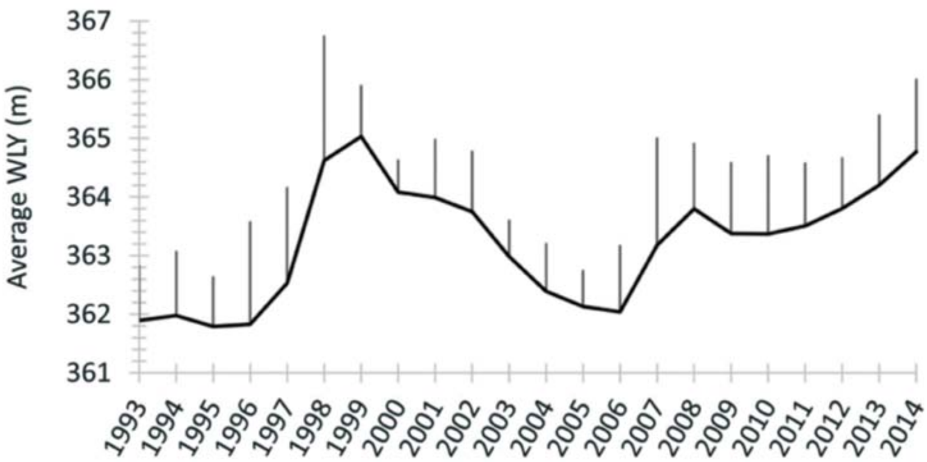
4. **The small Lake Chad dry**: A new state has been recently defined (IRD, 2013) to describe a small Lake Chad without sufficient water inflow from the southern basin to the northern basin and thus remains dry throughout the year. This occurs when the annual contribution of the River Chari is less than 15 km^3/year. The difference between the small Lake Chad, as described above, and this state relates to the northern basin only. During this state in the northern lake fishing is not possible, there is some livestock raising and agriculture, and the supply of drinking water becomes difficult. This state occurred in 1985, 1987, 1988 and 1991 with the northern lake completely dry throughout the year, and in 1975, 1977, 1982, 1984, 1990, 1992, 1993, 1994 with the northern lake completely dry during certain parts of the year.

production. In contrast, the nomadic pastoralists in arid areas maintain much higher stocking levels, because the mobile animals provide their only means of reliable subsistence, and the desired products are mainly milk and offspring. Each strategy depends on the ability to access and adapt to the availability of the natural resources controlled by rainfall and surface water. For instance, surface water bodies are used by pastoralists to water their livestock (Baijot *et al.*; 1997; Thébaud and Batterbury, 2001) or by farmers to irrigate crops or practise flood retreat farming (Sarch and Birkett, 2000; Koohafkan and Stewart, 2008). Surface water bodies are also indispensable habitats for fish. However, owing to the inverse relationship between average annual precipitation and variability (Figure 5) dryland water bodies are generally characterized by strong seasonal and interannual fluctuations, where the amplitude (variance) increases along the climatic aridity gradient (Figure 5).

Typical examples are Lake Turkana in northern Kenya, the largest desert lake in the world, which has undergone lake level fluctuations of nearly 20 meters in recorded history (Kolding, 1992), and Lake Chad which covered an area of 20 000 km^2 during the 1960s and contracted by 80 percent in the past 40 years (Lemoalle *et al.*, 2012; Box 2). However, in addition to these long-term variations, the lake levels in both lakes fluctuate annually by about 1.5 m in amplitude (Figure 6).

FIGURE 6

Average annual water levels in meters (amsl) for Lake Turkana from 1993 to 2014. Vertical bars signify the seasonal fluctuation amplitude for a given year.



Source: Satellite data collected from the United States Department of Agriculture: Global Lakes and Reservoirs Database, from Gownaris *et al.*, 2016a.

2.1.1 Climate change and future scenarios

Climate change will further influence precipitation regimes and the recent Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) indicates that it will have a significant impact on crop production and water management systems in coming decades. Predictions suggest that differences in precipitation between wet and dry seasons in Africa will widen and that extreme flood and drought events will become more prominent, intensifying seasonal fluctuations (IPCC, 2013). Higher temperatures may also amplify water level fluctuations in dryland water bodies as a result of increased evaporation, particularly in exposed systems where evaporative water loss is high. In northern Kenya, Burkina Faso and Botswana, for example, the evaporation rate is around 2 m per year (Kolding, 1992; Marshall and Maes, 1994; Baijot *et al.*, 1997). Ongoing climate change has already caused increasing trends in average, minimum or maximum temperatures in many regions of Africa (Boko *et al.*, 2007). Acting in concert, these effects have the ability to considerably alter the hydrological regimes of freshwater ecosystems in arid regions of Africa. The most likely medium-term scenario is increased variability, volatility and seasonal fluctuations in water volumes and rain-fed production (FAO, 2008a).

There is already evidence that such changes are emerging. Gownaris *et al.* (2016b) analysed long-term changes in seasonal and interannual relative lake level fluctuations (RLLF)[2], Kolding and van Zwieten (2012) in 13 African lakes and reservoirs in association with general ecological attributes (Table 1; Figure 7). They found that temporal trends in interannual fluctuations existed for six of the 13 systems, half of which were positive (higher amplitude) and half negative, while trends in seasonal fluctuations were significant for ten of the systems (Table 1). The temporal trends in seasonal water level fluctuations were overwhelmingly positive, with significant increases in eight of the systems studied and decreases in only two. All of the lakes situated in drylands showed significant positive increase in seasonal water level fluctuations, thus supporting the IPCC predictions of intensified seasonal oscillations.

TABLE 1

13 African lakes and reservoirs and their RLLF (annual = RLLF-a; seasonal = RLLF-s), as well as changes in fluctuations over time and sources of Ecopath models for the corresponding ecosystems. The table shows that RLLFs have significantly increased over time in eight of the 13 lakes. Averaged results of the Ecopath models are shown in Figure 12.

Lake	Country	Water level data (#years)	1990s–2000s Water level data (#years)	RLLF-s	RLLF-a	Change RLLF-a	Change RLLF-s	Model publication	Model data years
Lake Tanganyika	DRC, Tanzania, Burundi, Zambia	1909–1992 (106)	1990–2014 (25)	0.13	0.04	NS	decrease**	Moreau *et al.*, 1993c	1970s–1980s
Lake Kivu	DRC and Rwanda	1945–1973 (34)	1996–2008 (13)	0.46	0.13	NS	NS	Villanueva *et al.*, 2008	2002–2003
Lake Malawi	Malawi, Tanzania Mozamb-ique	1900–2014 (93)	1990–2014 (25)	0.59	0.14	increase*	increase***	Darwall *et al.*, 2010	1990s
Lake Victoria	Kenya, Tanzania, Uganda	1900–1989 (112)	1993–2014 (22)	1.31	0.64	NS	increase***	Moreau *et al.*, 1993b	1970s–1980s
Lake George	Uganda	1992–2014 (11)	2000–2010 (11)	2.81	1.18	NS	decrease**	Moreau *et al.*, 1993a	1970s–1980s
Lake Turkana	Kenya	1888–1989 (112)	1993–2014 (22)	3.72	1.59	increase˙	increase***	Kolding, 1993b	1970s–1980s
Lake Tana	Ethiopia	1960–1992 (55)	1990–2014 (25)	18.62	2.15	decrease**	increase**	Wondie *et al.*, 2012	1990s–2000s
Lake Chad	Chad, Cameroon, Niger, and Nigeria	1954–1977 (46)	1993–2014 (22)	30.28	2.59	increase*	increase***	Palomares *et al.*, 1993	1970s
Lake Kariba	Zimbabwe and Zambia	1963–1999 (52)	1990–2014 (25)	15.02	3.97	decrease***	increase***	Machena *et al.*, 1993	1970s–1990s
Lake Awassa	Ethiopia	1970–1999 (30)	1990–1999 (10)	16.04	4.22	increase***	increase***	Fetahi and Mengistou, 2007	1990s
Lake Hayq	Ethiopia	1975–2012 (29)	1990–2012 (16)	NA	8.85	decrease*	NA	Fetahi *et al.*, 2011	1990s
Lake Naivasha	Kenya	1900–1998 (110)	1990–2014 (20)	28.34	11.32	NS	increase***	Mavuti *et al.*, 1996	1970s–1990s
Lake Nakuru	Kenya	1958–2000 (29)	1993–2000 (9)	40.77	38.7	NS	NS	Moreau *et al.*, 2001	1970s–1980s

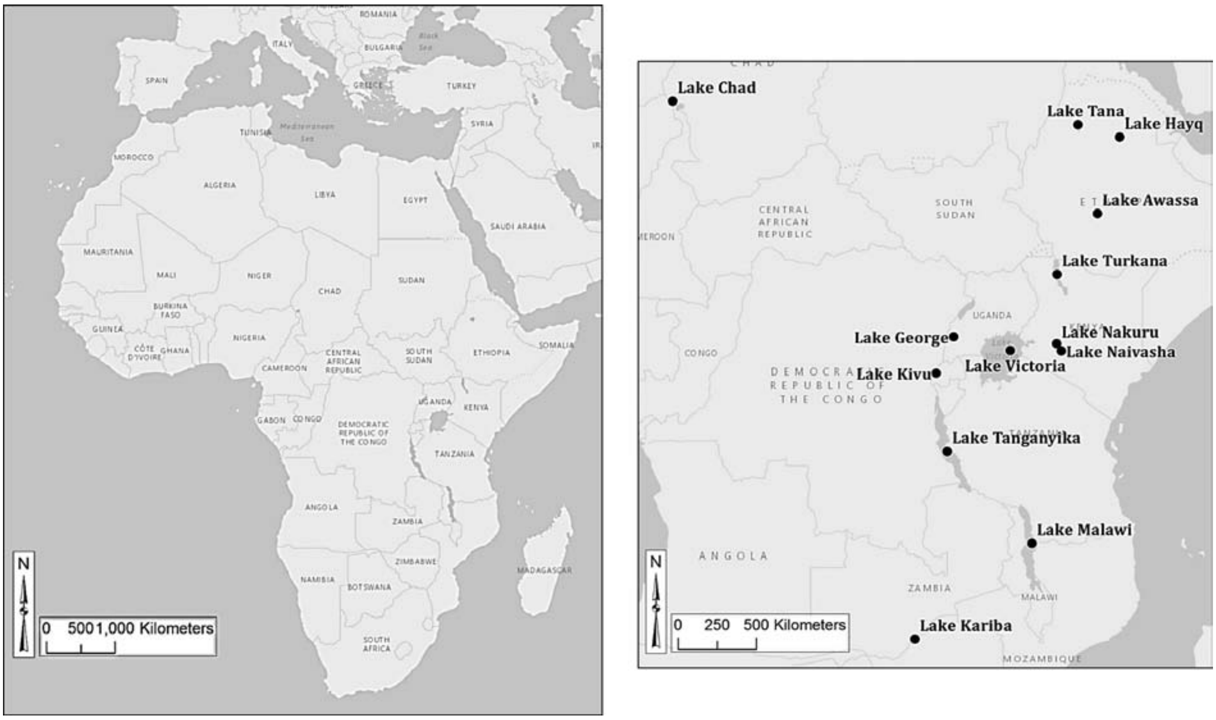
NA = Not applicable, NS = not significant, *= p<0.05, **=p <0.01, ***= p<0.001

Source: modified from Gownaris *et al.*, 2016b

2. The relative lake level fluctuation (RLLF) index is defined on a seasonal (RLLF-s) or interannual (RLLF-a) basis as the amplitude of lake level fluctuations divided by the mean depth of the water body. See also Section 3.5.

FIGURE 7

Map showing the location of the 13 African lakes and reservoirs analysed for long-term trends in interannual and seasonal lake level fluctuations (Table 1). All of the dryland lakes and reservoirs: Turkana, Tana, Chad, Awassa, Kariba and Naivasha (except Nakuru) showed a significant (p <0.01) increase in seasonal water level fluctuations, reflecting increased climatic variability (Table 1).



Source: Gownaris *et al*., 2016b.

2.2 Environmental variability and fish production

There is increasing evidence that fish production in African inland fisheries in general, and dryland fisheries in particular, is more dependent on the external climatic drivers (amongst which are increased long-term and seasonal variability of surface water bodies, Table 1), than on human exploitation rates and various management interventions (Jul-Larsen *et al*., 2003; Kolding and van Zwieten, 2011, 2012; Gownaris *et al*., 2016a & b).

While the recorded yields of African inland fisheries have increased almost linearly by around half a million metric tonnes per decade over the past 60 years, there are clear cyclical variations in the residuals of about 20 years periodicity above and below the trend line (Figure 8). When comparing this cyclical pattern with the most conspicuous observed changes in African lakes and reservoirs − the long-term, interannual and seasonal fluctuations in water level and river inflow − there appears to be a correlation between the de-trended landing statistics (from SADC countries) and long-term climate driven oscillations in the water levels (Figure 9), which are remarkably correlated with most of the large lakes over the past 200 years[3].

Smaller lakes follow the same pattern of climatic change and, like most terrestrial farmers, the biggest environmental concern for African fishers is usually insecurity about annual rainfall. "Fish come with the rain" is the most commonly expressed statement when asking African inland fishers about the factors controlling fish production (Kolding *et al*., 2016; Figure 9). Good empirical examples of this aphorism are the many isolated endorheic (closed) water bodies in African drylands, such as Lake Ngami (Botswana), Lake Chilwa (Malawi), Lake Mweru Wa' Ntipa (Zambia), Lake Liambezi (Namibia), or Lake Nakuru (Kenya) which periodically dry out completely, becoming muddy swamps or even dusty depressions.

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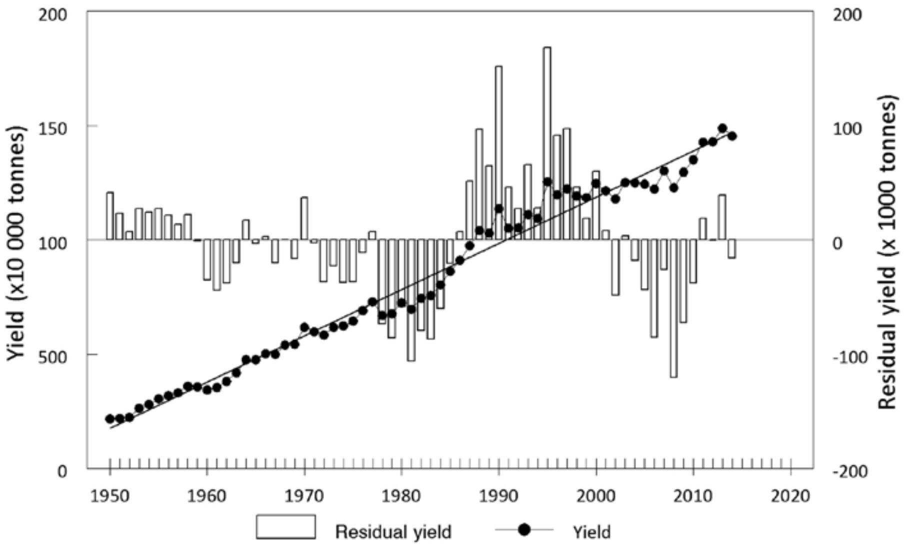
[3] Comparisons between Lake Malawi and Lake Victoria over the past 200 years generally show opposite trends consistent with the most typical patterns of rainfall anomalies that show strong opposition between equatorial and southern Africa in most years (Nicholson, 1998).

FIGURE 8
Total annual recorded yield (tonnes) from inland fisheries in 27 African countries comprising drylands[4] and the catch anomalies (residual yield, tonnes) showing an approximate 20 year periodicity around the trend.



