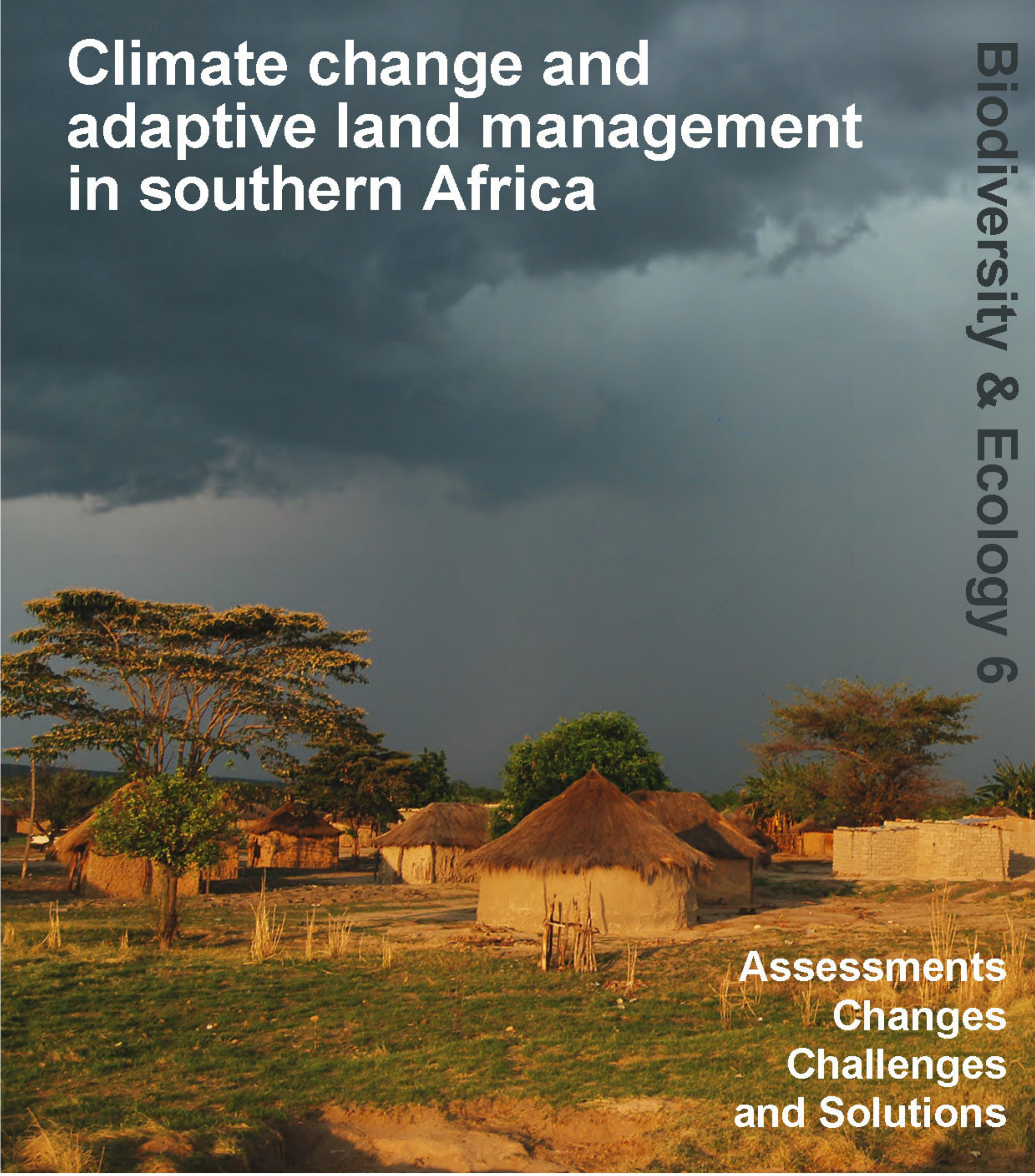
Climate change and adaptive land management in southern Africa



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Challenges
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Climate change and adaptive land management in southern Africa

Assessments, changes, challenges, and solutions

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Biodiversity

Climate, fish, and people in Zambezian fisheries, with emphasis on a natural flood cycle in the ephemeral Lake Liambezi

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Abstract: Northern Namibia is fed by the Kavango, the Kwando, and the Zambezi Rivers, which flow from Angola and Zambia. Flows fluctuate in both the short and long terms as a result of climate fluctuations, with major impacts on fish stocks. Rural communities' fishery-dependent livelihoods are thus vulnerable to impacts of climate change, illustrated here by changes in the fish and fisheries of the ephemeral Lake Liambezi over a filling, stabilisation, and recession cycle between 2009 and 2016. The fish population of the lake, after filling from the Zambezi in 2009, was initially dominated by small cyprinids, mainly *Enteromius paludinosus*, and later by other small species, notably *Brycinus lateralis*. A lucrative fishery developed for more valuable large cichlids that became well established from 2010. The establishment of the fishery led to an influx of migrant fishers and an export fish trade to Zambia and the Democratic Republic of the Congo. Lakeside communities organised fisheries committees to address management issues, and the fishery remained productive until a natural stock collapse when the lake went into recession in 2016. This followed years of low river flow that resulted in negligible inflow to the lake after 2011. In contrast to the productive Liambezi fishery, other Zambezian riverine fisheries experienced economic collapse over the same period due to rapid and uncontrolled increase in destructive fishing methods that communities appeared powerless to prevent. Management recommendations from the project's research results have now been implemented by the government and adopted by some communities, but with the likelihood of lower flood levels in future as a result of climate change, the situation remains critical. Developing proactive management approaches to maximise yields from ephemeral water bodies, while mitigating against excessive exploitation in perennial rivers, is a major challenge.

Resumo: O Norte da Namíbia é alimentado pelos rios Kavango, Kwando e Zambezi, os quais fluem de Angola para a Zâmbia. Os caudais oscilam tanto a curto como a longo prazo, como resultado das flutuações climáticas, com importante impacto nas populações de peixes. A subsistência de comunidades rurais dependentes das pescas está assim vulnerável aos impactos das alterações climáticas, ilustradas aqui pelas mudanças no peixe e na pesca no efémero Lago Liambezi ao longo de um ciclo de enchente, estabilização e recessão entre 2009 e 2016. A população de peixe do lago após a enchente do Zambezi em 2009 foi inicialmente dominada por pequenos ciprinídeos, *Enteromius paludinosus*, e posteriormente por outras pequenas espécies, nomeadamente *Brycinus lateralis*. Uma pesca mais lucrativa desenvolveu-se com base em ciclídeos maiores e mais valiosos que se estabeleceram em 2010. O estabelecimento da pesca resultou num influxo de pescadores migrantes, com um comércio de exportação de peixe para a Zâmbia e a República Democrática do Congo. As comunidades junto ao lago organizaram comités de pesca para abordar questões de gestão e as pescas permaneceram produtivas até ao colapso natural da população, quando o lago iniciou a recessão em 2016. Esta resultou dum período de reduzidos fluxos fluviais, que resultaram num influxo negligenciável para o lago após 2011. Em contraste com as produtivas pescas de Liambezi, outras actividades pesqueiras ribeirinhas Zambezianas verificaram o colapso económico durante o mesmo período, como resultado de um aumento rápido e descontrolado do uso de métodos destrutivos de pesca que as comunidades não conseguiram prevenir. Recomendações de gestão provenientes dos resultados da investigação do projecto foram implementadas pelo governo e adoptadas por algumas comunidades. No entanto, com a probabilidade de níveis de inundação mais baixos no futuro devido às alterações climáticas, a situação mantém-se crítica. O desenvolvimento de abordagens de gestão proactivas para maximizar rendimentos dos corpos de água efémeros, enquanto mitigam a exploração excessiva em rios perenes, representa um grande desafio.

