To connect or not to connect? Floods, fisheries and livelihoods in the Lower Rufiji floodplain lakes, Tanzania

Olivier Hamerlynck[1], Stéphanie Duvail[2], Leen Vandepitte[3], Kassim Kindinda[4], Dorothy W. Nyingi[5], Jean-Luc Paul[2], Pius Z. Yanda[6], Aggrey B. Mwakalinga[7], Yunus D. Mgaya[8] and Jos Snoeks[9]

[1] *Centre for Ecology and Hydrology, Maclean Building, Crowmarsh Gifford, Wallingford OX10 8BB, UK*
olivier.hamerlynck@gmail.com

[2] *Institute of Research for Development (IRD), UMR 208 Paloc (IRD/MNHN), PO Box 58480, Nairobi, 00200, Kenya*

[3] *Flanders Marine Institute (VLIZ), Wandelaarkaai 7, B-8400 Oostende, Belgium*

[4] *Institut Français de Recherche en Afrique (IFRA), PO Box 58480, Nairobi, 00200, Kenya*

[5] *National Museums of Kenya, Ichtyology Department, PO Box 40658, Nairobi 00100, Kenya*

[6] *Institute of Resource Assessment, University of Dar Es Salaam, PO Box 35097, Dar Es Salaam, Tanzania*

[7] *Agricultural Department, Rufiji District Council, PO Box 28, Utete, Tanzania*

[8] *Faculty of Aquatic Sciences and Technology, University of Dar es Salaam, Milimani Campus, PO Box 35064, Tanzania*

[9] *Zoology Department, Royal Museum for Central Africa, Leuvensesteenweg 13, B-3080 Tervuren, Belgium*

Received 25 August 2010; accepted 17 May 2011; open for discussion until 1 June 2012

Editor D. Koutsoyiannis; **Guest editor** M.C. Acreman

Citation Hamerlynck, O., Duvail, S., Vandepitte, L., Kindinda, K., Nyingi, D.W., Paul, J.-L., Yanda, P.Z., Mwakalinga, A.B., Mgaya, Y.D. and Snoeks, J., 2011. To connect or not to connect? Floods, fisheries and livelihoods in the Lower Rufiji floodplain lakes, Tanzania. *Hydrological Sciences Journal*, 56 (8), 1436–1451.

Abstract For seven years, village-based recorders monitored fish catches and water levels in seven floodplain-associated lakes of the Lower Rufiji, Tanzania. The lakes differ in the number of days and volume of inflows from the river, and thus provide a natural experiment to explore the links between catch composition, income per hour of fishing (IPHF) and hydrological connectivity, and to analyse the response of the users. The fishers adapt their fishing mode and equipment to achieve a rather constant IPHF of between 0.2 and 0.8 US$/fisher/hour. In situations of low connectivity, during a series of drought years, the less well-connected lakes lost many species and became a virtual monoculture of *Oreochromis urolepis*. Only in one extreme case was average fish size significantly reduced, indicating a high fishing pressure. Catch was therefore highly resilient to shifts toward illegal, non-selective and active fishing techniques. Fish diversity and lake productivity were quickly re-established when the larger lakes reconnected. The potential impacts of changes in the flood hydrograph (through dams, increased abstraction or climate/land-use changes) are assessed, and management options discussed.

Key words floods; floodplains; tropical fisheries; ecosystem services; livelihoods; participatory monitoring

La connexion des lacs est-elle utile? Inondations, pêche et moyens de subsistance dans les lacs de la plaine d'inondation du bas Rufiji en Tanzanie