Source: FAO FishStat (2016)

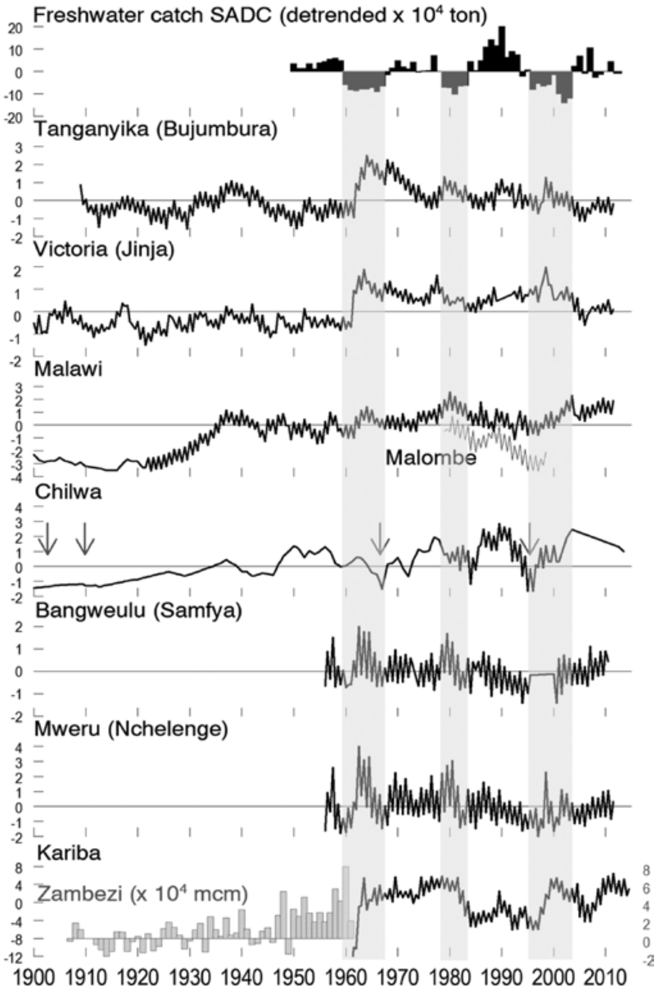


FIGURE 9

Relative water levels of lakes Tanganyika, Victoria, Malawi, Malombe, Chilwa, Bangweulu, Mweru and Kariba expressed as deviations from the long-term mean of annual mean levels over the period for which data were available. Light grey bars are the deviations of the 89 year mean annual total inflow of the Zambezi at Victoria falls (mcm = million cubic meters). Arrows indicate the years Lake Chilwa was reported to be dry. Lake Malombe is hydrologically considered a satellite of Lake Malawi: when water levels in Lake Malawi are low, Lake Malombe completely dries up. The top panel shows the variability around the trend of the total fish catches of the SADC region, with grey bars comparing periods of low catches relative to the trend.

Source: Adapted from Kolding *et al*. (2016).

[4] Angola, Botswana, Burkina Faso, Central African Republic, Chad, Egypt, Ethiopia, Gambia, Guinea, Guinea Bissau, Kenya, Lesotho, Madagascar, Malawi, Mali, Morocco, Mozambique, Namibia, Niger, Senegal, Somalia, South Africa, Sudan (former), Swaziland, Tanzania, Tunisia, Zambia and Zimbabwe.

However, upon refilling during years of good rains, the fishery immediately recovers and resumes very high productivity within a very short time – usually less than a year. At the moment, both Lake Ngami, which was dry from 1982 to 2002, and Lake Liambezi, which was dry between 1986 and 2009, are highly productive and characterized by outstanding fish yields (Keta Mosepele, pers. com.; Peel *et al*., 2015). Another human-made example is the Khasm el-Girba reservoir in Sudan, which is physically flushed and completely drained on an annual basis owing to siltation problems, causing massive fish kills in the process. Still, after refilling, the fish populations recovered rapidly (El-Thair and Kolding, 1995) and there is no evidence that the recurrent flushing had any significant impact on the species composition, demographic composition or potential yield. Similarly, the Kokologho reservoir (max. area 64 ha, 2.5 m depth) in Burkina Faso was completely drained in 1991 in order to enlarge the dyke. After only one hydrological cycle (in 1992) the recorded catch was a remarkable 170 kg/ha (Baijot *et al*., 1997).

2.2.1 Pulsed and stable hydrological systems

Jul-Larsen *et al*. (2003), in a series of case studies of Southern African Development Community (SADC) inland fisheries, examined the relationship between environmental variability and the ecological attributes of fish communities. The authors found that the interannual lake level changes indicated medium-term trends and persistence of conditions directly affecting the variation and resilience of fish stocks. On a shorter time scale, the intra-annual lake level fluctuations represented seasonality in productivity. The potential impacts of changing water levels in relation to the time scale and size of the aquatic ecosystem were summarized as follows:

- **Long-term trends and fluctuations** (including complete resetting of systems) acting on the composition and structure of whole fish communities.
- **Short-term trends and interannual fluctuations** operating on fish species within communities in the short-term, depending on lifespan and response of species to changes in externally driven lake productivity.
- **Variations in seasonal pulses** acting on the recruitment of species with short lifespans, triggering fish migrations and, being the starting point of the annual productivity pulse, the year-class strength of longer-lived fish.

By examining these different scales of temporal variability, the various systems were positioned within a general classification of lakes and reservoirs in terms of system stability (*sensu* Odum, 1969) and corresponding productivity (Jul-Larsen *et al*., 2003). In unstable fluctuating systems, such as dryland lakes and reservoirs, biological productivity – from algae to fish – essentially depends on the nutrients introduced or recycled by the annual flood regime, including the nutrient mobilization through flooding of lake margins or associated floodplains and swamps (Kolding, 1994; Baijot *et al*., 1997). Such systems are also called "allotrophic" systems (Rai, 1978) because they strongly depend on external nutrient loads and/or recurrent physical stirring and mixing for maintaining productivity. Seasonal inundations of the so-called ecotone, or aquatic terrestrial transition zone (ATTZ) – the portion of the littoral zone that fluctuates between wet and dry conditions – depends on seasonal water level fluctuations. Several studies have shown increased phosphorous mobilization following wet–dry cycles owing to the alteration of physical, microbial and chemical processes in the ecotone (Watts, 2000, Keitel *et al*., 2015). Thus, the changing set of linked inorganic chemical and bacterially mediated reactions (solution, oxidization, nitrification, denitrification, etc.) as a function of the fluctuating redox potential creates a particularly efficient nutrient transfer and leads to enhanced productivity (Junk *et al*., 1989; Kolding, 1993a; Wantzen *et al*., 2008). The water budget, monitored through water levels, can thus be used as a proxy for abiotically driven changes in productivity operating on a range of time scales (Kolding, 1992; Karenge and Kolding 1995; Jul-Larsen, *et al*., 2003; Kolding and van Zwieten, 2006). What this means is that fluctuations in water levels act as an efficient "nutrient" pump in the interface between land and water and such fluctuations strongly enhance biological production.

2.2.2 The relative lake level fluctuation (RLLF) index

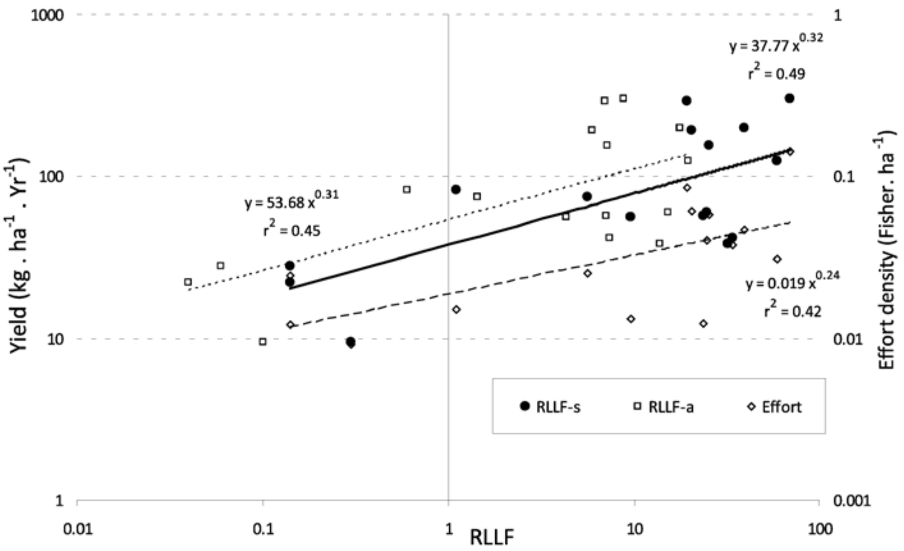
To capture these complex dynamics in a simple indicator, and building on previous work on the morpho-edaphic index (MEI) of fish production in lakes (Henderson and Welcomme, 1974), and the so-called "flood-pulse concept" in rivers (Welcomme, 1979, Junk *et al*., 1989), Kolding and van Zwieten (in Jul-Larsen *et al*., 2003) suggested a simple metric called the RLLF index. They defined it as:

$$\text{RLLF} = \frac{\textit{mean lake level amplitude}}{\textit{mean depth}} .100$$

The average interannual water levels (change in annual mean = RLLF-a) and the average seasonal pulse (RLLF-s) (see Table 1) are thus indices, both for the average interannual stability of a system and the average strength of the seasonal pulse with which different systems can be scaled and classified in terms of stability and productivity. In fact, the normalized water fluctuations represented by this index are strongly positively correlated with fish productivity and ecosystem resilience and negatively correlated with ecosystem maturity (Kolding and van Zwieten, 2012; Gownaris, *et al*., 2016b). Thus, the more the water level in the system fluctuates on a regular basis, the higher is the average productivity, which is clearly reflected in both average fish yield and the corresponding level of fishing effort in African lakes (Figure 10).

FIGURE 10

Standardized annual yield (kg·ha^{-1}·yr^{-1}) against mean seasonal RLLF-s, and mean annual RLLF-a for 16 African lakes and reservoirs[5]. Superimposed is the effort density (number of fishers ·ha 1) against the mean seasonal RLLF for these African lakes and reservoirs, except Lake Rukwa where effort data were not available. All regressions are highly significant (p < 0.01). Note the double logarithmic axes which make the relationship between yield and water level fluctuations exponential.



Source: Kolding and van Zwieten (2012).

In addition, by combining theoretical concepts of ecosystem maturity (Odum, 1969), disturbances (Kolding, 1997), biomass-size spectra (Sheldon *et al*., 1972; Kerr and Dickie, 2001) with environmental variability and forcing, Jul-Larsen *et al*. (2003) developed a generic conceptual model for the constellation and structure of fish communities in stable and pulsed systems (Figure 11).

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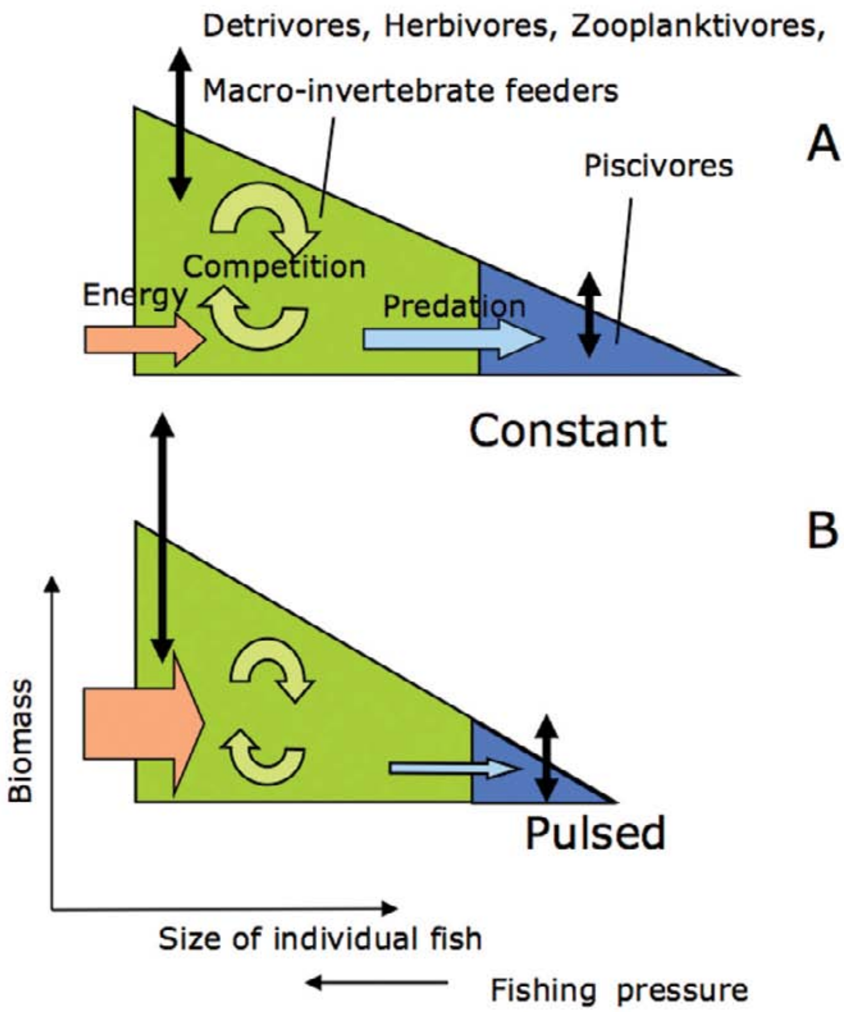
5. Lakes Kivu, Tanganyika, Malawi, Victoria, Edward, Kariba, Volta, Malombe, Naivasha, Mweru, Nasser/Nubia, Rukwa, Bangweulu, Chilwa, Chiuta and Kainji.

FIGURE 11

A generic conceptual model for aquatic communities in stable constant (A) and unstable pulsed (B) ecosystems, illustrated as biomass-size distributions, variability, and energy pathways. Triangles characterize fish communities by biomass and size (or trophic level) while variability (vertical arrows) and energy flow (horizontal arrows) indicate dominant mortality patterns (predation or abiotic). Biomass decreases with fish size and predatory fish (blue triangles) are generally larger than their forage prey. Energy flow through pathways starts from seasonal input of nutrients resulting in seasonal changes in productivity (red arrows). Energy in a fish community is partitioned through competition and predation (green and blue arrows). Variation in biomass caused by changes in energy input is larger with smaller-sized fish (black arrows). Increasing fishing pressure generally results in a decrease in biomass of large fish and increased catches of smaller fish.

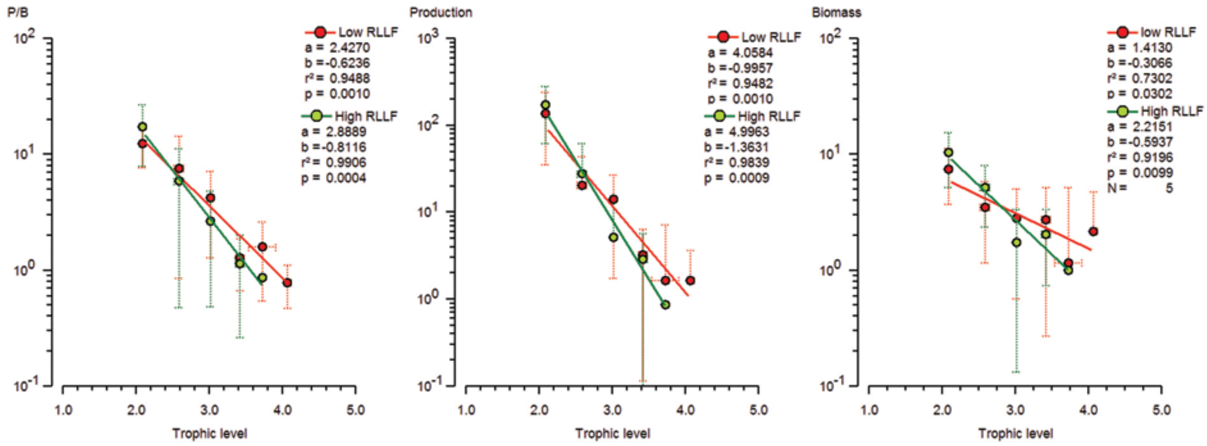


Source: Jul-Larsen *et al.* (2003)

To test the predictions of this generic model (Figure 11), we can use the comprehensive ecosystem and fish community data from the series of published Ecopath models of African lakes (Table 1), as well as the corresponding average RLLF values (Kolding and van Zwieten, 2012; Gownaris *et al*., 2016b). This is illustrated in Figure 12, where the lakes have been separated into two groups: stable (RLLF-a < 2.5) and pulsed (RLLF-a > 2.5). Figures 11 and 12 show that pulsed systems have steeper slopes and higher intercepts of the turnover rate (the so-called production to biomass ratio, P/B), as well as total production and total biomass (kg/km^2) as predicted. Large, long-living apex predators (high TL > 4) are generally absent from unstable systems.