Introduction

Namibia is an arid country, and rainfall in the northern regions is inadequate to generate perennial rivers. These regions are, nevertheless, well-watered by a highly complex system of rivers (Kavango, Kwando, and Zambezi) that flow from the southern highlands of Angola, with Zambezi flow augmented by a number of large tributaries in northern Zambia (Fig. 1 and 2). These rivers feed floodplains, swamps, and ephemeral lakes in the north of Namibia. In years of unusually high flood levels, the three river systems are interlinked. The Okavango Delta links to the Kwando/Linyanti swamps via the Selinda spillway, and the Kwando links through the Linyanti Swamp and Lake Liambezi to the Chobe and thence to the Upper Zambezi (Skelton, 2001). Thus, the river systems largely share the same fish fauna, though with some local endemics, particularly in headwater tributaries.

Because the scale of annual flooding reflects rainfall intensity hundreds of kilometres to the north, independent of climate variability in Namibia itself, changes in the extent and intensity of Namibia's rainfall have a minimal impact on these rivers.

There are long-term variations in the scale of annual flooding in these rivers, seen in the Zambezi river level data from Victoria Falls (Fig. 3). From the late 1940s to the end of the 1970s, average annual rainfall was much higher than in the preceding decades and in the years since 1980. This places in perspective the floods of 2009 and 2010 that were considered to be "disastrous" floods in Namibia. They were in fact normal, with peaks comfortably exceeded in 1948, 1952, 1957, 1958, 1961, 1963, 1969, and 1978. The major variations in flooding will obscure impacts, if any, of anthropogenic climate warming on the fisheries. Instead, we illustrate the impacts of natural changes in the aquatic environment on fish and fisheries. The major focus is on the changes in the dynamics of the fish and fisheries of Lake Liambezi over the last decade as the fish populations and fishery of this large floodplain lake responded to a natural cycle that is

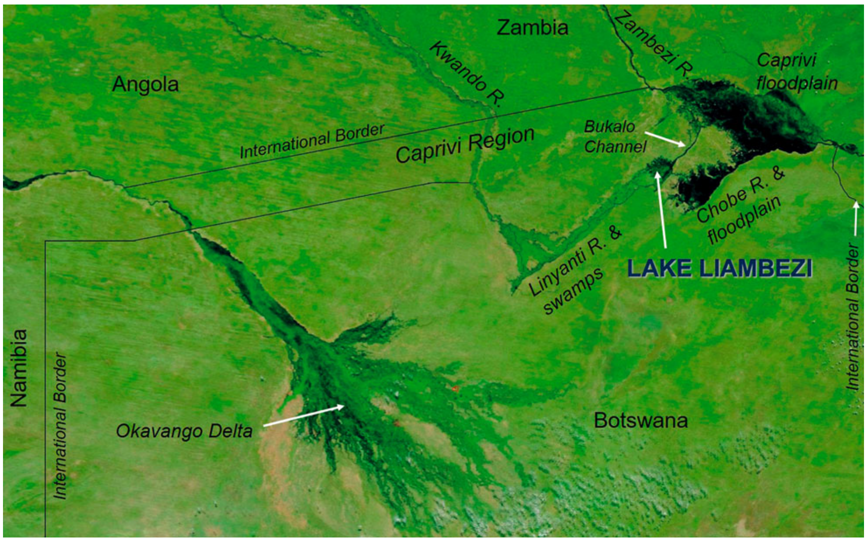

Figure 1: Satellite photo of the Zambezi, Kwando, and Kavango River systems taken at high water in May 2009, showing their interrelationships and the position of Lake Liambezi, the main focus of this chapter (from Tweddle et al., 2011, satellite photo © NASA Earth Observatory).

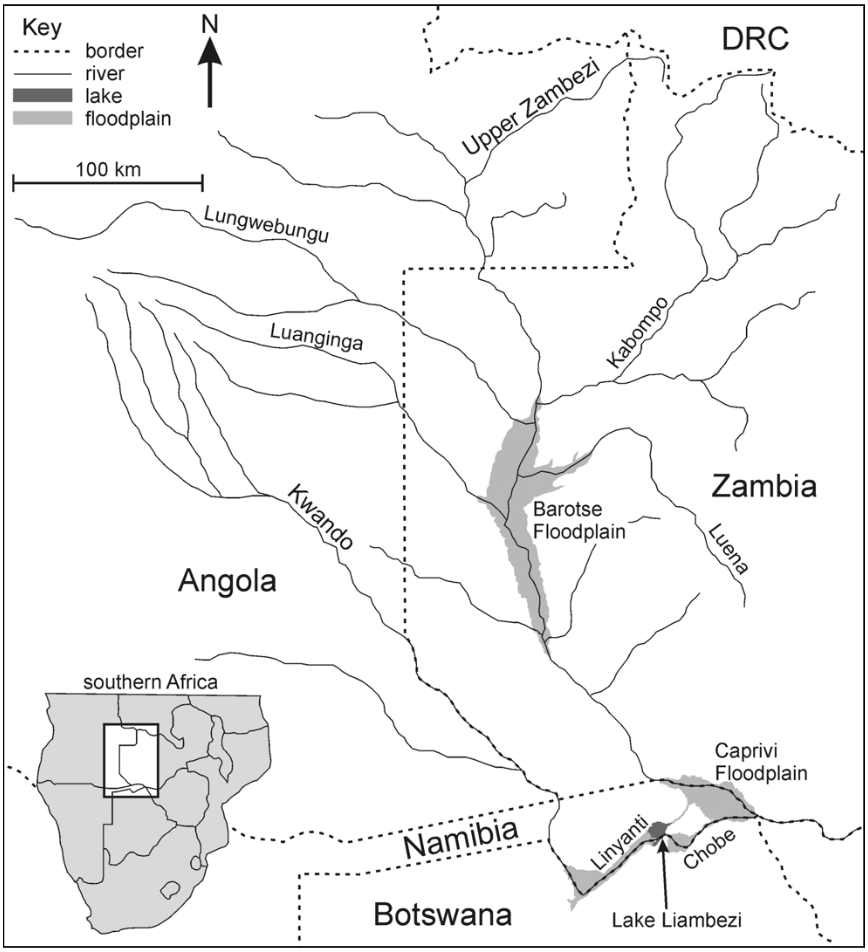

Figure 2: The Upper Zambezi system, showing the location of the major floodplains and Lake Liambezi (from Peel, 2017).

a microcosm of what might be expected to occur in the larger system as a whole if the rivers and floodplains are reduced in area and volume as a result of longer-term climate changes that are projected for the region (Midgley et al., 2005; Turpie et al., 2010). Lake Liambezi is ephemeral, undergoing cyclical phases of flooding and drying (Peel et al., 2015b). Prior to the most recent full phase, an earlier period of inundation lasted from circa 1966 until, after five consecutive years of