Résumé Les captures de pêche et les hauteurs d'eau de sept lacs attenants à la plaine inondable de la basse vallée du Rufiji ont été suivies par des observateurs locaux pendant sept ans. Le nombre de jours de débit entrant et le volume d'eau en provenance du fleuve diffèrent d'un lac à l'autre, fournissant ainsi une zone d'expérimentation naturelle permettant d'analyser les liens entre la composition des captures, le revenu par heure de pêche (RPHP) et la connectivité hydrologique, ainsi que pour analyser les réponses des utilisateurs. Les pêcheurs ont adapté leurs engins de pêche pour atteindre un RPHP quasi constant entre US$ 0.2 et 0.8/pêcheur/heure. Les années sèches, dans des situations de faible connectivité, les lacs les moins bien connectés ont perdu de nombreuses espèces et se sont transformés en une monopisciculture virtuelle d'*Oreochromis urolepis*. La taille moyenne des poissons a été significativement réduite dans un seul cas extrême, montrant ainsi la forte résilience des captures au changement vers des engins de pêche illégaux et non sélectifs et aux techniques de pêche active. La diversité halieutique et la productivité des lacs sont rapidement restaurées quand les plus grands lacs se reconnectent. Les impacts potentiels de modifications de l'hydrogramme de crue (par des barrages, des prélèvements additionnels et des changements climatiques/changements de l'utilisation des sols) sont évalués et des options de gestion sont évoquées.

ISSN 0262-6667 print/ISSN 2150-3435 online

http://dx.doi.org/10.1080/02626667.2011.630002
http://www.tandfonline.com

Mots clefs crues; plaines inondables; pêcheries tropicales; services écosystémiques; modes de vie; suivi participatif

INTRODUCTION

The importance of fish as a source of comparatively cheap protein for people in the tropics, especially its most vulnerable groups, and the importance of allocating sufficient water to sustain these fisheries can hardly be overemphasized (Dugan *et al.* 2006). The complexity of tropical fisheries in general and of floodplain fisheries in particular is well recognized (Welcomme 2008), as is the importance of maintaining the flood pulse for their productivity (Junk *et al.* 1989). In general, wetlands are considered to be the most valuable terrestrial ecosystems (Costanza *et al.* 1997). In spite of this, tropical wetlands are amongst the natural ecosystems with the highest rate of conversion (mainly for irrigated agriculture), especially in Africa (Junk 2002). This is due, at least partly, to a lack of data on and understanding of their multiple use values (Barbier 1994). Tropical wetlands are also losing value through increased regulation and fragmentation of rivers by large dams (Nilsson *et al.* 2005), which, through a decrease in the magnitude of the flood pulse, affect connectivity i.e. "*the ease with which organisms, matter or energy transverse ecotones between adjacent ecological units*" (Ward *et al.* 1999). In riverine systems, water-mediated or hydrological connectivity is thought to be key for the persistence of aquatic biota (Jenkins and Boulton 2003), including fish, in both temperate (Fullerton *et al.* 2010) and tropical systems (Pains da Silva *et al.* 2010). Science-based fisheries management advice has largely failed to deliver even in biologically "simple", single-species, single-type, temperate-zone fisheries (Bayley 1988), as stocks have continued to collapse, often because the political will to fully implement the advice has been a stumbling block (Pauly *et al.* 2002). Still, improved understanding of a floodplain fishery can be helpful to explore site-specific management options relevant for vulnerable people.

The Millennium Ecosystems Assessment has called for increased research on measuring, modelling and mapping ecosystem services, and assessing changes to their delivery with respect to human well-being (Carpenter *et al.* 2006). The field of ecosystem services research is at a relatively early stage, and spatially explicit empirical research is still urgently required to counteract the dearth of information concerning the patterns of ecosystem service provision, particularly in areas where little social and ecological research has been undertaken (Nicholson *et al.* 2009). Freshwater fisheries in flood-dependent systems in the tropics are an obvious candidate for such research, as they concern a vital element of human well-being that is increasingly under threat. These fisheries, as a provisioning ecosystem service, come as part of a bundle of associated flood-dependent services in complex socio-ecological landscapes (Hamerlynck *et al.* 2010a), e.g. soil fertilization, freshwater provision, water purification and regulation (including the reduction of flood hazards), groundwater recharge with improved forest productivity (increased flowering and honey production, more wild fruits and traditional medicine), in addition to their cultural and spiritual values. The study of these services, from biodiversity through to the ecosystem services it produces, and onwards to their contribution to human well-being, precisely captures the kind of linkages and processes that Nicholson *et al.* (2009) state should receive priority research attention.