FIGURE 12

P/B, total production and total biomass (kg/km²) of species or functional groups in relation to their average trophic level (binned in 0.4 TL intervals) in 12 African lake ecosystems. The low RLLF category represents systems with RLLF-a < 2.5 (n=8), while high RLLF systems have RLLF-a > 2.5 (n=6) (Table 1). Compare with Figure 11.



The shape (slopes and intercepts) of the biomass-size (or trophic level) distributions tells us something about the species resilience and susceptibility to fishing (Jul-Larsen *et al*., 2003). In general it can be said that highly vulnerable, slow growing, large fishes are on the right – and small, fast growing but not so susceptible fishes are on the left in a biomass–size distribution. In summary, unstable pulsed systems, such as dryland water bodies, are characterized by highly productive and highly resilient, small opportunistic species with "boom and bust" fluctuations. Such fish species are adapted to strong environmental disturbances and are therefore difficult to overfish. Owing to their high productivity (P/B) they can produce very high yields in years of good rains, but because they also respond rapidly to changes in the climate driven hydrological regimes (Sarch and Allison, 2000) alternating periods of low productivity during droughts are expected. The exact processes by which fish rapidly "return" or recover in systems where a serious "bust" has taken place are still unclear. In some places, broodstock is assumed to migrate up tributaries when desiccation of water bodies or flushing of reservoirs begins; in other instances broodstock is thought to bury in the sand/mud, while in other cases fish are observed to migrate with the flood water. In some cases, there might be a need to restock small water bodies/reservoirs when these are being refilled. In any case, because of these uncertainties, specific measures (like not draining a reservoir completely, or allowing connectivity between areas under pressure and other water bodies) might be necessary to secure the "boom" after a bust.

The literature and data reviewed here show that climatic driven rainfall patterns, reflected in water level fluctuations, have a significant impact in African lakes and reservoirs and that this impact is inversely proportional to the size and depth of the system. In general, system productivity seems to increase with increased instability (increased RLLF, Figure 10) and there are no signs of decreasing trends within the ranges so far examined. Some of the most productive African lakes, such as Lake Chilwa and Lake Chad, are in fact behaving more like floodplains than lakes. Human-made reservoirs are generally more productive than natural lakes (Marshall, 1984), but usually also fluctuate more because of drawdowns for electricity or irrigation purposes. Actually, the most productive reservoirs in the data reviewed by Kolding and van Zwieten (2012) have regular drawdowns that exceed the mean depth of the system. This shows that the resilience and regenerative rate of fish populations in unstable tropical systems, such as drylands, is phenomenal. On the other hand, people living in such environments must adapt to boom and bust situations because resources are unstable and largely unpredictable.

The overall conclusion is that the potential for increasing fish production in dryland areas is significant, that the resources are highly resilient and productive, but that a general and increasing unpredictability in the pattern of rainfall necessary to sustain surface water bodies imposes uncertainties in annual production levels. Such uncertainty must be counteracted by an adaptive and diversified livelihood strategy (Little *et al*., 2001; Barret *et al*., 2001).

2.3 Fish resources

Africa as a whole is well endowed with fisheries resources from the sea and inland waters (rivers, floodplains, lakes and reservoirs). Africa is also a continent in which aquaculture is expanding rapidly and where the potential for increased fish production is considerable. Many of the countries in Africa with large dryland areas, such as Egypt, Ghana, Kenya, Namibia, Nigeria, Senegal and Uganda, also produce large quantities of fish (see Table 2) which are traded locally, preserved and transported to regional and international markets. Other countries that do not have drylands also produce fish that are traded into dryland areas and contribute significantly to food security and nutrition in those areas. Whilst it is recognized that statistics on fish capture and trade are limited and underestimated in Africa – 61 percent of countries did not provide adequate catch statistics to FAO in 2009 (Garibaldi, 2012) – the value of fish in the diet of people across the continent is well known from specific country studies.

Although drylands are characterized by their low AI, many areas also support lakes, rivers and underground water resources, and some are subject to periodic floods. In addition, there is increased construction of small dams and reservoirs in order to store and preserve runoff water during the short, but often intense rainy season. Many dryland countries are supplied with fish from the lakes and rivers that are enclosed by dryland areas. For instance, the lakes Chad, Malawi, Tanganyika and Victoria, and the rivers Gambia, Niger, Nile and Senegal, all contribute significantly to inland fisheries landings. In addition, there are numerous ponds, floodplains, swamps and seasonal water bodies that contribute fish to the overall diet of people living in dryland areas.

Box 3: Small reservoir fisheries in Burkina Faso

Burkina Faso has important fisheries resources associated with more than 1 000 small reservoirs, built primarily for water harvesting and scattered throughout the country.

All reservoirs are small, with dykes less than 8 m high, a maximum storage capacity of 30 mcm, usually covering less than 100 ha at maximum capacity and as small as a few hectares at drawdown. Annual water level fluctuations are 2 to 3 m of amplitude and the shallowness of the reservoirs can make the ratio between maximum and minimum capacity as much as an order of magnitude.

The evaporation rate is high (around 2 m during the dry season), which means that any reservoir shallower than 2 m dries out completely almost every year. Fish production is determined by the hydrological regime; in years with good rains production increases significantly and vice versa. Severe ecological conditions caused by drought are identified as the main constraint to fish production. In some cases, regular seasonal restocking may be necessary to increase production. However, restocking is most successful if predatory fish are absent or reduced prior to the release of fingerlings. Catches from small reservoirs consist mainly of hardy species such as tilapia species and the African catfish (*Clarias gariepinus*) and vary between 60 to 120 kg/ha, which is consistent with larger artificial lakes in Africa.

Source: Baijot *et al*., 2012

2.3.1 Small water bodies and reservoirs

Although only 5 percent of the world's dams are located in sub-Saharan Africa (ADB *et al*., 2008) thousands of small reservoirs dot the rural landscape (Marshall and Maes 1994; Venot *et al*., 2012). In southern Africa, about 20 000 small water bodies have been identified, covering a total area of 25 million hectares (ALCOM, 1994[6]). With a conservative estimate of an average annual fish production of 50 kg/ha, this area alone would produce around 1.25 million tonnes of fish, or nearly half the total recorded inland fisheries yield from Africa[7]. In semi-arid Burkina Faso, for example, some 1 400 dams have been built

6. The ALCOM programme database contains more than 18 000 reservoirs, lakes and swamp in the SADC region, and the river database contains more than 40 000 river segments. See also Jenness *et al*. (2007).

7. The reported catches are most likely seriously underestimated, see section 3.3.

to create water reservoirs, ranging in size from one to 25 000 ha, and contributing some 82 percent of the nation's surface water (Melcher *et al*., 2012; Box 3). Small reservoirs support and enhance synergies between multiple livelihood strategies and cushion seasonal variability in access to water. They have long attracted development and donor interest because they provide vulnerable communities in drylands with a buffer against droughts, allow for livestock watering and extend the growing season through irrigation. When used for livestock watering, which results in dung deposits around their edges, reservoirs are usually eutrophic with high nitrate (NO_3^-) and phosphate (PO_4^{3-}) levels and therefore potentially very productive. For example, the small reservoirs in Burkina Faso are richer in mineral concentrations than large artificial lakes, but less stable (Baijot *et al*., 1997). Although fisheries resources are often neglected in relation to small reservoirs, they can provide important protein yields in the order of 150 kg/ha or more (Marshall and Maes 1994; van der Mheen, 1994; van der Knaap 1994; Kolding *et al*., 2016). However, the importance of fish for sustainable and healthy livelihoods in Africa, and in particular the importance of small fish from the multitude of small water bodies and reservoirs, as well as their strong relationship with climate-driven water dynamics, are generally undervalued and little understood because most are consumed locally and go unrecorded in catch statistics (Kolding *et al*., 2016).

2.4 Fish production

Total fish supply in Africa in 2011 was 9 million tonnes (FAO, 2012) made up of 84 percent capture fisheries and 16 percent aquaculture – although the production of inland capture fisheries is thought to be considerably underestimated. After Asia, Africa is the second largest producer of fish from inland waters, with production reported to be 2.6 million tonnes per year; Lake Victoria alone produces 1 million tonnes (Kolding *et al*., 2014b). However, Kolding *et al*. (2016) estimated the actual total inland catches to be significantly higher (around 20 million tonnes), based on the total area of freshwater resources (lakes, rivers, reservoirs, floodplains and swamps) on the continent of around 1.3 million km^2 (Lehner and Döll, 2004; de Graaf *et al*., 2012) with an average annual production of fish of around 150 kg/ha (van der Knaap, 1994; Marshall and Maes, 1994; Kolding and van Zwieten, 2006). It is highly probable that the official production records are underestimated by nearly an order of magnitude. Production in landlocked dryland countries, such as Burkina Faso, Mali and Niger, has grown as a result of production from the Niger and Senegal rivers, although the recorded levels of production are much less significant than those of coastal countries (Ndiaye, 2013). Table 2 provides data on selected countries with significant dryland areas.

2.4.1. The importance of small fish.

The most productive African fisheries all target small fish species weighing between one and a few grams. The "Kapenta" (*Limnothrissa miodon* and *Stolothrissa tanganicae*) fishery in lakes Tanganyika, Kariba, Cahora Bassa and Kivu, is the most important in all these lakes. Likewise the "*Chisense*" (a mixture of *Potamothrissa acutirostris*, *Microthrissa stappersii* and *Poecilothrissa moeruensis*) fishery in lakes Mweru, Bangweulu and Mweru-Wa-Ntipa; the "*Usipa*" (*Engraulicypris sardella*) and "*Kambuzi*" (many small demersal haplochromine species) fisheries in lakes Malawi, Chilwa and Malombe; the "*Dagaa*", "*Omena*" or "*Mukene*" (*Rastrineobola argentea*) fishery in Lake Victoria; the "*Mazeze*" (mainly small sized cyprinids) fishery in the Okavango Delta; and the similar "*Kapesa*" fishery in the Bangweulu swamps (Figure 13) are all high yielding, extremely important for local consumption and most go unrecorded in official catch statistics. Post processing and conservation is straightforward and fuel conserving because these species are simply sundried in a few days, in contrast to larger fish that need gutting, salting or smoking for preservation. The simple preservation techniques and ease of storage and transportation make these small fish species available at most African markets at low cost. They are sold in small portions by weight, fetching the same price as large fish (Brummett, 2000) and thus are highly accessible. Heaps of small fish are ubiquitously found on local markets far from their place of capture (Figure 13): *Dagaa* from Lake Victoria are found all over the riparian countries (Hoffman, 2010); Lake Mweru *Chisense* and Lake Kariba *Kapenta* are found in all large cities in Zambia and southern Democratic Republic of Congo (Overå, 2003; IOC, 2012). Because small fish are sundried whole, with heads, bones and internal organs in tact, they are a concentrated source of multiple essential nutrients, in contrast to large fish which are usually not eaten whole, are filleted and therefore do not contribute as much to micronutrient intake (Longley *et al*., 2014).

TABLE 2
Marine, inland and aquaculture production (2009) in selected countries in Africa with significant drylands (tonnes)

	Marine production	Inland production	Aquaculture production	Total production
Egypt	121 362	263 847	919 585	1 304 794
Nigeria	323 599	293 382	200 535	817 516
South Africa	623 020	900	3 133	627 053
Uganda	0	413 805	95 000	508 805
Senegal	375 414	34 164	78	409 656
Namibia	367 200	2 800	545	370 545
Ghana	261 205	90 000	10 200	361 405
Tanzania	49 438	293 043	454	342 935
Mauritania	261 238	15 000	n/a	276 238
Kenya	8 264	134 847	12 154	155 265
Mali	0	100 000	2 083	102 083
Malawi	0	98 299	3 163	101 462
Sudan	5 700	66 000	2 200	73 900
Chad	0	40 000	n/a	40 000
Somalia	29 800	200	n/a	30 000
Niger	0	29 884	70	29 954
Ethiopia	0	18 058	25	18 083
Burkina Faso	0	14 520	300	14 820

Source: FAO Yearbook of fisheries and aquaculture statistics, 2010

PLATE 1
Left: *Kapesa* (mixture of small fish, mainly cyprinids) being sundried in Bangweulu swamps, Zambia. Right: Sundried *dagaa* (*Rastrineobola argentea*) at a local market, Tanzania

Photo: Carl Huchzermeyer

Photo: Modesta Medard.

2.4.2 Aquaculture

The aquaculture industry in Africa has a very long history but also a slow incubation period (Hara, 2001). Governments, international organizations and NGOs have since the early 1970s implemented aquaculture development programmes in rural Africa, particularly under the umbrellas of FAO and ALCOM (Box 4), and the International Centre for Living Aquatic Resources Management (ICLARM)/WorldFish (Hecht *et al.*, 2005). Between 1970 and the 1990s, generally regarded as the "golden age" of donor support for the sector, the development was facilitated by increased technical and financial assistance from multilateral and bilateral donors amounting to around US$ 500 million (Coche *et al.*, 1994). None of these investments, however, have ever had the desired outcomes and their sustainability remains uncertain (van der Mheen, 1999).

TABLE 3

Aquaculture production in Africa (tonnes) by year

REGION	1970	1980	1990	2000	2009	2010	2012
AFRICA	10 271	26 202	81 018	399 676	991 183	1 288 320	1 485 367
SUB-SAHARAN AFRICA	4 243	7 048	17 184	55 690	276 906	359 790	454 691
NORTH AFRICA	6 028	19 154	63 831	343 986	714 277	928 530	1 030 675

Source: The state of world fisheries and aquaculture (SOFIA), 2014

Africa produced 1.5 million tonnes of fish from aquaculture in 2012, but most of this came from Egypt, with less than 500 000 tonnes produced in sub-Saharan Africa. This represented an increase from 1.2 to 2.2 percent of global production over a period of ten years, mainly as a result of the development of freshwater fish farming (Table 3). In sub-Saharan Africa the contribution by aquaculture to gross domestic product (GDP) is negligible, ranging from 0.001 to 0.715 percent (Hecht *et al.*, 2005).

African aquaculture production is overwhelmingly dominated by finfishes (99.3 percent), with only a small fraction of production from marine shrimps and molluscs. Major aquaculture producers include Egypt, Nigeria, Zanzibar, Uganda, Ghana, Kenya, Zambia, Tunisia, Zimbabwe, and Tanzania. Production from Egyptian aquaculture has grown rapidly since 1997, to more than 1.1 million tonnes in 2014. Tilapia and carp comprise 83 percent of that country's aquaculture production (Goulding and Kamel, 2013). From an initial focus on low-input pond culture, there is now increasing emphasis on high-density re-circulating systems (in Nigeria and South Africa) and open water cage culture is expanding rapidly. The

Box 4: ALCOM

The Aquaculture for Local Community Development Programme (ALCOM) programme was a large programme in southern Africa (primarily Botswana, Lesotho, Malawi, Zambia, Zimbabwe and Tanzania) that was implemented from 1986 to 1998 and supported primarily by Sweden (initially), Belgium (later) and FAO.

Initially it was dedicated to implementing small-scale aquaculture in rural communities, but later it expanded to also investigate the utilization of small water bodies (SWB), such as dams and stock-watering reservoirs, for aquaculture and fisheries production. Many small reservoirs had been built in southern Africa (by the end of the project the ALCOM database included more than 18 000 reservoirs, lakes and swamp in the SADC region), but fish production was usually a secondary function.

Unfortunately, owing to disjointed funding and programmatic restructuring, the ALCOM programme was not brought to a satisfactory conclusion and many of the results have never been published or disseminated (FAO, 1999). Most of the activities initiated under ALCOM collapsed shortly after the programme terminated.