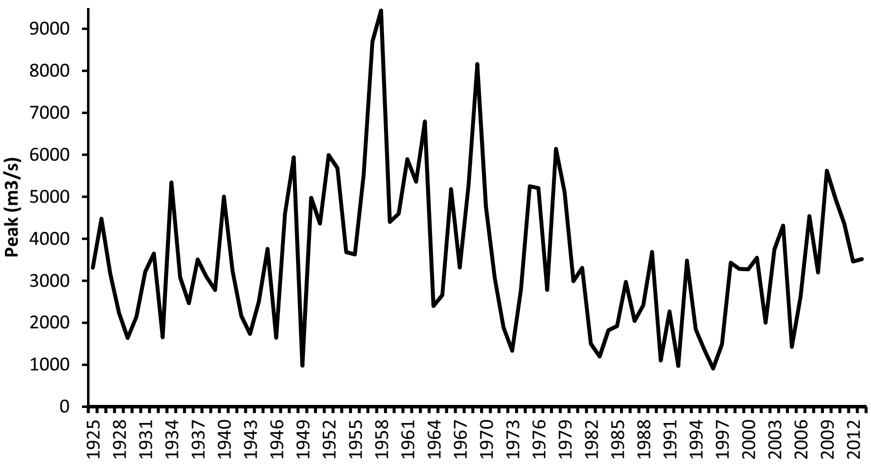

Figure 3: Peak 5-day average flow rates per year of the Zambezi River at Victoria Falls.

low floods, it dried up in 1985 (Grobler & Ferreira, 1990). The lake supported an important commercial fishery through the 1970s, yielding over 600 tonnes in 1974 (van der Waal, 1980). These catches were greatly exceeded in the most recent period of inundation, starting in 2007, through complete inundation in 2009; thereafter the lake saw declining water levels and was near drying out by the end of 2016.

There is usually a direct correlation between the size and scale of annual flooding in river/floodplain fisheries and fish yields (Welcomme & Hagborg, 1977). Large floods lead to high recruitment because of the greatly increased breeding and nursery areas, and this is reflected in catches. In some cases there is a time lag, depending on the rate of growth of the fish species, the size at recruitment to the fishery, and the fishing intensity. There may be a direct correlation between the scale of flood and catches in the same year in cases where the fishery is based on young of the year or short-lived fish species (e.g., Lae, 1992; Halls, 1998; Tweddle, 2015), or there may be a time lag of 2–4 years (Welcomme, 1978, 2001) between high floods and consequent high yields where the fishery is for longer-lived species.

In addition to the impact of annual and long-term natural flood cycles, fishing effort has a major impact on the fish faunal assemblages. The freshwater fisheries of Namibia and its neighbouring countries are under increasing pressure, resulting in overexploitation of the resources (Tweddle, 2010; Tweddle et al., 2015). In this chapter, we discuss the biodiversity and complex dynamics of the riverine and floodplain ecosystems and the livelihood strategies of riparian and floodplain dwellers and their dependence on the resources. Understanding of the complex interrelationships of climate, fish, and people is essential for management of these vitally important resources. The lessons learned through the research and through existing management programmes in north-eastern Namibia should contribute to effective fisheries management mechanisms throughout the region.

Research approach

The SASSCAL programme provided the opportunity for an interdisciplinary research approach that applied fisheries and social survey data to better understand the fish populations of the rivers, floodplains, and lakes of north-eastern Namibia and south-western Zambia in relation to both fisheries yields and potential climate change impacts. In Lake Liambezi, changes in fish populations during filling, stabilisation, and recession were studied using a range of standardised experimental fishing gears, of which a standardised fleet of gillnets with 11 different mesh sizes was the main sampling gear. Sampling was conducted quarterly during the SASSCAL programme (Peel, 2017) and was supplemented by recording fishers' catches at Shamahuka landing site. The ecology of key fish species and population dynamics in relation to the productivity of the system and food web structure changes over time were researched in depth, including age, growth, and reproductive studies of the key fishery species to assess their vulnerability to fishing (Peel, 2017; Taylor, 2017). Structured interviews with lakeshore communities, fishers, and traders elucidated the impacts of changing dynamics in the Lake Liambezi fishery on fishing communities. The river and floodplain fisheries were assessed through the use of community-based monitors and standardised research netting. Low-water and high-water sampling and catch assessment surveys were conducted for the Barotse floodplain (Fig. 2) fishery in Zambia.

Lake Liambezi

The Lake Liambezi wetland system covers some 300 km^2, of which 100 km^2 is open water when the lake is full (Seaman et al., 1978; Peel et al., 2015b). The lake is shallow, with an average depth of approximately 2.5 m and a maximum depth of 7 m at its peak in 2010. It receives water from several sources. The primary source is the Zambezi River, whose waters enter the lake during years of high flooding from two directions. Annually, when the Zambezi floods, the Chobe River reverses flow direction and enters the lake from the south-east, while the Bukalo Channel flows from the Zambezi River floodplains into the north-east of the lake. The Kwando River flows south from Angola into the Linyanti wetlands to the west of the lake. Its waters percolate through the wetlands and out via the Linyanti Channels, which flow eastward along the Namibia–Botswana border into the lake. Rainfall and runoff from the area north of the lake also contribute water inputs. Outflow from the lake via the Chobe River when floodwaters recede is intermittent and dependent on lake level.

Lake Liambezi was inundated from ~1966 until 1985 (Grobler & Ferreira, 1990); since then it has remained mainly dry until receiving moderate inflow in 2007, and then filled completely in the 2009 flood. After further inflow in 2010 and 2011, it has not received inflow since, and dried to shallow turbid lagoons by