With a mean annual flow of some 800 m^3/s, the Rufiji River is the largest river in Tanzania, and its lower floodplains are subjected to highly variable and often bi-annual flood peaks. These are considered beneficial by the local communities (Duvail and Hamerlynck 2007). Flood control, in combination with hydropower production and a—probably overestimated—irrigation potential (Hamerlynck *et al.* 2010b) are invoked by the authorities as key arguments in favour of the construction of a large multipurpose dam at Stiegler's Gorge, just upstream of the lower floodplains (Fig. 1). Calls for its immediate implementation resurface regularly in the media, and this in spite of a very negative assessment of its environmental impacts (Mwalyosi 1988).

From 1997 to 2003, the local government of the Rufiji District in southern Tanzania was supported by the Rufiji Environment Management Project (REMP), which had as one of its main objectives, "*to promote the integration of environmental conservation and sustainable development through environmental planning*". Part of the REMP activities consisted, therefore, in data collection through the establishment of research and monitoring activities designed to improve understanding of the links between the environment and local livelihoods, and resulted in the production of a series of technical reports (REMP

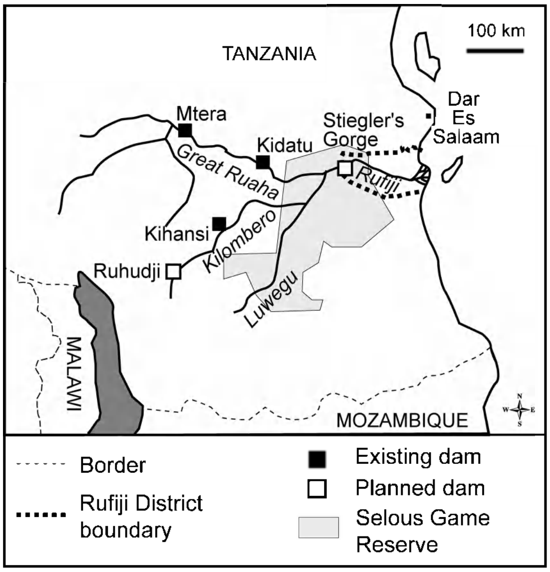

Fig. 1 Map of southern Tanzania with Rufiji River and district.

2003). The general approach was to involve the local communities and various other stakeholders in all planning activities, including the establishment of research priorities (Ochieng 2002).

Despite its perceived success by all stakeholders, the REMP was discontinued in October 2003, but some monitoring and research activities were continued or revived, and others initiated as part of a research project that investigates the links between floods and ecosystem services in eastern African wetlands (Duvail 2004), including the monitoring of water levels in the 10 main floodplain-associated lakes, and of their fisheries, predominantly in two of those lakes (Mtanza and Zumbi).

The participatory monitoring was conducted by village-based water-level and fisheries data recorders, and coordinated by local government staff. Feedback workshops, bringing together the recorders, researchers and district staff were conducted in 2002, 2005, 2007 and 2010 (mostly constrained by the availability of funds). These allowed presentation and discussion of the results and collective analysis of their implications for flood-dependent livelihoods under various scenarios, also explored in the form of role play. This paper presents some preliminary results from the analysis of the fisheries monitoring when linked up with the hydrological monitoring in order to:

- assess the possible links between the fish catch composition and the hydrological connectivity of the floodplain-associated lakes;
- assess the impacts of the hydrological connectivity on income per hour of fishing (IPHF) as a measure of the economic contribution of the fisheries to individual fishers;
- assess the strategies of the fishers when faced with lakes that have reduced connectivity (as would be the case if additional dams that reduce flood peaks were built upstream, or if other factors such as climate change, land-use change or increased abstraction reduce peak flows); and
- assess current management practices and provide some recommendations on knowledge-based management interventions that could mitigate the impacts of reduced connectivity.

The study therefore attempts to capture links between fish biodiversity (catch composition), connections of the lakes with the river (in relation to its flooding pattern) and human well-being (through fisheries income).