Source: van der Mheen (1999); FAO (1999) non-commercial small-scale sector makes an insignificant contribution to fish supply in the region but makes an important contribution to household or community livelihoods. However, the non-commercial sector is unlikely to make any significant contributions to national protein supply in any of the target countries in the short- to medium-term (Hecht *et al.*, 2005). The main reasons for the failure of aquaculture to develop in Africa have been identified as a failure to adopt the appropriate technology; a lack of sustainability; and the fact that the target beneficiaries (of development projects) have usually been rural resource-poor farmers (FAO, 1999). In retrospect, however, it appears that aquaculture in sub-Saharan Africa has had difficulties in competing economically with the capture fisheries, the production of which continues to rise steadily by about 3.7 percent per year (Welcomme and Lymer, 2012, Figure 8) even though catches are probably underestimated by nearly an order of magnitude (Kolding *et al.*, 2016).

Given the massive support and technical assistance that has been provided for the implementation of small-scale aquaculture in rural communities in sub-Saharan Africa, with largely negligible results (Box 5), and the current shift towards intensive, highly technological commercial enterprises aimed at supplying a growing urban market, there is little optimism among aquaculture experts that small-scale aquaculture in dryland areas will become economically feasible, contribute to food security or improve the resilience of vulnerable rural communities (van der Mheen, 1999; Hecht *et al.*, 2005; Morten Frost Hoyum, pers. comm.).

Box 5: Aquaculture in Malawi

Malawi has a total land area of 118 500 km^2 of which 20 percent is water. Approximately 10 to 25 percent of the total land area, or 11 650 km^2, is suitable for aquaculture (Brooks, 1992). There are currently over 4 000 registered fish farmers who own 9 500 fishponds. However, the vast majority of fish farmers belong to a category that have ponds but receive only minimal production from them and in almost all cases fish farming forms part of a variety of activities that are combined to maximize food security. The sector is currently contributing insignificant amounts of fish on a national level (less than 1 percent) as compared to the capture fisheries. The average production is 7.5 kg/pond, corresponding to 700 kg/ha or around 12 kg/year per farmer. Based on the number of ponds or farmers, the total annual production in Malawi was estimated to be between 50 to 75 tonnes/year in 2003.

Aquaculture fish production consists of 93 percent tilapia (*Oreochromis shiranus*, *Oreochromis karongae* and *Tilapia rendalli*) 5 percent catfish (*Clarias gariepinus*) and 2 percent exotic species such as common carp, black bass and trout. The most commonly used production system is low-input integrated aquaculture, using polyculture of mainly *Oreochromis shiranus* and *Tilapia rendalli. Clarias gariepinu*s is sometimes included.

Source: Andrew *et al.*, 2003

The main constraints for aquaculture in arid rural areas can be summarized as i) lack of reliable water resources; ii) lack of affordable feed ingredients; and iii) stunted growth as a result of oxygen limitations.

i. The generally irregular rainfall and the high annual evaporation rate that characterize dryland areas mean that ponds and reservoirs for aquaculture that are less than about 2 m in depth need to be replenished by groundwater supplies, otherwise they would dry out during the dry season. Thus, without adequate groundwater aquifers and reliable pumping systems, or backup dams, the risk of losing fish from seasonal desiccation is high. As water management in agriculture is a story of intensifying competition, it is also an open question whether available water resources are best used for crop irrigation or fish culture.

ii. Feed availability, quality, distribution and acceptable food conversion ratios remain major constraints to both non-commercial and commercial producers in sub-Saharan Africa (Hecht *et al.*, 2005). Fish are not adapted to utilize grain or cereals (carbohydrates) efficiently because these are not a natural part of aquatic ecosystems, as they are on land. Fish and crustaceans are therefore, by and large, carnivores and require a very high percentage of protein and oils in their feed (Tacon and Metian, 2015). Even so-called herbivorous and omnivorous species, such as tilapia, have on average nearly

40 percent protein and oils in their formulated commercial feed, which is around two times more than intensively reared pigs and chicken. The composition of fish feed for aquaculture is therefore high in protein and oils, and very low in carbohydrates. This makes fish feed very expensive to produce because it is largely dependent on imported raw materials. In general, fish farmed on a small scale in Africa have difficulty competing economically with wild captured fish (Béné *et al.*, 2009). The increasing use of small, locally caught pelagic fish species in commercial aquaculture feed, such as the use of *Dagaa* (*Rastrineobola argentea*) in Lake Victoria – a very important source of protein for many households in the region – was noted as a serious concern for participants at the New Partnership for Africa's Development (NEPAD)-FAO Fish Programme (NFFP) event at the 2014 Committee on Fisheries (COFI) meeting in Rome. In contrast to expensive high protein feed used by commercial aquaculture producers, non-commercial, small-scale farmers generally use different types of brans, vegetable matter, household kitchen waste, termites and a variety of crude farm-made feeds and rely heavily on natural productivity enhanced by the use of green compost cribs or animal manure (Hecht *et al.*, 2005). Such feed, however, results in very low production rates (Box 5) that cannot compete with capture fisheries in terms of returns on invested labour and capital inputs (Béné *et al.*, 2009).

iii. The concentration of dissolved oxygen in water is around 30 times less than it is in air, and the solubility decreases with increasing temperature. Stagnating, warm water therefore generally has very low oxygen concentrations, and this is particularly true for turbid eutrophic ponds or reservoirs enriched with kitchen waste and/or manure. For example, in the small reservoirs of Burkina Faso, recorded levels of oxygen vary greatly during the day and between seasons (Baijot *et al.*, 1997). Usually, the lowest concentrations of around 2.5 mg/l (approximately 25 percent saturation) are recorded in the mornings and during the rainy season. Differences between morning and afternoon are high (from 4 to 8 mg/l) owing to respiration and photosynthesis of the phytoplankton, and the water column becomes strongly stratified with super-saturation at the surface. Fish growth in such environments is significantly constrained by oxygen limitations (Kolding, 1993a; Kolding *et al.*, 2008), which is also one of the reasons that open water cage culture has gained increasing prominence instead of ponds. Small-scale fish farmers using ponds with stagnating water have serious problems because their attempts to enhance growth by adding decomposable feed ingredients or organic nutrients to the water has the reverse effect of stunting growth because this results in insufficient oxygen concentrations. The more eutrophic the ponds are, the more energy the fish use for respiration instead of growth. Small-scale aquaculture in ponds therefore easily ends up in a vicious cycle where increased feeding, with the aim of increasing growth, has the opposite result: stunted growth because of increased hypoxia.

In summary, as history has shown (van der Mheen, 1999; FAO, 1999), it is highly doubtful whether small-scale aquaculture will be a viable option for improving protein production in dryland environments, compared to traditional terrestrial animal husbandry. However, culture-based capture fisheries in which restocking takes place or species are introduced to small dryland reservoirs can be effective methods of increasing fish production in reservoirs with diminished fish populations or after severe droughts (van der Mheen, 1994). Baijot *et al.* (1997) reviewed and compared the establishment of fish populations in newly created small reservoirs across the Sahel, and found that the evolution of fish communities with indigenous and/or introduced species is more or less similar. Nearly all of these reservoirs were successfully populated by small cyprinids (*Barbus* and *Labeo*) and characids (*Alestes* and *Micralestes*); tilapia species (*Oreochromis niloticus*, *O. mossambicus*, *O. gallilaeus* and *Tilapia zilli*); mormyrids and gymnotids (*Marcusenius* spp.); and catfish (*Clarias*). Deeper reservoirs and lakes would sometimes accommodate larger predators such as tigerfish (*Hydrocynus* spp.), Hepsetus and Nile perch (*Lates niloticus*). In water bodies that did not dry out completely, the introduction of *O. niloticus* was always successful (Beijot *et al.*, 1997). Even shallow lakes and reservoirs, which regularly dry out almost completely, are still able to support viable populations of hardy species such as *Clarias spp.* because these species are able to survive buried in the mud, or will usually be the first species to populate new inundations through tributaries or even move over land for short distances (Huchzermeyer, 2013).

3. Contribution to food security and nutrition

There is no question that fish contributes significantly to nutrition and food security (Béné *et al*., 2016). Fish and fishery products represent a valuable source of nutrients of fundamental importance for diversified and healthy diets. Fish are low in saturated fats, carbohydrates and cholesterol, and not only provide high-value protein, but also a wide range of essential micronutrients, including various vitamins (D, A and B), minerals (including calcium, iodine, zinc, iron and selenium) and polyunsaturated omega-3 fatty acids − which are important for optimal brain and neurological development in children. Small sized fish species that are consumed whole, with heads and bones, can be an excellent source of many essential minerals such as iodine, selenium, zinc, iron, calcium, phosphorus and potassium, but also vitamins such as A and D, and several vitamins from the B−group (Kawarazuka and Béné 2011; HLPE 2014; Longley *et al*. 2014; Béné *et al*., 2016). Nutritional value is particularly important in sub-Saharan Africa where approximately 28 percent of all deaths are attributed to malnutrition (Benson, 2008). Fish forms a vitally important part of food security and nutrition and makes up on average 19 percent of total animal protein supply in Africa. This varies across the continent with fish making up over 50 percent of animal protein in Equatorial Guinea, the Gambia, Ghana and Sierra Leone. However, in many areas of sub-Saharan Africa fish consumption levels remain too low and some countries are failing to benefit from the contributions that fisheries and aquaculture are increasingly making elsewhere in terms of sustainable food security and income (FAO, 2012).

The fish consumed in dryland areas consists of a combination of fish landed and processed in coastal areas that are transported to the drylands for sale, such as Namibia horse mackerel (Sen, 1995; Hara, 2001); fish that are caught locally in the drylands; and fish that are farmed locally. In some cases fish may also be imported from outside the region. Average per capita fish consumption in Africa is 9.7 kg/year, roughly half the global average (FAO, 2014). However, even when per capita fish consumption is low, small quantities of fish can have a significant positive nutritional impact by providing essential amino acids, fats and micronutrients that are scarce in vegetable-based diets (FAO, 2012; WFP, 2012c).

TABLE 4

Per capita fish availability in selected countries with significant dryland areas (average 2008 to 2010)

Country	Per capita supply (kg)	Country	Per capita supply (kg)
Senegal	27.0	South Africa	5.7
Ghana	24.8	Tanzania	5.7
Egypt	18.6	Chad	3.7
Nigeria	14.9	Burkina Faso	3.5
Uganda	13.2	Kenya	3.4
Namibia	11.7	Somalia	3.1
Mauritania	9.2	Niger	2.2
Malawi	5.3	Sudan (former)	1.8
Mali	7.9	Ethiopia	0.2

Source: FAO Yearbook of fisheries and aquaculture statistics, 2013

Per capita fish consumption has remained static or decreased in some countries in sub-Saharan Africa (e.g. South Africa, Gabon, Malawi and Liberia) but increased in North Africa (from 2.8 kg in 1961 to 10.6 kg in 2009). In the future, it is predicted that per capita fish consumption will increase on all continents, except Africa (owing to population growing faster than supply) (Béné and Heck, 2005). The anticipated decline in per capita fish consumption is of particular concern because fish tends to be the lowest priced animal protein across much of Africa. This trend suggests that the nutritional quality of the overall diet is declining, particularly in sub-Saharan Africa (World Bank and FAO, 2009). Figures of fish availability in some dryland countries are shown in Table 4.

Table 4 clearly demonstrates the enormous variability of supply within these countries and the scope for increased per capita availability. In some countries falling supply has been quite profound. In Malawi, for example, low total fish landings have led to per capita consumption falling from 13 kg/person/year in the 1980s to 5.3 kg/person/year in recent years (Banda *et al*., 2010).

The transportation of fish into dryland areas is poorly documented but fish is widely recorded as being part of dryland diets. In northern Kenya, for example, fish is an important food source among pastoralist people who have lost their livestock to droughts or are refugees from war-torn southern Sudan (USAID and FEWSNET, 2011). In Chad it is reported that in households where fish are caught, food insecurity is lower (WFP *et al*., 2012).

In some locations fish is turned into a sauce where it is used in small quantities to provide flavour to other foods, thus allowing a small amount of fish to supplement the diets of many people e.g. in Burkina Faso (FAO, 2008b). Fish is also a source of emergency food aid − although in 2003 this was reported to be very small (Murphy and McAffee, 2005). In northeast Kenya it was found that even with food aid, malnutrition among the young was high, but when imported food was replaced by locally sourced food, including fish, nutrition was improved and the sourcing stimulated local markets (Save the Children, Nd.). Somalia has a 3 300 km coastline yet the people of Somalia eat very little seafood. The country's per capita fish consumption is one of the lowest in the world (http://www.wfp.org/node/3584/3413/582064). The fish resources are under-utilized and FAO has started a campaign and initiated pilot activities to encourage displaced families and local youth living in and around Dolow and Jowhar to start including fish in their diets.

3.1 Livelihoods

There are around 6.1 million fishers and 0.9 million aquaculture workers in Africa (de Graaf and Garibaldi, 2014). This is about 5 percent of the total 120 million full-time or part-time fishers globally (Kolding *et al*., 2014b). In addition, about 5.2 million people work in the post-harvest sector, meaning total employment in the fisheries sector Africa is some 12.3 million people, or 7 percent of the global total. When dependents are also considered, some 50 million people depend upon fisheries for their livelihood. However, most small-scale fishers in Africa, and particularly in dryland areas, usually combine fishing with other activities such as farming or animal husbandry (Baijot *et al*., 1997; Sarch and Birkett, 2000; Kolding *et al*., 2016; Box 6). Africa showed the highest annual increase (5.9 percent) in the number of people engaged in fish farming in the period 2000 to 2010 (FAO, 2012), although the actual success in increased production remains uncertain (see section 3.3). Even in countries with relatively small fisheries the employment provided by fisheries and aquaculture can be significant, e.g. in Burkina Faso 20 000 people are engaged in harvesting, processing and trading fish (FAO, 2008b).

Of the 3.4 million women working in fisheries and aquaculture[8], 91.5 percent are employed in the post-harvest subsector, 7.2 percent work as fishers and 1.3 percent are employed in aquaculture (de Graaf and Garibaldi 2014). Most of the people involved in the sector work at a small-scale level of operation using rudimentary levels of technology and that makes them particularly susceptible to extreme weather events and other threats.

As is seen in many parts of the world (Whittingham *et al*., 2003) the dependency of households on fisheries is highly variable. Some depend upon fishing all year round as their main source of food, income and employment. Most, however, make fishing part of a diversified set of livelihood activities. For some it is a key resource that they use at certain times of the year or as a safety net when other livelihood activities fail. Furthermore, because migration has always been a significant strategy in dryland areas, marine and freshwater

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8. 27.3 percent of total employment

fish production systems, both in and adjacent to dryland areas, can be seen as a safety net for displaced people that lose access to traditional livelihood assets (Box 6).

3.2 Processing, handling and trade

Fish not only contributes to local consumption; across the drylands, fish is transported from areas of abundance to areas of scarcity. Regional trade continues to be important even though it is not always adequately reflected in official statistics. Improved domestic distribution systems for fish and fishery products have played a role in increasing regional trade, as has growing aquaculture production (see Box 7). For example, in the period 2008 to 2010, 45 percent of the fish (by value) imported into the Central African region[9] came from the West African region (FAO, 2010). The IOC (2012) describes some of these complex trading links between production systems and internal markets.

Fish is also a key part of Africa's trade with the rest of the world and is a vital source of foreign exchange (see Table 5). By value, Africa has been a net exporter of fish since 1985, but it is a net importer in quantity terms, reflecting the lower unit value of imports (mainly for small pelagic species). While the evidence of the role that international trade in fish plays in food security in Africa is inconclusive (Béné *et al*., 2010, 2016), a redirection of fish that are traded internationally has the potential to substantially increase fish availability within Africa, especially in the drylands (Hara, 2001). The potential for regional trade within Africa is recognized as being considerable (Ndiaye, 2013) but is hampered by a

Box 6: The fishers of Lake Turkana, Kenya

The people fishing in Lake Turkana, the largest desert lake in the world, are generally from the Turkana and Dassanech ethnic groups, with some Lou emigrants from Lake Victoria. About half of the indigenous inhabitants are fully settled, 40 percent are nomadic and 10 percent migrant labourers. The main economic activities are animal husbandry and fishing. Culturally, the fishing community is still very much a part of the pastoralist community, though many have lost their livestock to droughts and fishing has become a necessary activity.