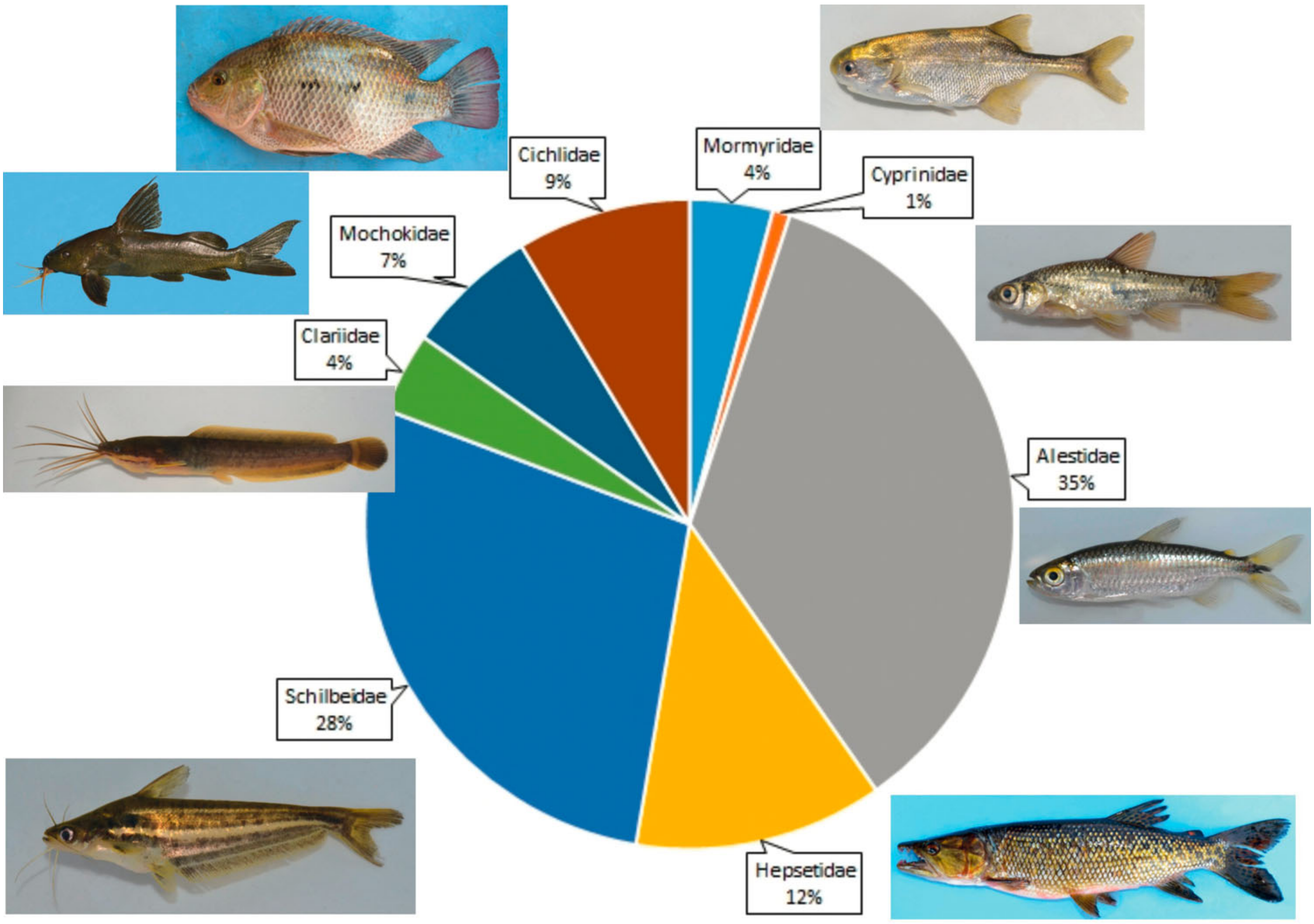

Figure 4: Percentage contribution by weight of the fish families. Illustrated with common species representative of the experimental gillnet catches in Lake Liambezi, 2013–2014. The commercially important large cichlids made up only 9% of the overall catch, whereas the small alestid *Brycinus lateralis* made up 35% of the catch. Species illustrated: Cichlidae — *Oreochromis andersonii*; Mormyridae — *Petrocephalus* cf. *okavangensis*; Cyprinidae — *Enteromius paludinosus*; Alestidae — *Brycinus lateralis*; Hepsetidae — *Hepsetus cuvieri*; Schilbeidae — *Schilbe intermedius*; Clariidae — *Clarias gariepinus*; Mochokidae — *Synodontis nigromaculatus*.

late 2016. This chapter reports on the major collaborative research programme that followed the complete filling, stabilisation, and recession of the lake over that time.

Fish assemblage in Lake Liambezi and changes over time

In the period from inundation of the lake in 2007 to 2009 to recession in 2016, the fish assemblage of Lake Liambezi underwent a succession from a colonising assemblage dominated by floodplain specialists to a relatively stable lacustrine assemblage. The evolution of the fish community was characterised by three distinct phases. The first phase involved the inundation and colonisation of the lake in 2007, followed by its decline up until the floods that filled the lake in 2009. During this phase the lake was colonised by fishes from the Zambezi and Chobe floodplains, composed predominantly of cyprinids, notably the straightfin barb, *Enteromius paludinosus*; the dashtail barb, *E. poechii*; the catfishes *Schilbe intermedius* and *Clarias gariepinus*; and the bulldog *Marcusenius altisambesi*. These are specialists at colonising newly flooded environments. Following inundation, the water level declined, concentrating fishes in an increasingly harsh environment that resulted in high mortality from both abiotic drivers and fishing. The filling of the lake in the March 2009 floods marked the beginning of the second successional phase. The initial main coloniser, *E. paludinosus,* saw a significant decline in abundance despite the possibility of external recruitment from the neighbouring floodplains. The slender robber, *Rhabdalestes maunensis*, underwent explosive population growth between 2009 and 2010 but crashed equally rapidly within a year. The striped robber, *Brycinus lateralis,* surpassed its smaller relative and went on to dominate the fish community. This marked the beginning of a third phase, in 2011, as the fish community began to approach a more stable state. Larger, slower-growing species increased steadily in abundance, highlighted by the development of the fishery, based primarily on large tilapiine cichlids. From 2011 to 2014, the fish community was dominated by *B. lateralis* and *S. intermedius*. These two species made up 63% of the fish by weight in the experimental fishing gears by 2014 (Fig. 4) (Peel et al., 2015a). By 2016, however, the lake went into recession. Unfortunately no data are available on the changing fish community during that time. Plates 1 and 2 illustrate all species recorded in the lake during the project research programme.

Plate 1


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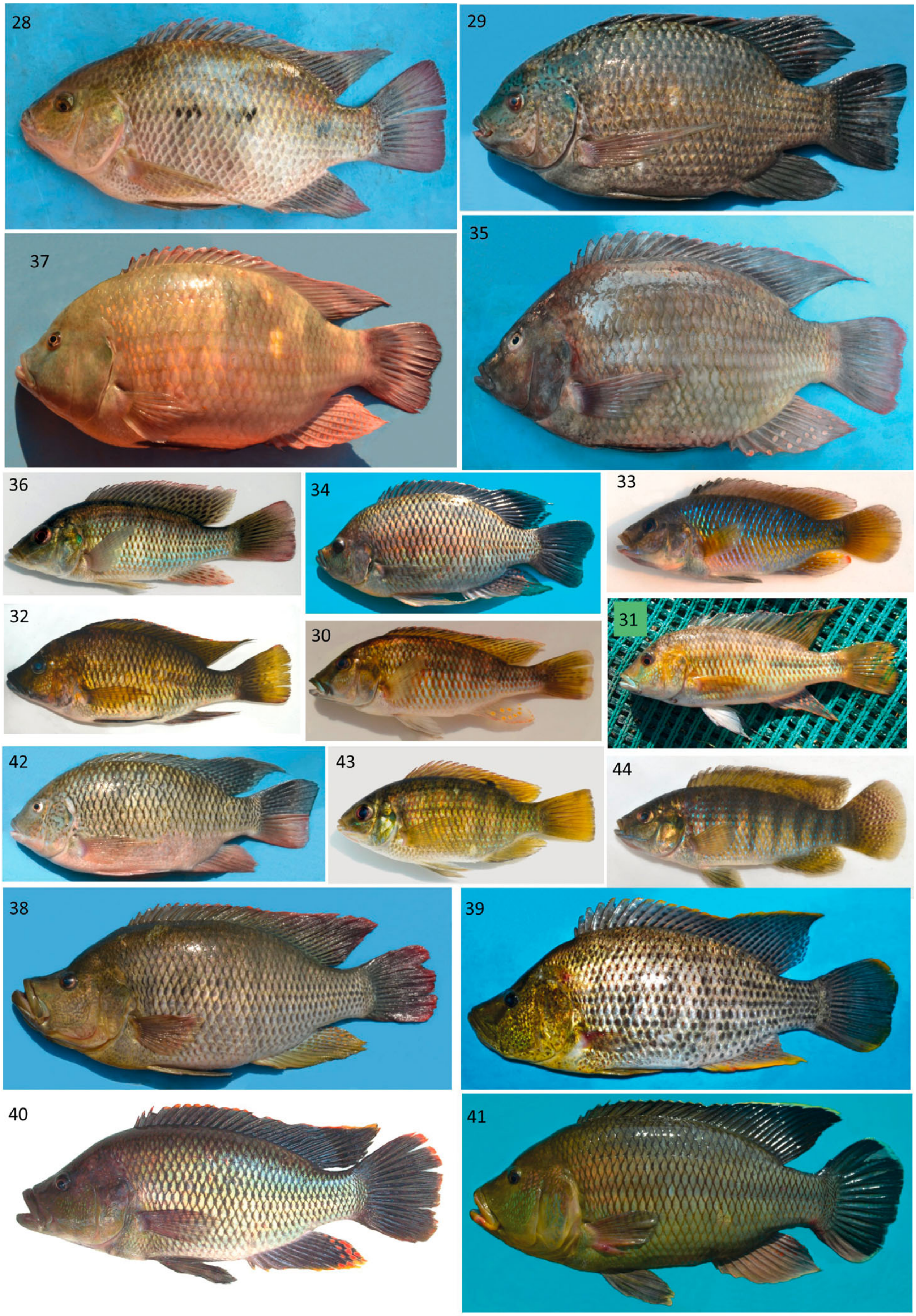
Plate 2