STUDY AREA

The Lower Rufiji floodplain forms the central part of the Rufiji District in Tanzania, around the economic hub of Ikwiriri (7°57′S; 38°59′E, approx. 15 000 inhabitants) just north of the Rufiji bridge (completed in 2003) that connects Dar es Salaam to coastal southern Tanzania. It is one of the least-developed districts in Tanzania, in spite of comparatively abundant renewable resources, linked to the presence of one of the largest rivers in Africa. According to the *Poverty and Human Development Report* (United Republic of Tanzania 2005), an estimated 34% of the 203 000 people living in Rufiji District (of which about 100 000 depend directly on the freshwater floodplain) do so below the "basic needs poverty line" which, in Tanzania, is defined as less than US$ 0.26 a day, i.e. much lower than the internationally accepted extreme poverty standard of US$ 1.25 a day, even after purchasing power parity correction. Some other indicators for the district are an adult literacy rate in women of 41%, access to piped or protected water for 9%, access to electricity for 2.4%, and an infant mortality rate of 97 per 1000 live births (national average in Tanzania: 68, in Sweden: 2.7). Moreover, there is inequitable access to basic health services (Mwageni *et al.* 2005), meaning that the disease and mortality burden is considerably higher in the poorest households. Education levels have improved recently, but, for the active generation that is now 25–30 years old, less than 50% has completed primary education and only 1.2 (1990) to 7.4% (1996) enrolled for secondary school (Rufiji District Council 1997).

The area is therefore characterized by vulnerable people whose well-being depends very strongly on the delivery of ecosystem services by the local environment and especially the river. According to Turpie (2000), livelihoods are essentially based on the harvesting of natural resources, on recession and, to a lesser extent, rainfed agriculture. Over 90% of the households engage in the collection of wild food plants, of grasses and palm leaves for roof thatch and weaving, and also of firewood. Over 55% of households engage in fishing and in the collection of medicinal plants, while 46% harvest wood for poles. Other important activities are timber, pottery, honey collection, hunting and charcoal production. The gross economic value of these natural resource-related activities amounts to about double that of agriculture. Over 75% of households produce cereal crops, mainly rice, from 0.8 to 1.2 hectares. Additional crops are maize, sweet potato, millet, vegetables and fruits. Cash crops, such as sesame and cashew, represent less than 10% of gross economic value. The direct use value of freshwater habitats is estimated at US$ 42 ha^{-1} year^{-1} and that of agricultural land at US$ 63 ha^{-1} year^{-1} (Turpie 2000).

The lower floodplain of the Rufiji River has eight major floodplain-adjacent lakes (Fig. 2) that are shallow remnants (less than 8 m deep) of old tributaries entering the Rufiji River. These lakes are dammed by alluvial deposits, and vary in size, volume and distance from the main river (Table 1). Most lakes therefore have tributaries from local catchments entering on the side opposite to the connection with the main river. The water from the tributaries can be mixed with water from the Rufiji River when the flood peak exceeds the altitude of the threshold that separates the lake from the river. These thresholds, called *kingo* in Swahili, are a concept familiar to local users, as any connection will result in a fishing feast, where men, women and children use any sort of device, including items of clothing, to scoop out the densely-packed migrating fish. The connection with the river can extend for several weeks, allowing exchange of water, suspended matter and biological material. Traditional fish weirs are often installed on the connecting channels to cover both directions of the fish migration (J.-L. Paul, unpublished). At flood recession, excess water (above the threshold) flows back to the river until the connection is severed and the water level in the lake evolves independently from the level in the Rufiji River until the next connection. The floodplain-associated lakes comprise over 50% of the standing water bodies in the Rufiji District (Mwalyosi 1990), and have become increasingly important for local livelihoods since the late 1960s when the *Ujamaa* "villagization" policy forcibly resettled the inhabitants of the fertile floodplains in their proximity to protect them from supposedly "dangerous" floods (Duvail and Hamerlynck 2007).

Table 1 Characteristics of the main floodplain lakes with surface areas as derived from aerial photography in June 1999, and volume on the basis of a bathymetric survey in June 2000 (S. Duvail, unpublished data).