Those who succeed and make a profit in fishing usually reinvest in livestock and return to pastoralism. Relative wealth is determined by the number of livestock owned as well as access to boats, nets and lines for fishing. However, the fishery is not very well developed. Most fishing is done using simple lines and nets set from rafts or plank boats, or by beach seining. The fish trade is inhibited by outdated infrastructure and the prices achieved by the fishers are low. Lake Turkana is the least exploited of the great lakes of Africa, but the future of the fishery is uncertain owing to the possible impacts of the Gibe III dam on the Omo River in Ethiopia, which supplies 90 percent of the water that flows into the lake.

Source: Kolding, 1989 and Gownaris *et al*., 2016a

Box 7: Fish trade in the Lake Chad basin

There are two major components to the fish trade in the Lake Chad basin. One is a local trade within each country, with fishers and local merchants supplying both fresh and some processed fish to local markets within villages and towns. This trade does not involve long distance or cross border transportation and occurs in close proximity to fishing grounds and landing sites.

The second component of the fish trade involves long distance cross border transportation of processed (smoked or sundried) fish to markets located far away from fishing grounds. For example, a large proportion of fish products from Cameroon, Niger and Chad are moved by their nationals into Doro Baga fish market in Nigeria on a weekly basis. From Doro Baga, the fish product is trucked to distant southern Nigeria and the wholesale/retail fish markets of Onitsha, Enugu, Lagos, Ibadan, Ilorin, Benin and Ondo. About 80 to 90 percent of the fish products from the Lake Chad basin end up in southern Nigeria.

Source: Olvie and Emma, 2012.

9. Including Angola, Cameroon, Central African Republic, Democratic Republic of Congo, Republic of Congo, Equatorial Guinea, Gabon and São Tomé et Príncipe.

number of constraints. Principal among the barriers are poor transportation networks; cumbersome import and export procedures and border crossing problems; limited use of information and communication technology; limited involvement of the private sector in the design of programmes intended to raise intraregional trade; and poor trade settlement systems and financial encumbrances (Ekra, 2010).

TABLE 5

The amount (tonnes) and value (US$1 000) of fish exports and imports from selected African countries (2013)

	Exports		Imports	
Country	**Tonnes**	**USD 1 000**	**Tonnes**	**USD 1 000**
Nigeria	86 119 *	283 390	885 043 *	1 213 562
Ghana	21 846	53 752 *	356 097	373 034
Cameroon	2 605 *	1 758 *	170 521 *	220 415 *
South Africa	135 079	517 873	138 975	364 991
Angola	3 220 *	17 304 *	100 553 *	290 092 *
Benin	481	376	85 932	39 189
Burkina Faso	2 160	650	63 705	10 702
Morocco	529 409	1 817 852	53 427	161 979
Mozambique	9 463	43 431	45 671	94 393
Zambia	1 078	860	35 740	55 167
Namibia	404 498	784 565	24 341	46 184
Mali	389 *	155 *	21 942 *	13 210 *
Gabon	538 *	2 017 *	18 749 *	40 715 *
Zimbabwe	3 258	8 790	18 689	30 658
Kenya	11 710	39 044	15 850	15 535
Equatorial Guinea	24 *	46 *	12 092 *	29 384 *
Tanzania, United Rep. of	36 113	80 967	9 287	5 894
Senegal	149 917	288 730	8 913	19 283
Liberia	98 *	541 *	6 828 *	7 414 *
Central African Republic	0 -	0 -	4 954	2 609
Niger	1 282	1 123	4 856	2 277
Botswana	254	523	4 450	11 709
Mauritania	261 949	353 003	3 142	958
Sudan	202 *	422 *	3 043 *	7 572 *
Burundi	158	320	3 015	2 478
Somalia	1 256 *	1 083 *	2 004 *	11 489 *
Malawi	23	254	1 925	2 241
Guinea	9 645	8 036	1 916	2 515
Sierra Leone	5 420 *	10 812 *	1 371 *	3 390 *
Ethiopia	798	406	1 237	3 836
Uganda	20 835	125 590	1 036	2 408
Chad	66 *	53 *	729 *	1 173 *
Guinea-Bissau	4 579 *	3 102 *	562 *	1 266 *
Eritrea	4 *	115 *	28 *	137 *
Total	**1 704 476**	**4 446 943**	**2 106 623**	**3 087 859**

* = FAO estimate, updated 2016. Available at: http://www.fao.org/fishery/statistics/software/fishstatj/en

Fish perish easily and post-harvest fisheries losses in Africa are often substantial. NEPAD estimates that annual fish losses are between 20 percent and 25 percent of fish landed in Africa, equivalent to some 2 million tonnes of fish per year. Losses can involve physical weight loss, a loss of nutritional value, particularly from smoking (Stolywho and Sikorski, 2005), contamination and other quality losses or value loss. In part, this is due to the high perishability of fish but it is also the result of poor handling, storage and primitive processing. Weather changes during fish drying, inadequate fires during fish smoking, insect infestation, poor use of ice, the absence of cold storage facilities and refrigerated transport, power supply fluctuations and poor roads all contribute to these losses. Fieldwork recently carried out in five sub-Saharan countries (Ghana, Kenya, Mali, United Republic of Tanzania and Uganda) indicates that post-harvest fish losses in small-scale fisheries occur at all stages in the fish supply chain, from capture to consumer. Significant physical and quality losses were found to occur in some supply chains in all the countries, with quality losses reported to account for more than 70 percent of total losses (Akande and Diei-Ouadi, 2010). If post-harvest losses could be reduced, there is potential for a substantial increase in the supply/value retention of fish in Africa.

3.3 Contribution to the economy

Given the low level of accurate reporting of the production, processing and trade of fish in Africa, it is difficult to estimate the economic contribution of the sector. Using an African average price for fish indicates the estimated landed first sales value of fish in Africa is in the order of US$19 billion. Africa is estimated to generate US$4.8 billion in exports alone (see Table 5).

The contribution of fish produced in the drylands is unknown but increasingly estimates are demonstrating that the value is considerable. Welcome and Lymer (2012) emphasized that particular clarification is needed for the Sahelian zone countries because catches are reported as rising there despite negative climatic conditions. In Senegal alone an estimate of the value of fish from two of the three major river fisheries was between US$19 to US$26 million (UN, 2011, Box 8). Lake Chad is particularly important economically, with fisheries providing 45 percent of regional household income across the Lake Chad basin. This amounts to US$45.1 million (Ovie and Emma, 2012).

Small-scale fisheries play a remarkable role in poverty alleviation through their capacity to absorb surplus labour (Béné *et al*., 2007; Béné *et al*., 2010). Actually, the small-scale fisheries sector − often denigrated for its backwardness and inability to generate wealth − is remarkably efficient (in an economic sense) in absorbing the excess of unskilled labour in the developing world (Kolding *et al*., 2014b). However, the links between fisheries/aquaculture and poverty alleviation are sometimes complex and still unclear (Béné *et al*., 2016).

Box 8: Inland fisheries in Senegal

Based on studies in two of the three major river basins in Senegal, freshwater fisheries were estimated to be worth US$14.5–US$19.6 million in value added in the country as a whole. These values were 19–26 percent of the value of marine fisheries, the primary sector by value in the Senegalese economy.

Source: United Nations, 2011.

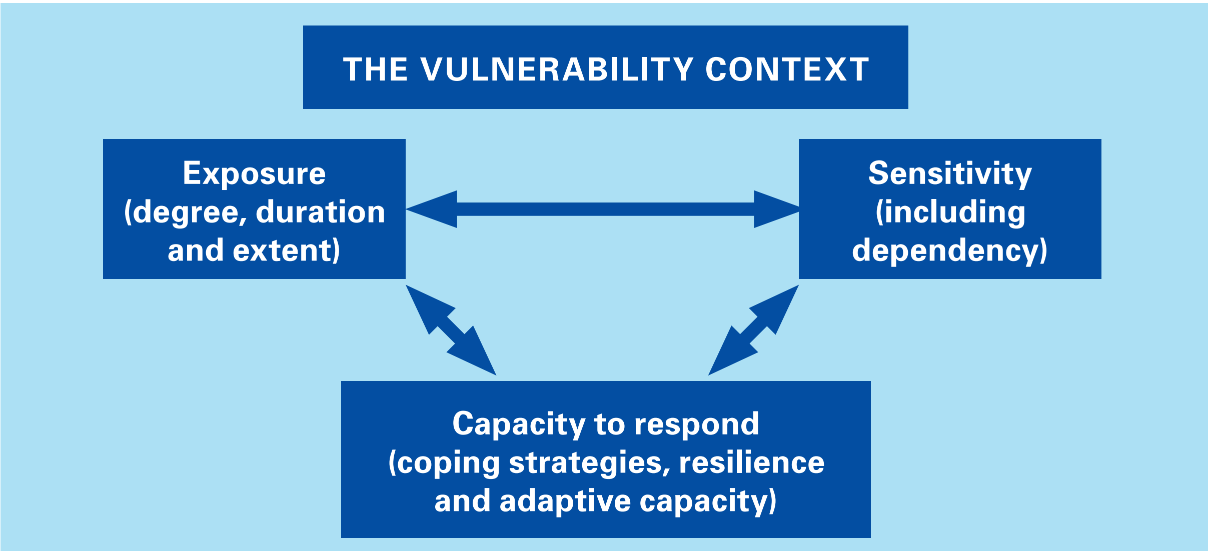
The overall contribution of the fisheries sector to GDP in Africa has been estimated at 1.26 percent (de Graaf and Garibaldi, 2014). But there are large regional differences: Ghana's fisheries contribute around 8 percent of GDP, Mauritania 4.5 percent, Mali 4.5 percent, Malawi 4 percent, and Namibia 3 percent (World Bank, 2012). There are also large variations in the different sources of information. These estimates included only the direct impacts from commercial fisheries (primary production of harvest and post-harvest subsectors). Indirect economic impacts were not included, nor was the aquaculture subsector (which is still negligible, as described above). Given the importance of small-scale fisheries in Africa (Kolding *et al*., 2016), and the difficulties with respect to data collection, these recorded figures are likely to be substantially below the actual figures.

The illegal, unreported and unregulated (IUU) marine fisheries catch across sub-Saharan Africa was estimated to be valued at 16 percent of current total catch value, amounting to about $0.9 billion − a value that is lost to the national economies and to food supplies in the region (MRAG, 2005).

4. The vulnerability of dryland fisheries and aquaculture at household and national levels

According to a recent review by Béné *et al.* (2016), there is a large but inconsistent amount of literature that links stress, exposure and vulnerability of fishing communities to a combination of many (often reinforcing) sets of risk, such as dangers, diseases and misfortunes. While fishing is considered one of the most dangerous occupations in the world, and many fishing communities have a very high prevalence of diseases and infections (particularly waterborne), the origins of many vulnerabilities are often found outside the fishery itself, and are related to basic human needs such as access to drinking water, health facilities or schools, or simply a need for political recognition (Kolding *et al.*, 2014b). For these people, poor or degrading environmental conditions are often not considered the primary cause of "poverty". Thus, confronted with the immediate perils of disease, accidents, death, theft or loss of fishing gear, unavailability of alternative productive assets (such as land) or basic human rights, local communities often do not give highest priority to the risks of resource degradation or climate change, which are often highest on the agenda of international organizations. Therefore, there is often a distinct gap between local communities and the international community when analysing and understanding the concept of vulnerability.

FIGURE 13
A synthesis of concepts



In developing a framework to understand vulnerability and the resilience of communities, households and economies, it is useful to bring the different concepts together, as shown in Figure 13. Vulnerability is seen as being composed of three elements (Chambers, 1989, 2006):

- exposure to shocks (adverse change);
- sensitivity to their effects; and
- the capacity to respond to those changes.

These elements, as they relate to fish production and consumption, are outlined below.

Exposure that affects fisheries takes many forms and may include long-term gradual changes, such as changes in precipitation regimes as a result of climate change, as seen in section 2.2; increased food and fuel prices; changes in global fish markets; changes in weather (droughts; floods, damage from storms and other disasters); and increased frequency of conflicts and outbreaks of diseases. In 2009, for example, fish stocks in the Zambezi River Valley were infected by Epizootic Ulcerative Syndrome, threatening to spread the disease to seven countries surrounding the river basin and potentially affecting the food security and livelihoods of 32 million people (FAO, 2013). The growth of fish farming and the use of genetically improved species (such as the "GIFT" tilapia) have potential effects on the natural biodiversity of the fish resources of Africa[10] which need to be closely monitored (Lind *et al*., 2012). Other changes the sector is exposed to include habitat destruction, species loss, water abstractions and changes in access to harvestable fish stocks. Exposure is influenced by the duration of the change and the extent of the area that may be affected.

Currently, one of the most pervasive stresses on global fisheries is highly selective fishing patterns, which alter the ecosystem structure (Garcia *et al*., 2012). In a recent global review, based on 110 Ecopath models, Kolding *et al.* (2015a) showed that the global fishing pattern was highly skewed towards large species with low productivity, situated at a high level in the food web, many of which were locally overfished. In contrast, highly productive small species, and species on low trophic levels, were only lightly exploited. Such a skewed fishing pattern, driven primarily by consumer demand in Western industrial countries, results in potentially large long-term changes to the ecosystem structure and functioning. These changes are against the intentions of biodiversity conservation norms and the ecosystem approach to fisheries (EAF) (Garcia *et al*., 2015). Small-scale inland fisheries in Africa are generally less selectively fished, because small nutritious fish are in high demand across the continent (Kolding and van Zwieten, 2014). Capturing small fish, however, is often in conflict with current fisheries regulations (Kolding and van Zwieten, 2011). This dilemma causes strong antagonism between fishers and fisheries managers and often results in punitive actions, including gear confiscations that only reinforce the vulnerability and exposure of small-scale fishers. Sadly, these ongoing conflicts often have no ecological justification and will only reduce potential yields (Kolding *et al*., 2015b). In addition, they contribute to the generally poor public image of fishers, that they are unruly members of society, causing their own misfortunes by indiscriminate fishing. Such perceptions are another example of the general failure of governance that characterizes the view of global fisheries (Kolding *et al*., 2014a)

Selective overfishing is compounded by habitat destruction and pollution which reduce the carrying capacity of the environment. In coastal areas, inappropriate harvesting methods, tourism, coastal development and run-off from land are leading to reef, seagrass and mangrove destruction, with resultant negative effects on fish breeding and food sources. In inland areas, water abstraction, pollution and poor water body management are leading to declining water resources and polluted lakes and rivers (Dudgeon *et al*., 2006, Welcomme and Lymer, 2012). The damming of rivers and streams for irrigation and hydroelectric power is problematic because dams often harm potamodromous[11] fish resources (Kolding and van Zwieten, 2006; Badjeck *et al*., 2010). Increasingly fishing communities are being exposed to the effects of climate change (Cochrane *et al*., 2010) which is beginning to magnify these other adverse effects. Along the coast, climate change is increasing the frequency and duration of coastal storms and floods. Water temperature increases are causing large-scale destruction of coral reefs and causing some fish to migrate. In inland areas changes in precipitation may lead to increased drought or to sudden and unpredictable flooding that affects fish farms and capture fisheries production. In Ethiopia, for instance, a reduction in rainfall has dramatically reduced the flow of rivers and streams, and the volume of lakes and reservoirs. Climate change, in conjunction with human activities, has already severely affected Lakes Haramaya and Adele in Ethiopia (Alemayehu *et al*., 2007; Abebe *et al*., 2014). Lake Tana, Lake Ziway and River Awash are also reported to be under stress (Georgis, 2010). In Kenya the drought between 2008 and 2011 caused losses and damage in the fisheries sector of around US$50 million or about 30 percent of the value of fisheries production for 2010 (Government of Kenya, 2012). Likewise in Lake Chilwa in Malawi and Lake Victoria in East Africa, the effects of climate change are becoming more noticeable and have affected the ecosystems (Allison *et al*., 2007, Van Zwieten *et al*., 2016).