Plates 1 and 2: Photographs of all fish species recorded from Lake Liambezi during the course of the project. This list represents approximately half of the total number of species known from the neighbouring Upper Zambezi floodplains. The number on each photo identifies the fish as in this list. Scientific names are listed, plus an indication of average adult total length in cm. Several species need further taxonomic study, particularly the large *Pharyngochromis* species.

No	Species scientific name	Length (cm)
	Mormyridae	
1	*Marcusenius altisambesi* (Kramer, Skelton, van der Bank & Wink, 2007)	20
2	*Mormyrus lacerda* (Castelnau, 1861)	40
3	*Petrocephalus* cf. *okavangensis* Kramer, Bills & Skelton, 2011	10
4	*Pollimyrus* cf. *cuandoensis* Kramer, van der Bank & Wink, 2014	7
	Cyprinidae	
5	*Enteromius barnardi* (Jubb, 1961)	4
6	*Enteromius bifrenatus* (Fowler, 1935)	7
7	*Enteromius haasianus* (David, 1936)	3
8	*Enteromius multilineatus* (Worthington, 1933)	4
9	*Enteromius paludinosus* (Peters, 1852)	10
10	*Enteromius poechii* (Steindachner, 1911)	10
11	*Enteromius radiatus* (Peters, 1853)	7
12	*Enteromius unitaeniatus* (Günther, 1866)	7
13	*Coptostomabarbus wittei* (David & Poll, 1937)	3
14	*Labeo cylindricus* Peters, 1852	20
15	*Labeo lunatus* Jubb, 1963	30
	Alestidae	
16	*Brycinus lateralis* (Boulenger, 1900)	10
17	*Micralestes acutidens* (Peters, 1852)	6
18	*Rhabdalestes maunensis* (Fowler, 1935)	5
19	*Hydrocynus vittatus* Castelnau, 1861	50
	Hepsetidae	
20	*Hepsetus cuvieri* Castelnau, 1861	30
	Schilbeidae	
21	*Schilbe intermedius* Rüppell, 1832	28
	Clariidae	
22	*Clarias gariepinus* (Burchell, 1822)	100
23	*Clarias ngamensis* Castelnau, 1861	60
24	*Clarias stappersii* Boulenger, 1915	30
25	*Clarias theodorae* Weber, 1897	25
	Mochokidae	
26	*Synodontis nigromaculatus* Boulenger, 1905	30
27	*Synodontis* spp.	25
	Cichlidae	
28	*Oreochromis andersonii* (Castelnau, 1861)	35
29	*Oreochromis macrochir* (Boulenger, 1912)	30
30	*Pharyngochromis acuticeps* (Steindachner, 1866)	12
31	*Pharyngochromis* sp. 1	20
32	*Pharyngochromis* sp. 2	20
33	*Pseudocrenilabrus philander* (Weber, 1897)	7
34	*Sargochromis carlottae* (Boulenger, 1905)	25
35	*Sargochromis codringtonii* (Boulenger, 1908)	30
36	*Sargochromis greenwoodi* (Bell-Cross, 1975)	25
37	*Sargochromis giardi* (Pellegrin, 1903)	35
38	*Serranochromis altus* Winemiller & Kelso-Winemiller, 1990	40
39	*Serranochromis angusticeps* (Boulenger, 1907)	25
40	*Serranochromis macrocephalus* (Boulenger, 1899)	20
41	*Serranochromis robustus jallae* (Günther, 1864)	40
42	*Coptodon rendalli* (Boulenger, 1896)	25
43	*Tilapia ruweti* (Poll & Thys van den Audenaerde, 1961)	9
44	*Tilapia sparrmanii* A. Smith, 1840	14
	Poeciliidae	
45	*Micropanchax hutereaui* (Boulenger, 1913)	2
46	*Micropanchax johnstoni* (Günther, 1893)	5
47	*Micropanchax katangae* (Boulenger, 1912)	4
48	*Micropanchax* sp. 'pygmy topminnow'	2
	Anabantidae	
49	*Ctenopoma multispine* Peters, 1844	6

The Lake Liambezi fishery

Until 2016, when the lake entered a drying phase, the fishery targeted large cichlid species, most notably the tilapiines *Oreochromis andersonii*, *O. macrochir*, and *Coptodon rendalli*, together with the predatory *Serranochromis macrocephalus*. To catch these fishes, the most common mesh sizes used in gillnets were between 89 and 114 mm (Peel et al., 2015b). Unlike those in other fisheries in the region, such as the Upper Zambezi including the Barotse Floodplain in Zambia, the Lake Liambezi fishers did not follow a trend towards using ever smaller mesh sizes; as a result, the fishery remained healthy and economically productive until the lake recession in 2016. Plates 3 and 4 illustrate the changes in the lake and fishery over time. Commercial gillnet catch per unit effort (CPUE) varied seasonally, being lower during summer from October to January. Overall, the CPUE estimated from the commercial fishers, averaging 7 kg per 100 m net per night was significantly higher than that recorded by independent sampling using similar monofilament gillnets. This reflected the fishing methods used by the commercial fishers. Although illegal, driving fish into nets by bashing the water (known as *kutumpula*) and by actively using the nets as seines were widely used techniques. In total, 343 canoes were counted in the lake in May 2013. Assuming that all canoes were used for fishing, and extrapolating from the quantity of fish brought in per day by each dugout canoe at Shamahuka landing site in 2011 and 2012 (mean catch 36 kg), the annual yield of the fishery for 2011/2012 is estimated to have been 2,700 tonnes.