	Lake surface area (km^2)	Lake volume (hm^3)	Distance to Rufiji River (km)
Umwe	1.43	1.4	7.6
Uba	3.18	7.2	6.2
Mtanza	0.3	0.4	0.4
Ruwe	8.76	20.6	8.2
Zumbi	6.87	29.2	0.2
Weme	1.99	2.6	2.8
Ilu	3.54	4.8	0.2
Lugongwe	2.47	5.9	1.0

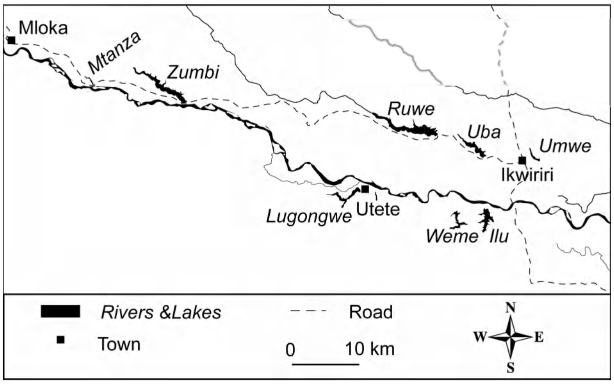

Fig. 2 Map of the Lower Rufiji floodplain lakes.

River discharge is highly variable between years and, within a year, often characterized by multiple flood peaks that sometimes wash away all planted crops. Still, these losses are largely compensated for by high yields in the subsequent "*mlao*" cultivation, high fish yields and productive ecosystems in general (Duvail and Hamerlynck 2007). Long-term trends are hard to assess, as reliable discharge data at Stiegler's Gorge only exist between 1957 and 1984. Annual rainfall in the lower floodplain is also highly variable, both temporally (average between 1923 and 2005 about 860 mm, but varying between 450 and 1350 mm) and spatially. Drier conditions, in terms of both discharge and local rainfall, seem to have prevailed since the late 1990s (Duvail and Hamerlynck 2007), with the notable exception of the 1997/98 El Niño-related floods (Erftemeijer and Hamerlynck 2005).

The agricultural potential in the Rufiji floodplain has been described by Hamerlynck *et al.* (2010b). The inhabitants of the floodplain practice a peasant economy with, as its basic unit, the household, which derives most of its staple food from agriculture. Households provide their own manual labour to cultivate and harvest one or a few plots of about 4000 m^2 each. Ideally, these are spread out across the floodplain to cover a range of elevations, thus improving the chances of success under various flood/rainfall combinations. A major part of the production, essentially maize and rice, is destined for household consumption, but, especially in favourable years, part may be sold for cash. Other sources of cash are sesame and cashew nuts, but also a wide range of non-agricultural activities. Thus, over 50% of households in the floodplain practice some form of fishery, and it is a close second to farming as an income-generating activity, including subsistence (Turpie 2000). Fish, produced or bought, constitute the main source of animal protein for the vast majority of the population, e.g. in the average household around Lake Zumbi (a small quantity of) fish is present in 40% of the main meals (twice a day), while meat is present only in 1.4% (J.-L. Paul, unpublished data).

Total fish production, though highly variable depending on the year's flood characteristics, is estimated at between 5500 and 7500 metric tonnes of fresh fish (Turpie 2000). Some fresh fish is consumed locally, but most of the catch is smoked and dried for road transport to markets and towns to the north and south of Rufiji District (Richmond *et al.* 2002), where demand for cheap animal protein is high. Peak flooding (and fish reproduction) usually occurs between March and May. A first peak in fish production occurs, when water recedes and catchability increases, in July–September (when there is also a lull in agricultural work after the rice harvest in June and before the preparation of the fields for the October short rains). A second peak occurs in December–January, when the lakes have drawn down and juveniles of the year reach harvestable size. This is also the main season for export of fish, as road conditions are comparatively favourable in between the two rainy seasons (Richmond *et al.* 2006), i.e. before the harvesting of the "short-rains" maize and the planting of the "long-rains" rice. Fishery studies in the Lower Rufiji were conducted by Hopson (1979) and, in addition to providing the first species lists, already pointed out the vulnerability of the lakes and the fisheries to changes in the hydrograph, should the Stiegler's Gorge dam be constructed.