The **sensitivity** to shocks and other changes reflects the extent to which the change adversely affects the household, community and/or economy. In part, this will be affected by the dependency that the affected

10. The Nile tilapia (*Oreochromis niloticus*), was introduced to Lake Kariba by a commercial fish farm around 1994, and has since invaded the whole of the Zambezi River below Victoria Falls and almost exclusively replaced the indigenous Oreochromis species. Likewise, the predatory snakehead (*Parachanna obscura*) has escaped from aquaculture farms and invaded the Luapula province in Northen Zambia. https://www.lusakatimes.com/2014/08/22/alien-fish-species-invades-luapula-waters/

11. Potamodromous fish species migrate upstream in river tributaries for spawning and reproduction. Many important African fish species, such as cyprinids and characids, are potamodromous.

population has on the resource and how they are affected by change. Dependency is highly variable between men and women and between households, which often have diversified livelihoods, precisely to reduce sensitivity, as discussed above. A study of Lake Chilwa in Malawi, for example, noted that fishers were either migrants, heavily dependent on fishing and fish-trading (contributing greater than 80 percent 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 percent to 50 percent of total household income (Allison and Mvula, 2002). This diversification of livelihood strategies is often seen in arid areas where exposure to natural hazards is high. Likewise, the lack of controls on entry to fishing, the low cost of entry, diversity of opportunity and the immediate nature of harvesting are significant attractants to the poor and the displaced with few other opportunities (Kolding and van Zwieten, 2011). These different forms of dependency will affect the sensitivity that different groups of people have to changes in the fisheries resource base.

The sensitivity of people dependent on fisheries and aquaculture will also be affected by an array of other factors such as the frequency, duration and form of the threat and how people are exposed to those threats. The poverty of many fishers further compounds this and increases their exposure to danger. In coastal areas it is the poor fishing households that tend to occupy the more exposed locations where flooding and storms affect dwellings, fishing boats, shore infrastructure and fishing gear (Blaikie *et al.*, 1994). Floods and fish disease can also wipe out fish farm production (as observed in northern Nambia where flooding in the Caprivi district demolished newly constructed aquaculture facilities (Shigwedha, 2014) or increase production costs which have direct effects on the availability and price of fish in dryland markets. Increased rain and unpredictable rainfall patterns can also affect the ability to preserve and transport fish. On the other hand, flooding may be seen as highly beneficial because water levels that fluctuate seasonally strongly boost fish productivity, as described above. Floodplain fisheries are considered among the most productive in the tropics, with an average potential fish production rate of 2.5 to 4 times that of tropical lakes and reservoirs on an annual mean water surface area basis (Bayley, 1991; Welcomme, 1979; Junk *et al.*, 1989). For example, in southern Sudan and the Omo Valley in southern Ethiopia, flooding is a common natural phenomenon and is essential for many livelihoods, including fisheries. Flood water increases the fish catch and enriches the soil. Traditionally, communities move to higher grounds when lowlands are inundated and practice recession cultivation in the productive flooded fertile fields once the rainy season is over (Sarch and Birkett, 2000; WFP, 2012b). Processors of fish are also sensitive to changes in weather, especially where fish is dried, smoked or brined. Poor weather conditions can lead to large-scale losses of fish during these processing stages.

The sensitivity of consumers to changes in the availability of fish will depend upon the availability and price of other proteins and sources of the micronutrients that fish provide. It will also depend upon the circumstances of the individual. The old, sick, very young and pregnant women are particularly sensitive to changes in the availability of key food sources such as fish. For those who depend upon a small quantity of fish in their diet as a source of vitamins and minerals, the effect of changes in availability can be very severe, especially when other sources are unavailable (HLPE, 2014; Longley *et al.*, 2014).

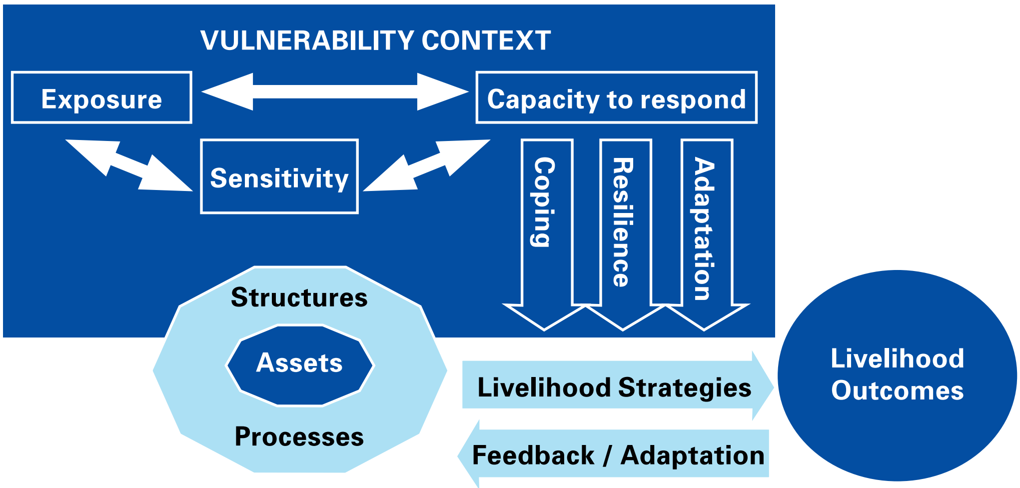
The **capacity to respond** to shocks can have three elements:

- Coping: the ability to cope with and accept the consequences of change;
- Resilience: the ability to bounce back from the effects of change; and
- Adaptation: the ability to adapt such that change will have less adverse effects in the future.

The need to adapt to change is something that most fishing communities are familiar with because they often occupy the dynamic natural environments that strongly drive fish production. However, resource decline, increased competition, habitat destruction and climate change – when combined with the increased frequency, severity and speed of change, as well as increases in the price of fuel and conflicts – are factors that are reducing their adaptive resilience.

The ability to cope with, be resilient to, or adapt to, change is dependent on a wide array of interconnected circumstances that make up and surround the livelihood strategies of fishers (see Figure 14). Not least of these are the range of assets that may be available at household, community and national levels. These include other natural assets that may provide alternatives to fish; social assets[12] that can provide support for adaptation and recovery; financial assets[13] that can help to rebuild livelihoods quickly; physical assets such as infrastructure, roads, houses and boats that may afford protection; and human assets such as knowledge, skills and leadership that can allow for innovation and change. The level of diversity of livelihood strategies can also affect the ability of fishers to respond to change. The diverse species and ecosystems that characterize many fisheries means that there are many opportunities for people with a variety of financial, physical and human assets to engage in fishing in different ways (Campbell and Townsley, 2013). The loss of some assets may mean shifting to another form of harvesting which makes better use of remaining assets.

FIGURE 14
Vulnerability and livelihoods



Households and communities with a high dependence on fisheries may not be able to diversify into other areas of work, and coping may consist of merely putting up with a poorer standard of living. For less dependent people with multiple livelihoods, shifting to another form of work may be possible (Sarch and Allison, 2000). For example, in some areas, such as around Lake Turkana in Kenya, people are involved in both fishing and livestock production (USAID and FEWSNET, 2011). However, in many cases where Turkana pastoralists have lost their livestock during droughts, fishing becomes the option of last resort and many are unable to later diversify back to livestock, and become permanently destitute in the society (Kolding, 1989). In South Sudan, for example community-level coping strategies in response to flooding include moving people and possessions to higher ground, relocating to friends or relatives in nearby villages or building dykes and mounds around houses to divert water flow, and many people start to move away from other activities and rely much more on fishing as a livelihood activity (WFP, 2012b). On lake Chilwa in Malawi, a number of responses to the recurrent declines in fishing opportunities[14] were identified (Allison *et al*., 2007): i) fishing on a very much reduced scale in the remaining swamps, streams and lagoons in the Chilwa catchment; ii) transfer to nearby Lakes Malombe, Malawi or Chiuta; iii) increasing the cultivation of rice, cotton, cassava and vegetables; iv) switching to commercial handicrafts such as plaiting carpets; v) spending considerable time trapping birds and digging for rodents; or, vi) seeking employment elsewhere. In many dryland areas people cope with food shortages by catching fish and selling it to buy less expensive staples.

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[12] Social asset is defined as the aggregate of all physical assets, human assets, political, social and legal rules, and so on, that are controlled by the whole society.

[13] A financial asset is an intangible asset whose value is derived from a contractual claim, such as bank deposits, bonds and stocks. Financial assets are usually more liquid than other tangible assets, such as commodities or real estate, and may be traded on financial markets.

[14] Lake Chilwa regularly dries up with 10 to 20 year periodicity in between periods of high water levels (Jul-Larsen *et al*., 2003, Figure 8).

The institutional structures that support or hinder livelihoods can also be very important. Where effective management of the resource base is in place, recovery may be faster and damage may be less. Where markets for labour are efficient, fishers may find alternative or complementary work. Where disaster risk reduction (DRR)[15] and climate change adaptation (CCA) programmes are in place the effects of hazards may be greatly reduced and where good community mobilization mechanisms exist, recovery may be faster. Unfortunately, the lack of recognized rights in most developing fisheries, low levels of empowerment and a lack of engagement with formal institutions often means that many fishers lack the support they need to cope with, recover from and adapt to adverse change. Similarly, the widespread tug-of-war between fishers and fisheries managers over the use of illegal fishing methods − which on closer examination turn out to be both sustainable and ecosystem conserving (Kolding and van Zwieten, 2014; Kolding *et al*., 2015b, 2015c) − is an example of institutional structures hindering the capacity of fishers to respond and adapt to changes.

Increasing demands on the production side of the fisheries and aquaculture sector, both within drylands and adjacent non-dryland areas, may ensure that fish supplies to dryland consumers are reduced and/or will increase in price. For dryland fish producers, the loss of harvests can be off-set to an extent through increased prices from fish sales that can be used to buy other, less expensive, food supplies. Other dryland consumers may be able to diversify protein sources to livestock, milk, and vegetables in the short-term but declining per capita fish supplies across Africa threaten food security and nutrition.

5. Options for strengthening resilience of fishing communities in dryland areas

Creating more resilient local communities and household economies means working at multiple levels and including both production households and consumers. The focus of this study is to identify options in three areas:

(i) Options for reducing exposure to adverse change or stress;

(ii) Options for reducing sensitivity to adverse change; and

(iii) Options for increasing the capacity to respond to adverse changes.

5.1 Reducing exposure

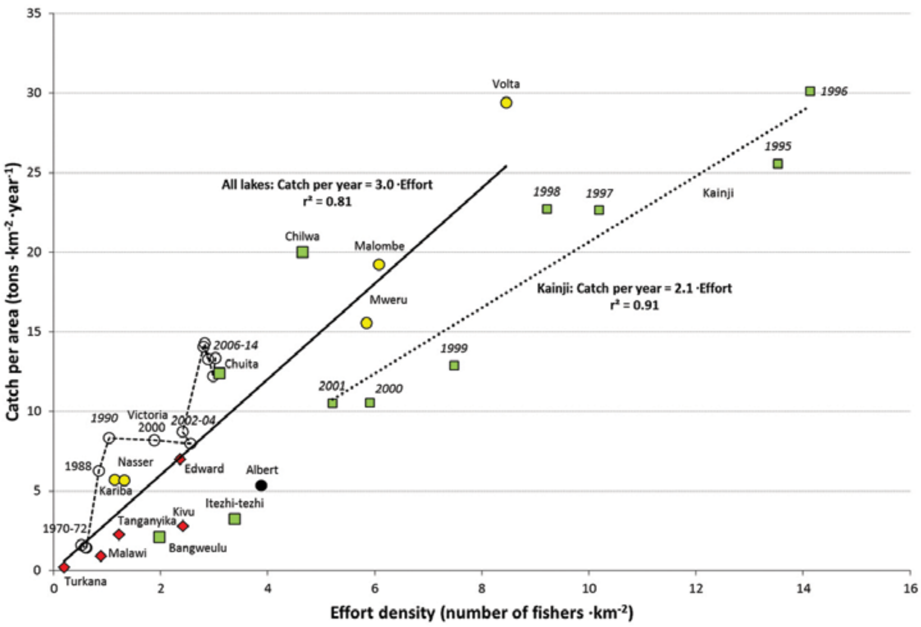
Reducing exposure to the risks that fishers, fish processors, fish farmers and fish consumers face from fish shortages requires addressing the current poor, or in many cases absent, state of fisheries management and development, which to a large extent is based on antiquated principles and theory. For example, much of the fisheries legislation in Anglophone Africa can be traced back to colonial British game legislation, where hunting and angling were seen as a "gentlemen's" sport with the important principle of "giving the game a fair chance" (Malasha, 2003). This attitude has important implications for various fishing methods that may be prohibited because they are seen as "herding", "indiscriminate", and "unselective" and considered particularly unethical when immature individuals are targeted. In addition, during the last decade of the colonial period, a new and ground-breaking fisheries theory was developed in the UK, which rapidly became the doctrine of modern rational fisheries management. The theory (Beverton and Holt, 1957) was based on mathematical models, stipulated minimum size limits for exploited species in order to maximize yields, and was soon exported to the colonies (Beverton, 1959), resulting in widespread mesh-size regulations and the condemnation of catching small and immature fish (Kolding and van

[15] UNISDR defines DDR as follows: The concept and practice of reducing disaster risks through systematic efforts to analyse and manage the causal factors of disasters, including through reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment, and improved preparedness for adverse events. Available at: http://www.unisdr.org/files/7817_UNISDRTerminologyEnglish.pdf

Zwieten, 2011). This has encouraged a simplistic and static view of fisheries, with fishing effort as the only driver, which does not adequately reflect its complex and dynamic nature, or its intimate relationship with environmental drivers, as elaborated above. For example, in Lake Victoria, the ubiquitous notion of overfishing is based on classical approaches to fish stock assessment based on steady state assumptions, ignoring the obvious observation that Lake Victoria is not in a steady state owing to continued eutrophication (catches are still rising steadily in spite of repeated model predictions to the contrary). Not only does this illustrate the danger of applying stock assessment models uncritically, but it also highlights the strange tendency to faithfully believe in model predictions (a limit is reached and a collapse is imminent), in spite of contradictory facts (the stocks have not changed and the catches are still increasing) (Kolding *et al.*, 2008). The result of this static view of fisheries is an unrelenting harassment of the fishers and continued calls for stronger enforcement and restrictions (Kolding *et al.*, 2014b).

FIGURE 15

Catch rates (tonnes ·km^{-2} ·yr^{-1}) plotted versus effort density (fishers ·km^{-2}) in 18 African lakes. Of these 16 lakes with data from the period 1989 to 1992 are used for the "All lakes" regression (solid line, excluding Lake Victoria and Kainji). The relationship shows an average yield of about 3 tonnes per fisher, per year, irrespective of water body and country. Red diamonds = low (<10), yellow circles = intermediate (10−30) and green squares = high (>30) RLLF-s, which indicates the productivity. Superimposed (dashed line, open circles) is the development in Lake Victoria between 1970 and 2014 that shows how productivity has increased over time concurrent with the increase in effort and eutrophication and the shift to the pelagic *dagaa* (*Rastrineobola argentea*) fishery around 2002. Highly fluctuating and productive Lake Kainji (dotted regression line on light green squares) shows an opposite downward trend between 1995 to 2001, where effort reductions since 1996, following donor-driven management actions, have resulted in a much reduced yield, but unchanged average catch rates of 2.1 tonnes per fisher, per year.



Source: adapted from Kolding and van Zwieten (2011)

The opposite and alternative position, that African fishers are actually controlled by the productivity of the fish resources, as indicated in Figure 10, is never considered. However, in a meta-analysis across 18 African lakes (Figure 15) the effort density (number of fishers) appears distributed according to system productivity so the average catch per fisher is around 3 metric tonnes per year irrespective of the system.