As the fishery targeted the larger, economically valuable cichlids, which in fact comprised only 9% of the fish biomass (Fig. 4), it was proposed to develop a 25 mm mesh surface gillnet fishery for the striped robber, *B. lateralis*, because of its abundance (Fig. 4), palatability, and ease of marketing (Peel et al., 2015a). Research netting proved that it was feasible to establish such a fishery without affecting the stocks of the economically important large cichlids, as the surface-set nets caught almost entirely *B. lateralis* and a negligible quantity of juvenile cichlids (photos in Plate 4). The establishment

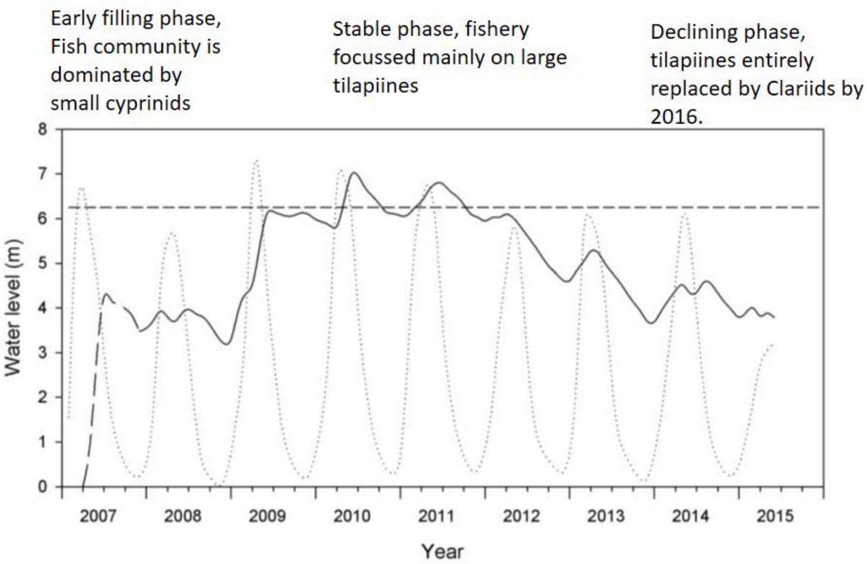


Figure 5: Water level of Lake Liambezi (——) since inundation starting in 2007 (dashed line at beginning as no data). The annual flood cycle of the Zambezi River (··········) and the level at which the Zambezi River spills into the lake (- - - - -) are illustrated to show when the lake received inflow. The phases of the fishery are described above the chart.

of such a fishery would have required changes to Namibia's fisheries regulations, as such small meshes are currently illegal (MFMR, 2003). The lake, however, entered a rapid drying phase by 2016 and plans for such a fishery were therefore shelved (Peel et al., 2015a). The changes in lake level and consequent changes in the fishery are summarised in Figure 5.

With the lake receding in 2016 to a series of small turbid lagoons, the cichlids disappeared from the catches and the drying lagoons yielded instead large quantities of catfish, *C. gariepinus* and *C. ngamensis*. No direct catch recording system was in place at this time, but enormous quantities were being salted and dried and exported through Zambia to the DRC (Plate 4).

Timeline of events in the Lake Liambezi Fisheries (2001 to 2017)

In addition to the biological and fisheries studies on Lake Liambezi, the fishing communities around the lake were a major focus of study (Murphy, 2017). Because the lake is ephemeral, communities have to be flexible in their livelihood strategies, switching from land-based sources of food and income to lacustrine sources as the lake rises and falls. To manage the harvesting of natural resources at optimum levels, research focused on the fishing communities along the lakeshore.

2001 – Lake started filling from the Chobe River and fishing started at the inflow.

2003 – Bukalo Channel flowed into lake for first time in twenty years.

2006 – Water entered the lake from the Linyanti River to the west.

2008 – Fish from Lake Liambezi traded at Katima Mulilo market.

2009 – Big flood filled lake. At Muyako village, influx of migrant fishers and traders (mainly foreign nationals, especially Zambians) and Namibian-owned small-scale fishing enterprises proliferated — traders supplied gear and hired fishers. Because of increased competition for fish, illegal fishing methods started and proliferated — bashing (*kutumpula*) and dragnetting (*ituwa*). Muyako Traditional Authority called community meeting, leading to election of Muyako Fish Committee.

2010 – Floods maintained high lake level. Widespread use of monofilament gillnets, replacing former less efficient multifilament nets (mono- is single-strand, almost transparent nylon; multi- is nylon twisted thread). Three tonnes per day of fresh fish passed through Katima Mulilo market, with 90% from Lake Liambezi. Lake yielded 1,000 tonnes per year of high-value tilapias (Tweddle et al., 2011). Trading dominated by Zambian nationals with fish loaded at the lakeside. Lakeside harbours, especially Shamahuka, grew to sizable settlements. Masokatwani Fish Committee was established in response to excessive exploitation. Namibian Ministry of Fisheries and Marine Resources (MFMR) and police (NamPol) active in the lake, enforcing fisheries and immigration regulations.

2011 – Floods maintained high lake level. To regulate the fish trade, Zambian trucks transporting dried and salted fish were relocated from lakeside villages to the Zambian border. Namibian traders from Masokatwani used fish trade corridor through Zambia to DRC for the first time.

2012 – Mainly monofilament nets in use. Estimate of 2,700 tonnes as annual yield in lake in 2011/2012, 4.5 times more than the 600 tonnes recorded in 1974 (Peel et al., 2015b).

2013 – Lusu and Zilitene/Kwena Fish Committees established. New road to Zilitene allowed for fish trading from Zilitene to switch from Muyako to lakeside harbours at Zilitene. Security forces enforced immigration regulations and deported illegal foreign migrants.

2014 – Helicopter used in support of government agencies engaged in curbing illegal activities.

2015 – Water level dropped. Closed season implemented in Namibia for the first time (December to February).

2016 – Water level continued dropping. Farmed fish (Nile tilapia from fish farm in Livingstone, Zambia) now sold at Katima Mulilo market as fish supply from Lake Liambezi dried up. Ban on use of monofilament nets implemented by MFMR.

2017 – Lake drying up. Lack of fish supply to Katima Mulilo market from Lake Liambezi caused fish price to soar.

Box 1: A historical summary of the changes that took place in the communities adjacent to the lake over the period from 2001, when some water first entered the lake after it had been effectively dry since 1985, until the study ended in 2016. The information is derived from participatory meetings conducted at four major fishing communities around the lake in 2016.

Plate 3

Lake Liambezi shortly after filling in 2010, showing extensive areas of flooded terrestrial vegetation and few canoes at landing site.

Catch of clariid catfishes in early filling phase of lake.

Anglers assisting research on fish species composition at flooded village.

Shamahuka fish landing site during fishery peak, 2012.

Good catch of large cichlids at Shamahuka, 2012.

Cichlids being sundried on rack at lakeshore for transport to market.

Fresh cichlids from Lake Liambezi being loaded with ice on truck for export to Zambia, Katima Mulilo market.

Valuable catch of large cichlids from Lake Liambezi when the lake was full and the fishery at its peak. Inset: Catches being weighed at the landing as part of the research programme.

Plate 4

Launching SASSCAL research boat on Lake Liambezi.

Successful experimental gillnetting (25 mm mesh) for *Brycinus lateralis*.

Successful experimental gillnetting (25 mm mesh) for *Brycinus lateralis*.

Salted catfish from Lake Liambezi being sundried in preparation for export to DRC, October 2016.

Dried salted catfish from Lake Liambezi being packaged at the Wenela Border Post between Namibia and Zambia for onward transport to the DRC, October 2016.

Abandoned canoes and fishing nets on shore of receding Lake Liambezi, October 2016.

Muddy turbid lagoon remaining as Lake Liambezi dries out, November 2016.

Figure 6: GoogleEarth image of the dry bed of Lake Liambezi in December 2006, showing a patchwork of agricultural fields (© GoogleEarth).