MATERIAL AND METHODS

The general principle of data collection in the study area is through village-based recorders trained through the REMP and subsequently through the IRA-IRD-IFRA research partnership. The recorders are supervised by a trained local research assistant with backstopping from district technical staff. When funds are available, feedback sessions to collectively analyse the results and their livelihood implications are organized with the recorders, district staff, researchers and staff from technical departments at ministry level. These feedbacks have allowed improved collective understanding of the functioning of the lakes, as the observers present the data of each lake and interpret rises and falls of the lake levels, appearance and disappearance of fish species in the catches, and jointly discuss additional observations, e.g. on rainfall, connections with the river and inflow from the upstream catchment.

Fishing data

Data of freshwater fisheries were collected at the landing points of the main floodplain-associated lakes of the Lower Rufiji between May 2000 and March 2009, with varying intensity and spatial cover (Table 2). Each lake has its own team of two trained fish recorders from a nearby village. Each record represents the catch of a single fishing operation, most commonly a single dugout canoe operated by two fishers at night, usually for about 10–12 h (up to about 24 h). For each sampling month, eight days were chosen at random and, during a few hours (the busiest landing hours, usually starting at sunrise), the contents of a number of canoes are analysed. Data recorded include: the number of canoes participating in the operation; the number of fishers per canoe; the fishing time (start, end); the gear/equipment (type, number, mesh or hook size); and the catch (total number of fish, total value, total weight, number and weight per species, individual fish lengths—often a sub-sample of up to 30 individuals per species). The data on the monetary value of the catch are, therefore, not collected from markets, but are estimates made by the fishers themselves on the basis of species composition, size and weight, should they choose to sell the entire catch in its fresh state.

Table 2 Number of fisheries records for the various lakes.

Lake	May–August 2000	May–September 2002	March–September 2003	November 2005–March 2009
Umwe	56	118	68	18
Uba	201	85	94	47
Mtanza	97	73	94	576
Ruwe	37	97	60	32
Zumbi	60	111	83	507
Weme	127	176	113	62
Ilu	49	77	95	62
Lugongwe	28	164	89	0
Total	**655**	**901**	**696**	**1304**

The database analysed for this paper contains information on some 300 000 fish from over 3500 records (Table 2), i.e. an average of about 100 fish per catch, ranging from zero to (very exceptionally) several tens of thousands. After the end of the REMP, the monitoring concentrated on two lakes in the most drought-prone western floodplain, Lake Zumbi and Lake Mtanza. Two comprehensive surveys were conducted in the other lakes (except Lugongwe, where there are issues with the reliability of the data) following the substantial 2008 flood peak, namely in July–August 2008 and February–March 2009. In Lake Umwe there was no fishery in July–August 2008, so it was decided that the fish recorders themselves would go out fishing in February–March 2009.

The survey method used misses out on important types of fishing, such as the trap fishing for catfish on the (cultivated) floodplains, or the mosquito-net fishing for juvenile shrimp (probably *Macrobrachium*) in the flooded grasslands (often practiced by women and children). It also does not cover fishing sites outside of the lakes, such as in the main Rufiji River and in temporary floodwater courses in the floodplains (that require specific fishing skills because of the current). Other fishing areas exist to the west of the study area, inside the Selous Game Reserve, but accessing these resources is very risky and several fishers have been arrested, wounded or even killed when caught trespassing (J.-L. Paul, unpublished data). Still, for most of the year, and for most young men that would mention fishing as an important activity in their time budget, the lakes are the primary fishing site. Teams of "migrant" (not originating from the villages closest to the lakes), full-time fishers also operate in the area, concentrating mostly on the lakes close to the main road and the town of Ikwiriri (J.-L. Paul, unpublished data).