In addition, there is now an increasing realization that fisheries and aquaculture management and development must be an integral part of the wider social, economic, environmental and political context at local, national and international levels. This view of fisheries as a complex socio-ecological system that is undergoing continuous change necessitates a more adaptive approach to management at all levels (Mahon *et al*., 2008; Ostrom, 2009; Campbell and Townsley, 2013; Downing *et al*., 2014). Appropriate regulations, policy and planning frameworks that facilitate change in fisheries towards more sustainable resource use, with gains for wider society as well as individual fishers, are needed to ensure equitable and sustainable use of the resources. While fishing and farming, and sometimes also fishing and pastoralism, are often integrated activities for food security all over Africa, the governance, policies and management of these activities are mostly segregated and often based on different paradigms (Kolding *et al*., 2016).

Box 9: Diversifying into fishing in Mali

A WFP food-for-work project that helped to build a small dam in Ouelessebougou, in the Koulikoro region of Mali, has helped people to diversify their agricultural production.

"Before, I was only cultivating millet", said one of the people that WFP had helped, "the farmers of the region were heavily dependent on the rain. When the rainy season was poor, like in 2011, our families were starving. Now, we can better control the circumstances, and diversify our cultures. Thanks to the water retained by the dam, we are now growing paddy rice, potatoes, tomatoes and of course millet. We have also built a small fishing pond, so we can eat better. And we sell our products, which brings in money for the community."

Source: http://www.wfp.org/stories/food-work-helps-farmers-in-mali-diversify-their-production

Closely linked to this is the need to ensure that the wider natural environment in which fisheries and aquaculture function is maintained or returned to a state that can support the sustainable production of fisheries. This requires linking fisheries and aquaculture into wider environmental management and adopting a cross-sectoral approach, as demonstrated by integrated coastal and watershed management schemes.

Integrating agriculture, livestock rearing and culture-based fishing through the provision of water harvesting facilities and small rain-fed reservoirs can have significant benefits for all three activities, particularly in the areas of waste and water management, but also in increased productivity (Critchley and Siegert, 1991; Baijot *et al*., 1997; Box 9). There is also scope for incorporating new technologies in water collection, storage, management and use that can benefit a number of sectors.

Part of the problem associated with the weak management of fisheries and the authority segregation between agriculture and fishing activities, is the lack of lawful rights that fishers have over access to resources (fish, water and land). Rights engender a longer-term perspective on resource use and lower risks to investment in unsustainable practices. The right to access resources is increasingly being seen in the wider context of human rights in the process of connecting fisheries more closely to the wider well-being of communities (Charles, 2011; Allison *et al*., 2012). Before the required levels of trust and cooperation can function between fishers and fisheries managers, adequate and enforceable rights need to be agreed and established. This will also reduce friction because fishers with rights to the resources will also have the rights to self-manage.

Changes of this nature will require the development of appropriate policy frameworks and plans, and the establishment of institutional structures and processes at the right level to make them work. At present, such an enabling environment is lacking in many countries, as are the infrastructure, skills and knowledge required to move the sector forward. It will be important to ensure that the right policy frameworks are developed for Africa and not merely transferred from other parts of the world. The effectiveness of the community taking over more of the roles of government in fisheries management is becoming more apparent (Berkes, 2006; Scott, 2010) and is likely to be more cost-effective. This should, however, not assume that communities always have the capacity to take responsibility for fisheries management without support or without an appropriate enabling environment, particularly in situations where the social power structures are highly uneven because this may just lead to increased marginalization of the poorest and most vulnerable people (Jul-Larsen *et al*., 2003). Changes will also require that the central management institutions effectively hand over the responsibility to local communities. In most African inland fisheries (Nielsen and Hara, 2003; Nielsen *et al*., 2004), the ongoing conflicts between the harmonized gazetted regulations on fishing gears and legal fish sizes, and fishers' compliance with them, have not been solved by the introduction of co-management. The result, however, is increasing frustration among governance institutions and managers, with ensuing demands for increased enforcement by government. To date, the co-management process in Africa – notwithstanding its social achievements – is still a centrally controlled exercise where local communities are not involved in (co)determining the objectives of the fishery, but are essentially expected to implement the existing regulations by self-policing (Kolding *et al*., 2014b).

Exposure to hazards can also be greatly reduced through better awareness of when, how, where and to what extent they will arise. Improving mechanisms to identify, monitor, assess risks and deliver early warning systems for floods, droughts, storms and other natural disasters and risks can mean that people are better able to take evasive action in time. The migration of fishers to less exposed sites may reduce loss of life and loss of equipment. Monitoring and early warning of the spread of fish disease may enable fish farmers to reduce their exposure. The past focus on humanitarian responses to disasters would be better shifted towards a stronger focus on DRR and linking this more closely to wider development strategies.

5.2 Reducing sensitivity

Whilst it may be possible to reduce exposure to some of the hazards and hurdles that fishers, fish farmers, processors and fish consumers face, there will inevitably be some exposure that cannot be avoided. Reducing sensitivity to such shocks is in part concerned with changing the dependence that people have on the fisheries resource base. It can also be about reducing the effects and impacts of that dependency.

Diversifying livelihood opportunities which are available to fishers can reduce their dependency on fluctuating climate-driven fisheries, and thus their sensitivity to change. This links closely to the wider economy and necessitates that fisheries are seen as integral to that. Livelihood diversification is also crucial for reducing pressure on the fisheries resources and the natural environment. For many households in dryland areas, a diversified livelihood strategy base is already a way of coping with hazards and provides a basis for building this further (Ellis, 2000; Little *et al*., 2001). There is also a need to ensure that where fisheries are seen as a route for diversification out of other livelihood activities e.g. livestock farming, other sectors are integrated into any livelihood diversification process. Whilst livelihood diversification is often seen as an important tool in fisheries management, it requires systematic and long-term support and infrastructure to be successful (Cattermoul *et al*., 2008).

The sensitivity of consumers to changes in protein availability is particularly acute in dryland areas where large fluctuations in livestock populations from recurrent droughts are becoming more common and human population density is increasing. The livelihood benefits of fisheries as an additional source of protein are obvious but mostly ignored or underestimated in the various discourses on food security, although there is a growing recognition of the importance of fish as a component of the human diet. Small, resilient fish species, as typically occur in small water bodies and reservoirs, have the highest level of biological production (Kolding *et al*., 2015b), and the highest level of essential micronutrients because they are usually consumed whole. In addition, small species are the most "eco-friendly" in terms of long-term preservation because they only need sun for drying, in contrast to large species that require refrigeration, salting and/or smoking for keeping.

Small, shallow water bodies, such as reservoirs and wetlands, are among the most productive aquatic systems per unit area (Marshall and Maes, 1994; Kolding and van Zwieten, 2012). Combined they cover an area larger than lakes, big reservoirs and rivers in Africa (Lehner and Döll, 2004; Welcomme *et al*., 2010), but their relative contribution to food security is largely unknown. Freshwater fish in fluctuating water bodies are probably among the most resilient harvestable natural resources, provided their habitats are maintained (Welcomme and Petr, 2004; Dugan *et al*., 2007). Water productivity increases with seasonal fluctuations in water level (Kolding and van Zwieten, 2012), which indicates that it is important that wetlands and lakes maintain their natural cycles, while human-made dams and reservoirs can be regulated to mimic natural fluctuations, and thus increase productivity.

Fish is increasingly seen in such areas as an alternative protein source. The consumption of fish is also highly sensitive to changes in its availability, although many of the benefits from eating fish can be achieved with relatively small amounts (Beveridge *et al.*, 2013, Longley *et al.*, 2014). Increasing the awareness of people to the benefits of fish in the diets of specific stakeholder groups such as pregnant women, the young, old and the ill can help to ensure small amounts of fish are eaten as an effective dietary supplement. Fish is also a valuable substitute for the loss of other animal proteins and has a greater role to play in emergency food assistance.

In addition, improvements in post-harvest processing have the potential to increase the availability of fish for enhanced food security and nutrition, and generate increased income for fishers and processors. Investment in both understanding the post-harvest losses and their causes, and in overcoming such losses where appropriate, has considerable potential to increase returns from the fish trade. This will require improvements in fish handling, storage, processing and transportation (Akande and Diei-Ouadi, 2010).

Box 10: WorldFish develops aquaculture in Mali

The droughts of the 1970s and 1980s impoverished most rural households living in the Sahelian regions of West Africa, and in many cases families were forced to send some of their members to live and work in cities. Since then, rural Malians have struggled to rebuild and diversify their livelihoods.

In the 30 000 km^2 area of the inner Niger River delta in Mali, the critical resources making livelihood diversification possible are the residual waters retained in mares (floodplain depressions) which enable agriculture, provide pasture and create fish habitat during the dry season. Fish culture has a very limited history in Mali but the extensive flood plains that traverse this country provide excellent, untapped opportunities for both extensive and intensive aquaculture in these mares.

Source: http://www.worldfishcenter.org/our-research/ongoing-projects/fish-culture-in-seasonal-floodplains-partners-mali

Communities that are exposed to storms, flooding and coastal/lakeshore erosion can be assisted through the building of enhanced infrastructure to withstand hazards, such as shoreline protection, beach landing equipment for boats, better stores for gear and homes that are located further from danger.

Environmental conservation measures, such as protected areas, can also be a significant threat to fishers and consumers alike, when not properly planned (Campbell and Townsley, 2013). The imposition of protective conservation measures without adequate understanding of the consequences for poor stakeholders can mean that essential livelihood opportunities are removed from them. All stakeholders (including fishers) need to be fully engaged in the design of such measures to ensure that fishers are not further marginalized. Likewise, conservation measures can have unforeseen consequences for dryland consumers and such measures need to be planned with the needs of consumers in mind. In particular, the availability and form of fish, as part of wider food security in the drylands, need to be linked to that of other protein sources in more integrated ways. However, fish communities in fluctuating dryland ecosystems are generally highly resilient and adapted to changing environmental conditions (Jul-Larsen *et al.*, 2003, Kolding and van Zwieten, 2012), which reduces the need for protective measures, except the prevention of habitat destruction.

The establishment and recognition of human rights within fishing communities also have an important role to play in ensuring that wider development or environmental conservation processes do not increase the sensitivity of fishers.

5.3 Increasing the capacity to respond

The ability of fishers and consumers to cope with, recover from, or adapt to, change can be improved through a number of interventions. In part this requires a recognition that the drylands and adjacent lands are becoming less predictable in the face of climate change and other threats and that approaches to fisheries and aquaculture management and the role of fish in nutrition and food security will change. This necessitates a form of planning and management which is much more adaptive and innovative than the current paradigms based on steady-state assumptions (Mahon *et al*., 2008; Allen and Gunderson, 2011; Evans *et al*., 2011), and that learns to live with uncertainty (McConney and Charles, 2008), and makes flexibility a goal itself (Kolding, 1992; Knapp, 2000).

The ability to adapt and innovate often necessitates people themselves having access to more diverse and better livelihood assets. Social protection programmes are increasingly recognizing the benefits of cash transfers for the very poor. These are particularly effective when supported by skills development. Cash-for-work programmes, as part of DRR programmes, can be particularly effective when used for environmental restoration and building water runoff storage structures that can be used for fish production systems in connection with farming and livestock. There is increasing innovation in insurance against major losses from shocks, especially in pastoralism and dryland agriculture (Venot *et al*., 2012), that could be developed and integrated to better suit the fisheries sector.

Better information about weather and climate change, and disease, is also important for enabling people to make the right livelihood decisions. As mentioned above, early warnings of floods, storms, droughts and other natural hazards can help people to avoid loss of life and equipment and make better harvesting decisions. It will be important to incorporate early warning systems into the wider mainstreaming of DRR into fisheries strategies − and fisheries into DRR strategies.

General water shortage is, of course, one of the major challenges facing drylands. In many cases, however, the problem is not absolute water scarcity but the highly uneven distribution of rain over the seasons, and a lack of infrastructure to regulate supplies for use in dry seasons and dry years. Most sub-Saharan African countries have low levels of water storage infrastructure: only 5 percent of the world's dams are located in sub-Saharan Africa according to the World Registry of Dams (ADB *et al*., 2008). Water storage in the form of small reservoirs is considered to be an effective means to face the environmental challenges in the region and is seen as a viable option for adapting to desertification and climate change (McCartney and Smakhtin, 2010).

Most of the research on increased food production under limited water supply conditions is focused on agriculture, with very little regard to the contribution from fish (Dugan *et al*., 2007; Molden *et al*., 2010). Nevertheless, where there is water there is usually also fish (Kolding *et al*., 2016) and fisheries or fish culture can mostly be integrated into water management systems, such as dams, reservoirs and irrigation schemes that are built primarily for agriculture. Thus, although most dams and small reservoirs in drylands are made and financed for agro-pastoralist purposes, they can, and do, contribute significantly to food security from fisheries, or culture-based fish production. Nonetheless, this additional benefit from dryland water harvesting can be significantly enhanced if dams and reservoirs are initially planned and designed to also provide fish products, for example through the inclusion of spillways that facilitate upstream migrations during floods (Baijot *et al*., 1997). In addition, dams can be designed better for fishing by clearing certain areas of trees and large obstacles before inundations (as was done in Lake Kariba), or by creating "deep zones" that will facilitate the survival of fish populations during droughts. However, not all areas should be cleared for fishing operations, so as to create refuge areas where fish are naturally protected from gillnets and beach seines, in order to prevent overfishing.

Where effective and well thought out policies and plans are in place to manage fish production systems these will enable people to cope with, and adapt to change. Well managed fisheries and water bodies have a better chance of preventing overexploitation or environmental damage. Gaining a better understanding of the dynamics of fish populations in relation to environmental variability and building on the experience-based knowledge of the scientific community and the traditional knowledge of the local community, can help fishers in both coastal and dryland areas to manage resources in ways that help them to adapt to change. Adopting an integrated approach to planning, which combines the needs of fishers, fish farmers, pastoralists and farmers, is essential to enhancing the complementarity and mutual synergism between sectors (e.g. FAO, 2008a; Venot *et al*., 2012).

However, the main response to future climate scenarios in arid areas, where increased variability and volatility in precipitation regimes is anticipated, is the storage dilemma (FAO, 2008a). Therefore, better water management, including increasing the number of small reservoirs, is proposed as one of the solutions to agricultural growth in sub-Saharan Africa by the NEPAD in its Comprehensive Africa Agriculture Development Program (CAADP) (NEPAD, 2003). There is general agreement that development in water management should take several forms and benefit many people by better integrating irrigation and other uses such as domestic and livestock water supplies, fisheries and hydropower (ADB *et al*., 2008). Thus, diversification of skills, attitudes and knowledge into improved fish production in combination with agriculture and livestock; better fisheries management and alternative livelihoods; will build capacity and opportunities for greater resilience. Building the capacity of communities and households to become more adaptive in their thinking and more innovative in their use of assets will help them to adjust more quickly and more successfully to future change. To facilitate this requires building the skills of support staff in government and NGOs, as well as partnerships across the private sector. Such developments need enhanced policy frameworks to support and enhance dryland fisheries production, as part of an integrated food strategy, along with appropriate financial support and legislative changes to natural resources management.

6. Economic options

It is not possible to make generalizations about investment decisions across different countries because the local context will determine needs and opportunities, but some key points on investment and returns can be made.

It is increasingly recognized that fisheries and aquaculture in Africa are not realizing their full potential. Maladapted and outdated legislation, selective overexploitation of less productive resources at high trophic levels, and the degradation of the environment from flow regulations result in catches below the maximum sustainable level (Kolding *et al*., 2015a, 2015b). Over-investment in export-oriented commodities − such as the Nile perch in Lake Victoria − and subsidies give rise to the economic rents from the resources being lost, or not being fully realized. IUU fishing for some marine resources is at such a level that much of the fish that could be available to Africa is being lost to other countries at a cost of nearly $1 billion a year. Moreover, at least 20 to 25 percent of fish is lost on the way to the consumer as a result of poor handling and preservation, and the post-harvest processing, storage and distribution of fish in Africa is of a low standard. Inland fisheries in Africa are in general more controlled by external environmental drivers than by management regulations (Jul-Larsen *et al*., 2003) although most public investments in fisheries are made based on steady state management models that rarely reflect reality (Kolding and van Zwieten, 2011). When the shocks that commonly affect communities of fish producers strike, they invariably inflict enormous costs at the household, community and national levels. These costs could be greatly reduced if more investment was made in adaptive forecasting and DRR, rather than waiting for disasters to strike.