Changes in the status of Lake Liambezi: the fishery in relation to community livelihoods

Prior to inundation, the main source of livelihoods was dry-land cropping (Fig. 6), with cattle ownership for wealthier households. Livelihood strategies changed considerably with the inundation of the lake as local residents were deprived of their farmlands in the fertile soils of the pre-inundated lake basin. Some local residents around the lake switched their livelihoods from dry-land cropping (with consumption and sale of surplus maize) to fish harvesting (with consumption and sale of fish). This was highly advantageous, as fish could be harvested throughout the year whereas maize is harvested and sold once a year. This had a major positive impact on livelihoods in general. While women in Namibia do not traditionally fish using boats and nets, the opportunity arose for them to trade in fish. To maximize returns, some local traders, including women, transported fish to the places commanding higher prices than markets at the lakeshore or in Katima Mulilo, and even took dried, baled fish to Kasumbelesa on the Zambia–DRC border for onward export into the Democratic Republic of the Congo.

Resource-poor households in Muyako village, as determined by a participatory wealth-ranking exercise among 145 households (Murphy, 2017), did not have access to resources to fish (e.g., labour, makoros, nets) but did, however, benefit from easy access to a protein-rich food at a relatively cheap price compared to pre-inundation times. With the exception of Muyako, all other villages had households that hired fishers.

Although the restoration of the Liambezi fishery brought considerable benefits to the communities, there were problems with the management of the fishery (Tweddle et al., 2015). The high catches resulted in an influx of fishers from outside the area, mainly from neighbouring Zambia, and thus very high fishing effort. While continuing to use the optimum mesh sizes in their nets, the fishers increasingly resorted to illegal and destructive fishing methods to maintain catch rates, including seine netting and *kutumpula*. Fishing camps on islands also became health hazards and centres for illegal activities. In response, government authorities made some coordinated campaigns to remove illegal migrants, while communities formed their own management committees, incorporating village headmen and working with the Traditional Authority (Murphy, 2017). These committees had varying degrees of success. The Muyako committee, for example, was initially successful in controlling the fishery, registering all fishers in their area and setting mesh size regulations stricter than those under the Fisheries Act (Tweddle et al., 2012). Despite problems created by the increased pressures on the fishery with the influx of migrant fishers, the committees continued to have an influence and with help from law enforcement bodies (through the MFMR Inspectorate) maintained the large cichlid fishery until the lake recession.

The drying up of Lake Liambezi through 2016 and 2017 had a negative impact on local people's livelihoods. Local residents are now returning to dry-land cropping and the sale of natural products including reeds, grass, poles, devil's claw, and thatching grass, but these activities do not adequately replace the livelihood value of the fishery. The negative livelihood impact of the drying up of the lake is severe and is expected to lead to problems such as an increase in hunger and theft.

Trends in the other inland fisheries of the region

Zambezi/Chobe floodplain

Until recently, studies on the fisheries of the Upper Zambezi River and associated floodplains were sparse, with no data on the status of the fishery prior to annual experimental gillnetting that began in 1997 (Hay & van der Waal, 2009). Their data suggested very intense fishing effort on the larger cichlid species. It was not until 2010 that any fish catch data were collected (Tweddle et al., 2015), using local villagers to record any fish catches they saw on twice-weekly walking patrols in the Zambezi/Chobe floodplains. Such data can be used to show trends in a fishery but are inadequate to conclusively demonstrate trends on their own. In this case they highlighted a dramatic decline in catches from 2010 to 2012, despite high floods that should have boosted recruitment (Tweddle et al., 2015). This agreed with trends demonstrated in the annual experimental gillnetting programme conducted by MFMR with support from Namibia Nature Foundation fisheries projects including SASSCAL. From 2010 to 2012 the catch rates declined by approximately 75% despite a rapid change in the fishery from using multifilament nylon nets to monofilament (Fig. 7, from Tweddle et al., 2015). The monofilament nets are more than three times as effective as multifilament in this area (Peel et al., 2015b), indicating that fish stocks in the Upper Zambezi River in the Zambezi/Chobe floodplain area had declined by more than 90%. More recent research data confirm that the catches have shown no sign of recovery (F. Jacobs, pers. comm.).

Central Barotse Floodplain, Zambia

Until recently, few studies had been made on the Central Barotse Floodplain (CBF) fishery in Zambia, upstream from the Zambezi/Chobe floodplains (Fig. 2), despite its enormous area and the dependence of the local population on its fish resources (Tweddle et al., 2015). Apart from outdated FAO reports (Duerre, 1969; Kelley, 1968; Weiss, 1970), a descriptive report by Bell-Cross (1974), and fish ecology studies by Winemiller (1991) and Winemiller & Kelso-Winemiller (1994, 1996), little information was available on the CBF fishery before fish biodiversity surveys carried out in 2002–2003 (Tweddle et al., 2004). At that time, the Barotse Royal Establishment and local fishing community leaders expressed great concern about declining yields and, more worrying, inappropriate fishing methods. Fishing pressure was intense, particularly in areas of relatively high human population, and the concentration of fishermen was much higher than reported previously (Welcomme, 1985). Because of the concerns raised by Tweddle et al. (2004, 2015), low- and high-water surveys of the fish and fisheries were incorporated into the SASSCAL research programme.

The low-water survey was reported on by Peel et al. (2014). They reported very low catches and a fishery based on small species, with a notable absence of the larger cichlid species that are the most economically important species in the fishery. The subsequent high-water survey conducted by D. Tweddle in May 2017 confirmed that the fishery was severely overfished both economically and biologically.

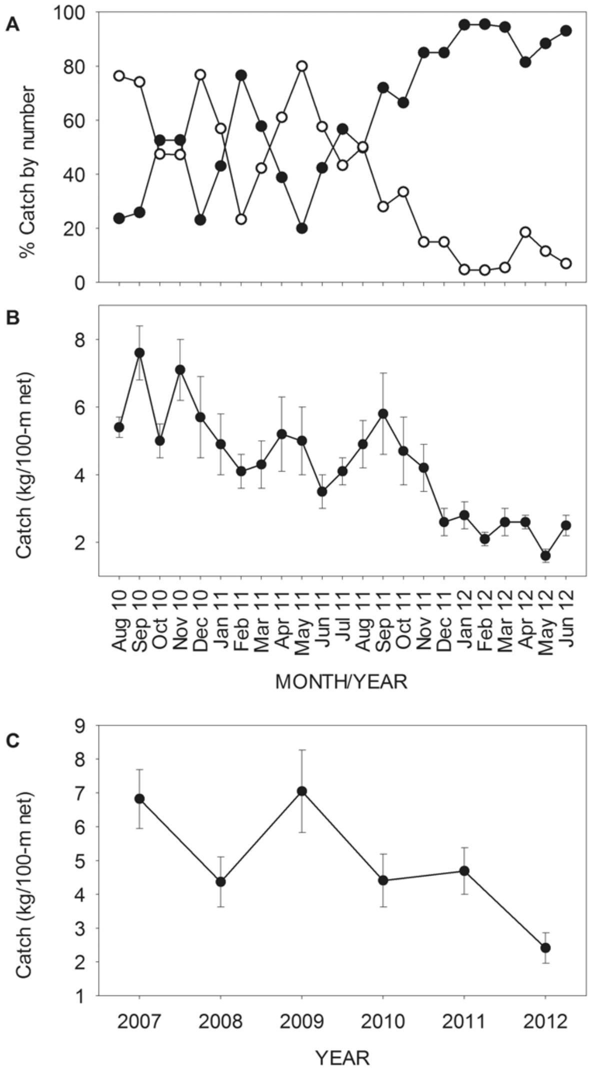


Figure 7: Evidence for decline in CPUE in the Upper Zambezi River fishery in the Zambezi/Chobe floodplain area. (a) Change from multifilament (open circles) to monofilament (closed circles) netting, demonstrated by the percentage of fish caught in each mesh type (data from community monitors). (b) Decline in CPUE in the fishery, all netting combined as passive and active gears not adequately differentiated (data recorded by community monitors). (c) Decline in CPUE in MFMR experimental gillnet catches at standard stations along the Zambezi River (source: Tweddle et al., 2015).

The fishing methods observed in use were fine meshed monofilament gillnets and dragnets made of shade cloth lined with cotton cloth, known as *sefa-sefa* (meaning 'sieve'). Over 50% of the observed catches were juvenile tigerfish, *Hydrocynus vittatus*, about 20 cm long, with most of the rest being small cichlid species, particularly the banded tilapia, *Tilapia sparrmanii*, and the banded jewelfish, *Hemichromis elongatus*. Experimental gillnetting yielded only small numbers of juvenile tigerfish and almost nothing else.

Like the Zambezi/Chobe floodplains, therefore, the CBF fishery is severely overfished, both biologically and economically. There is, however, one fishery area adjacent to the CBF where community fishery management works well. Over 200 pans in Liuwa Plain National Park adjacent to the CBF are managed through the system of Traditional Authority exercised by the Barotse Royal Establishment. Through this system, in cooperation with the park management, the pans are overseen by village headmen (called *indunas*), who control access rights and time of fishing (Peel et al., 2013). The successes of community participation in management in Liuwa Plain National Park and around Lake Liambezi demonstrate potential for similar management initiatives elsewhere in the system, although the problems faced in the larger floodplain systems are on a much greater scale.

Management recommendations based on the results of the SASSCAL research programme

Lake Liambezi

The fish stocks of Lake Liambezi during phases of inundation are largely independent of the adjacent river and floodplain fisheries (Peel, 2017). The species composition of the fish fauna differs between different periods of inundation, and changes over time as the lake fills, stabilises, and then goes into recession. Because of this, fisheries in the lake must be managed independently of the fisheries of neighbouring river systems. The lake, when full, is a highly productive fishery for valuable large cichlid species (Peel et al., 2015). Based on the results of the SASSCAL-supported research on the biology of the key species (Peel, 2017; Taylor, 2017), the fishery over the latest period of inundation used nets with the optimum mesh size for the species involved and thus maintained a productive and economically lucrative fishery until the major lake recession of 2016. The response of the communities was encouraging, with the establishment of a number of community fisheries management committees in conjunction with the Traditional Authorities. Some of these committees were set up with advice from MFMR and the Namibia Nature Foundation (NNF) fisheries programme, while others were formed independently in response to perceived problems in the fishery. These committees developed their own regulations, and in future when the lake is full it is recommended that the village management committees be fully supported by Namibia's MFMR and that the fishery be controlled by the local communities, with illegal immigrants excluded (or better regulated by the Namibian authorities if there should be spare fishing capacity once all Namibian fishers have been accommodated).

The fishery should be aimed at the large cichlid species as in the 1970s and in the most recent inundation (Peel et al., 2015b; Peel, 2017; Taylor, 2017), as these yield the most valuable returns. The fishery used nets with mesh sizes large enough to allow most of the valuable large cichlids to reach maturity before entering the fishery. There may, however, be scope for a small meshed floating gillnet fishery for *B. lateralis* if this species again becomes abundant in the lake in its next inundation (Peel et al., 2015a).

Upper Zambezi floodplain fisheries

In contrast to Lake Liambezi, the fisheries of both the Central Barotse Floodplain and Zambezi/Chobe floodplains underwent catastrophic economic collapse from 2010 following a change from using multifilament gillnets to nets made of monofilament (Tweddle et al., 2015). Collapse of the stocks of the valuable large cichlids was compounded by the use of fine-meshed dragnets.

The fisheries are grossly overfished and until now have effectively been unmanaged. The Zambezi-/Chobe floodplain fishery is transboundary between Namibia and Zambia, which complicates efforts to develop community management structures. Establishing effective fisheries management is therefore difficult, but there are encouraging developments taking place on both sides of the border, incorporating the results and recommendations from the SASSCAL and other associated NNF projects.

Management recommendations have been made to MFMR based on the research results, and the key recommendations have been implemented. These are (1) the establishment of a network of Fish Protection Areas (FPAs), (2) a ban on the use of monofilament nets, and (3) the establishment of a harmonised closed season between Namibia and Zambia.

In Namibia, increasing areas of the river and floodplains now fall under conservancies, where the communities have recognised rights over the management of natural resources. These community bodies are the focus of community management initiatives.

(A) Fish Protection Areas: The concept of community-based Fish Protection Areas (FPAs) where no fishing is allowed has been accepted by the floodplain conservancies, and pilot FPAs have been proposed and established by conservancies, recognised by Traditional Authorities, and gazetted by MFMR (2015). The Sikunga Channel FPA in particular is successful, with conservancy-appointed fish guards supported by private enterprise and conducting daily patrols. Their activities are covered by a Facebook page, 'Sikunga Fish Guards'.

(B) Ban on monofilament nets: A ban on the use of monofilament nets was gazetted in December 2016.

(C) Closed season: An annual closed season for the Namibia section of the Upper Zambezi and the Chobe Rivers and floodplain is now gazetted for the period from December 1 to the end of February, in harmony with that on the Zambian side of the river.

These measures should allow for improvement in the fisheries, but other recommendations need to be enacted. Recognition of conservancies is needed in the revision of the Fisheries Act that is currently in progress, to enable greater participation by conservancies in management. MFMR is recognising the conservancies, as shown by its gazetting of the FPAs, but the relationship needs to be formally strengthened. There needs to be more scope for the establishment of local by-laws, as the fisheries are highly diverse and dynamic, meaning that standardised regulations are not appropriate in some fishery areas. Recognised community organisations such as conservancies and community fisheries management committees need to have formal avenues through which by-laws can be agreed on and implemented.

Climate change impacts on Zambezi fisheries

The Zambezian riverine, floodplain, and lake fisheries are of immense value to the riparian communities, both economically and, much more importantly, for food security. In this chapter we have highlighted the high economic value of the Lake Liambezi fishery and shown how climate variability has a major impact on livelihoods. Under projected climate change scenarios for this region (e.g., Midgley et al., 2005; Turpie et al., 2010), rainfall is expected to decrease in the catchments of these rivers. This will not only reduce river flow volumes and thus potential fish production but will also expose fish populations to ever greater fishing pressure, exacerbating an already serious overfishing situation in the region. The risks from potential climate change therefore highlights the need for much greater emphasis on the management of the fisheries, with a major emphasis on community empowerment to learn the lessons from the Lake Liambezi fishery and apply these to the Zambezi as a whole. A major predicted consequence of global climate change is increased variability in the magnitude and duration of flood events. Developing proactive management approaches that allow for the maximisation of harvests from ephemeral water bodies such as Lake Liambezi when these are available, while mitigating against excessive exploitation in the perennial rivers during dry periods, will be a major challenge in the future.

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