The combined loss of opportunities to the fisheries of Africa represents a significant part of their value. If this was recouped through better management, less selective fishing on less productive large species (even though these species realize higher export prices) and adaptive planning, the costs of rebuilding these fisheries could be significantly offset. The importance of fish and fisheries is increasingly being recognized and the Partnership for African Fisheries (PAF) and the NEPAD-FAO Fish Programme (NFFP) have helped to raise the profile of fisheries in African national economies by assessing the current contribution of fisheries to GDP and Agricultural GDP (de Graaf and Garibaldi, 2014). Likewise, the inclusion of fisheries in National Agriculture Investment Plans (NAIPs) in Africa will also stimulate investment in capacity building, improved knowledge management, infrastructure, innovations in technology and research which could contribute to better water management, water storage and subsequent growth in associated fish production and fisheries. Such investments would have significant benefits for increasing resilience in the drylands. A longer-term perspective on investment can also be facilitated through such measures as the right to access and insurance.

As long as it is constrained by the requirement of affordable, high quality, protein-rich feed, aquaculture has limited potential to expand in African drylands and to contribute to increased food security, employment, exports and economic growth. There are too many risks associated with small-scale aquaculture in rural communities, as the long history of failed investments has shown. However, much can be done to develop small-scale, culture-based stocking fisheries in combination with the development of water storage infrastructure that is generally aimed at enhancing livestock farming and agriculture in drylands.

7. Recommendations and policy guidance

Fish availability is considered to be low in Africa when compared with other parts of the world, although both the reported catches and consumption statistics are probably seriously underestimated. With growing human populations and increasing global demand for fish, the situation is likely to worsen in coming years (World Bank, 2013). This will have particularly profound effects on the food security and nutrition of people living in the drylands, especially as they become increasingly vulnerable to the effects of climate change. For African drylands, the anticipated future climate changes are predominantly increased variability and volatility in the precipitation regimes (FAO, 2008a: Müller, 2013). The impact of the expected hydrological changes on food production will therefore be felt primarily in terms of supply stability. Most at risk from the climate change impacts are the rural populations subsisting in semi-arid and arid zones who have few options, other than migration, for adapting to yet more water scarcity. Permanent or seasonal out-migration is already a consistent feature of many rural communities in sub-Saharan Africa and South Asia where food security is no longer dependent upon locally grown produce (FAO, 2008a). Under the expected conditions of higher rainfall variability, increased temperatures and evaporative losses, understanding the nature of rainfall events and the scope for water management to buffer or store rainfall will be key to development and food security. Rain-fed systems will continue to offer the greatest scope for adaptation in terms of area, number of farmers and overall contribution to global food production. Runoff can be controlled to a degree, while rainfall and evapotranspiration cannot. The effective management and storage of water in drylands is therefore considered to be one of the most important challenges for continued livelihood support and food security. Most international organizations see small reservoirs as ‘‘effective instruments in using agriculture for development’’ (FAO and IFAD, 2008). New agricultural water management initiatives are highlighted because they are considered among the most important tools to improve food production and ultimately contribute to poverty alleviation and rural livelihoods, especially in sub-Saharan Africa (Molden, 2007; ADB *et al*., 2008; FAO and IFAD, 2008; Venot and Hirvonen, 2013). Consequently, better water management, including small reservoirs, is proposed as one of the solutions to agricultural growth in sub-Saharan Africa by the CAADP of NEPAD (Nepad, 2003). The implication is that in many dryland countries development of rain-fed agriculture will have to be accompanied by the construction of new water storage facilities to cope with seasonal variability and local water scarcity (ADB *et al*., 2008). However, there is general agreement that development in water management should take several forms and benefit many people by better integrating irrigation and other water uses, such as domestic and livestock water supplies, fisheries and hydropower (Venot *et al*., 2012). The overall general recommendation of ADB *et al*. (2008) is provided below, but this quotation incidentally also illustrates the general neglect of fisheries as part of the solution:

“Sub-Saharan African countries should develop national strategies for the agricultural water subsector that recognize both its importance for agricultural growth and poverty reduction ..., as well as the need for water to be developed within a broader framework that promotes agricultural growth through profitable investment and market oriented production. Agricultural water strategies should be integrated with both broader water resources management strategy and with poverty reduction strategy. Strategies need to be supported by analysis of the role of public and private investment, of ways to foster private investment, and of the range of public investment options incorporated into an investment plan, and be implemented wherever possible through sector wide approaches.”

The fisheries sector will depend on and need to be included in this development, and “agricultural” policy makers should recognize its importance. While natural water bodies will continue to play an important role, increasing the amount of surface water available from small reservoirs will also provide opportunities for significantly improved fish production.

To achieve this potential there is a need for a far greater level of investment in people, institutions, practices and infrastructure than is currently the case. The interdependence of coastal, lake and river fisheries and aquaculture, in both drylands and adjacent areas, means that they all have a critical role to play in the future resilience and food security of people in dryland areas. Consideration should be given to gender inequalities.

From the discussion above some key recommendations and policy guidance emerge:

1. **Integrate fisheries, farming and livestock to enhance fish production and food security**: there are many examples where fisheries have been combined with other livelihood activities such as livestock production and agriculture (van der Mheen, 1994; Baijot *et al*., 1997) and fisheries are rarely the sole occupation in African livelihood strategies (Jul-Larsen *et al*., 2003). Fisheries should therefore be integrated in developments relating to water harvesting, irrigation/agriculture and improved water storage facilities, not only to improve the way natural resources (especially water) are managed, but also to share knowledge of potential hazards, to reduce investment costs and provide a type of safety net. General water shortage is one of the major challenges facing drylands. National strategies for water resources management and storage should contribute to poverty reduction strategies, benefit the people involved in farming, irrigation, herding and fisheries and enhance domestic use and the generation of hydroelectric power.

2 **Support the inclusion of fisheries in the NAIPs of African countries**, as well as in CCA and disaster risk management (DRM) strategies and plans to stimulate investment and facilitate access to adaptation funds. Food policy is largely oriented towards food produced on land. Little is said about fish – even in countries where fish is central to people's diets, irrespective of their income levels and social status. The pivotal role that fish can play in direct food security and nutrition is not adequately recognized (HLPE, 2014; Béné *et al*., 2015).

3. **Include fish in nutritional programmes and interventions** aimed at tackling micronutrient deficiencies, especially among children and women, while respecting cultural specificities, promoting local procurement, and taking into account costs and benefits (HLPE, 2014). Fish is a source of protein, micronutrients and essential fatty acids in a combination that is seldom found in other types of food. The nutritional value of fish (and in particular small fish) and its role in the diets of vulnerable groups such as old people, infants and pregnant women, means that a small amount of fish can have significant nutritional benefits. The actual contribution of small fish to the diets of African households is largely unknown, but it is likely to be seriously underestimated (Kolding *et al*., 2016).

4. **Support better management of fisheries and aquatic ecosystems**: the effective management of natural and constructed water resources for improved fisheries or culture-based capture from stocking or appropriate species introductions is important at both national and regional level for the food security and nutrition of African populations, especially in the drylands, and for protecting and rehabilitating the environment. There is also a need for improved regional cooperation (through, for example, regional fisheries management organizations, RFMOs) particularly in the case of international shared water bodies. However, it must be realized that dryland water bodies that fluctuate in volume and productivity on a seasonal and/or interannual basis cannot be managed based on traditional steady state assumptions (Sarch and Allison, 2000; Jul-Larsen *et al*., 2003) and they may be shared between different countries. Management processes need to adapt to naturally fluctuating resources and much can be learnt from the traditional way fishers adjust their livelihood strategies to accommodate these changes. The institutional structures and processes required to achieve this will need to reconsider and adapt the present legislation and regulatory measures that are based on inappropriate assumptions that have not changed since the colonial period (Malasha, 2003; Kolding and van Zwieten, 2011; Kolding *et al.* 2016). The **Code of Conduct for Responsible Fisheries** (FAO, 1995) and the **EAF** provide guidance on how this should be achieved in connection with biodiversity conservation norms (Garcia *et al*., 2015).

5. **Respect the right to access resources** in line with the ***Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests*** (VGGT) and the ***Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication***

(SSF Guidelines, FAO 2015): part of the problem associated with the poor management of fisheries is the lack of rights that fishers have to access resources, including fish, water and land. Within small-scale fisheries, the right to access resources must be complemented by the right to manage those resources, and in particular to fish those resources across all trophic levels more effectively. Rights encourage resource users to take a longer-term view of resource use and therefore lower the risk of them investing in unsustainable practices. The right to access resources is increasingly being seen in the wider context of human rights, so as to connect fisheries more closely to the broader well-being of communities (Charles, 2011; Allison *et al*., 2012).

6. **Strengthen capacity at the local level in fishing practises and post-harvest management:** it is estimated that at least 20 to 25 percent of fish is lost along the supply chain in Africa. Losses result from on board handling and subsequent stages of processing, including packaging, storage and distribution of fish. This leaves a lot of room for improving and increasing supply through a reduction in post-harvest losses, and better post-harvest management and storage:

   - By investing in infrastructure like landing sites; roads that connect main centres of production or collection points with markets; ice machines; cold storage; processing facilities (e.g. drying tables or racks); storage facilities; and markets with hygienic facilities, etc.;
   - The boom-and-bust nature of fish production in most dryland water bodies, as a function of fluctuating environmental conditions, should be adapted to by investing in buffer capacities, so that fish can be caught, processed, dried and stored during good seasons, to be utilized during lean periods or used for emergencies elsewhere;
   - By changing practices, training, technical and/or non-technical interventions, e.g.:
     - Training of fishers, fish processors and fish traders on improved handling of fish products and developing and applying simple traceability systems.
     - Training public-sector staff and private-sector stakeholders on understanding the nutritional value of fish, consumer preferences, and the quality and safety of fish and fishery products.
     - Promoting and explaining the benefits of eating fish to consumers and helping them to choose/recognize good quality fish and keep it from perishing.
     - Integrating fish into the normal diet of school age children through school feeding programmes.

7. **Create the right policy, planning and support services to promote sustainable production and trade systems in a changing environment**:

   a. **Create an enabling environment for intraregional trade of fish**: in 2005, the FAO Declaration on Sustainable Fisheries and Aquaculture in Africa, called upon African countries to "promote trade in artisanal and industrial fish products to respond to regional and global market opportunities for African fish products". The NEPAD Action Plan for the Development of African Fisheries and Aquaculture (NEPAD, 2005) further recommended strengthening intraregional African trade in fish products. In order to realize the potential of intraregional trade in fish products, investments are needed in:

   - Hygiene and quality standards for processed products in particular;
   - Infrastructure and equipment for the handling, transport, storage and preservation of fresh, frozen or processed fish products;
   - The quantity and quality of information on trade rules and potential markets;
   - The creation of a more secure business environment conducive to the development of subregional trade (Ndiaye, 2013) for both men and women;
   - Improved market access, in particular for small-scale producers, processors and traders (NEPAD, 2005).

   b. **Mainstream disaster risk resilience and CCA in the fisheries policies and plans that are included in national and regional plans**: even with more adaptive planning, shocks, challenges and stresses will continue to afflict fisheries and aquaculture and climate change is likely to be particularly important in increasing these threats. Improved information about weather and climate change, and disease, is important because it allows people to make the right livelihood decisions. Early warning of floods, storms, droughts and other natural hazards can help people to avoid loss of life and equipment, and make better harvesting decisions. It will be important to incorporate early warning systems into the wider mainstreaming of DRR into fisheries strategies– and fisheries into DRR strategies. Likewise, with the growing emphasis on intensive aquaculture based primarily on genetically improved alien species, the potential for the rapid spread of disease in aquatic environments is increasing. Investments in infrastructure and services are needed to improve the security of aquatic areas and assets and to predict and respond to disease outbreaks. The current practice of responding to disasters after they have occurred must change radically to one where DRR is at the forefront, so that fishers and consumers become more resilient and adaptive to change, rather than the victims of it.

Greater cooperation between government extension staff, researchers, meteorological staff, NGOs and communities should be fostered so as to better understand the potential effects of climate change, to build resilience in this respect and facilitate disaster avoidance rather than disaster response. This requires the mainstreaming of DRR in policies, plans and development efforts and that these are consistent across sectors.

8. **Fully address the gender dimension of fisheries for each intervention and overcome the unintended gender blindness of many approaches**. Fishing is a gender-specific activity and usually it is the male members of the family who participate in fishing. However, women are often involved in fish processing or marketing, or in catching fish in the small reservoirs after the rainy seasons, or in small-scale fishing along the rivers. Consideration should be given to conducting gender awareness and capacity building for partners and communities to increase the understanding of gender inequality in fisheries and to ensure that aquaculture and fisheries policies and interventions **do not cause negative impacts for women but encourage gender equality**.

8. **Improve preparedness to crises** in line with the FAO Fisheries and Aquaculture Emergency Response Guidance[16] and related best practises: preparedness and contingency planning is undertaken to support effective and efficient emergency response. Training and capacity development is provided to relevant stakeholders.

16. http://www.fao.org/3/a-i3432e.pdf

8. Conclusions

In the mainstream development discourse, agricultural growth is considered central to rural poverty reduction. The agricultural sector accounts for 20 percent of sub-Saharan Africa's GDP and 67 percent of the total labour force (FAO and IFAD, 2008). But sub-Saharan Africa is also described as having the lowest agricultural productivity in the world, and as having witnessed an increase in the numbers of poor and malnourished people owing to a mounting gap between agricultural output and population growth (ADB *et al*., 2008; FAO and IFAD, 2008). Better water management, including increased construction of small reservoirs, is proposed as one of the solutions to agricultural growth and climate change resilience in sub-Saharan Africa (NEPAD, 2003; FAO, 2008a) and while there is general agreement that development in water management should take several forms and benefit many people by better integrating irrigation and other uses (Venot *et al*., 2012), the potential for fisheries and improved nutrition has generally received negligible attention (HLPE, 2014).

Climate change scenarios are primarily predicting increased variability and volatility in the precipitation regimes of drylands, and the impact of these anticipated changes on food production will be felt primarily in terms of fluctuating supply. Without increased resilience and better adaptation, the rural populations most at risk from anticipated climate change impacts are those subsisting in semi-arid and arid zones. Diversification and buffer capacity is a key to improved resilience and the potential to expand the role played by fish in the livelihoods of dryland people is considerable. Freshwater environments are among the most volatile and ephemeral ecosystems that exist and many fish species are highly adapted to fluctuating and variable conditions. In fact, recent research (Kolding and van Zwieten, 2012; Gownaris *et al*., 2016b) shows that the fluctuating nature of most African freshwater systems appears to promote fish production rather than impede it. Combined with the increased recognition of the nutritional value of fish for food security and healthy diets, the importance of fish for a diversified livelihood strategy in drylands should be emphasized, promoted and developed, in concert with other food producing activities.

The focus of this review has been on both documenting the general resilience of many fish resources to climatic variability and the underestimation of fish and fisheries in livelihood importance, but also on enhancing the potential supply of fish from dryland areas through the improved use of the available water bodies, and in particular from small reservoirs by focusing on small, highly productive species. The role of small water bodies in supplying essential micronutrients and protein to rural communities has largely been ignored since the termination of the ALCOM programme in 1998 (FAO, 1999) although they are more productive per unit area than the large lakes and reservoirs and comprise a much larger area of water combined. Most of the fish production, however, is consumed locally and goes unrecorded in official catch statistics.

By refocusing attention on fish productivity in small water bodies and reservoirs in drylands, and in particular by integrating fisheries with developments in water harvesting, irrigation and improved water storage facilities, the potential to increase the role of fish in the diets of dryland people, and to provide improved livelihood opportunities, is great.

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