The data from each canoe are considered as a single record and, for most types of analysis, all records from a single month are pooled. For example, for the analysis of the livelihood aspects, the IPHF for each month was calculated as the average net income (in US$, corrected for exchange rate fluctuations of the Tanzanian Shilling) per fisher per hour of fishing.

Hydrological data

In order to assess the vulnerability of the lakes to changes in the flood hydrograph, water-level data were collected along similar lines to the fisheries data, with village-based recorders doing daily readings of the stageboards installed in the floodplain lakes in 2001. River stage data are recorded three times a day at Mloka, a long-term monitoring station on the main river at the upstream edge of the floodplain (Fig. 2), that is part of the national hydrological grid. A simple water balance model has been developed for the floodplain lakes (S. Duvail, unpublished) and was used to calculate the number of days and the volume of inflow from the river (expressed as a percentage of the volume of the lake before the connection) in the various hydrological years (between 1 October of year N and 30 September of year $N+1$). These data have been used as a proxy for hydrological connectivity, even though the number of days of inflow (from the river) is not exactly the same as the number of days of connection between the river and the lake (which allows active migration to occur in both directions), but both numbers are very closely correlated. In any one hydrological year, there are, at most, a few extra days of connection without flow when water levels are identical in the lake and the river and, for each connection, a few hours of outflow from the lake to the river.

Limnological data

Comprehensive limnological surveys were conducted in most of the Lower Rufiji lakes by Pijnappel (2002), and repeated in October 2008. Lakes Ruwe and Uba were intensively monitored between 2002 and 2004 (Mwaitega 2003, Lamtane 2008). Conductivity measurements were conducted sporadically in the lakes throughout the study period. Because of the differences in conductivity between the inflow from the local catchments and those from the river, the data provide a village-observer independent check on the occurrence of hydrological connections. During these surveys, the cover of the floating Nile cabbage, *Pistia stratiotes*, is visually assessed, as it can develop closed mats that create problems for fishing operations (Howard and Hartley 1998).

RESULTS

Fisheries and floods

Over 40 species have been recorded in the catches, but only about 30 "categories" are recognized. For example, all the Mormyridae, probably at least five hard-to-distinguish species, are grouped together, as the local names are too variable between the lakes to ascertain specific status. For most other species, even though the local names can differ between north and south of the river, or between the western and the eastern parts of the floodplain, there is a one-to-one relationship between the local and the scientific name. Some 40 different types of fishing gear were recorded, but most of these are variations on a few themes and, broadly, the gear (from the fishers' point of view) can be classified as:

- Active gear, usually comparatively "non-selective", such as relatively small-mesh (less than 50.8 mm) seine nets, or cast nets (both considered "illegal"), but there is also a more selective hook-and-line fishing (legal), all operated from canoes. Such gear requires the full attention and, for the seine-netting operations, the strong, physical involvement of the fishers, and this precludes combining fishing with agricultural work. In fact, the operation of seine nets, which also requires beating the water to chase the fish into it, is almost exclusively limited to fit unmarried young men, the only social subgroup that has full-time fishers (J.-L. Paul, unpublished data).
- Passive gear, usually more selective than the previous type, i.e. various types of gill-nets (minimal legal mesh size 63.5 mm, but raised to 76.2 mm in 2010). This type of equipment can be put out in the evening and fish collected in the morning. Surveillance to prevent poaching of the catch by other fishers is advisable, as is the lifting of the net every few hours to prevent crocodiles or predatory fish from consuming the catch. As the fishers, who usually stay in a fish-smoking camp with a view of the lake, can rest in between checks of the nets, they are capable of doing agricultural or other work during the (rest of the) day.
- Semi-active gear, especially surrounding nets operated from the canoe and bottom-set lines with hooks targeting catfish (often combined with another fishing technique). These techniques usually require the fishers to stay in the canoe to interact with the gear at regular time intervals, but are less physically demanding than the active gear and allow for some other work to be done afterwards.

In general, one can say that passive gear is used when the water level is high and fishery is productive, while active gear is used when water level is low and also when fish have become rare and are not easily caught with passive gear. For example, between November 2005 and March 2009, fishing in Lake Zumbi used about 54% active, 42% passive and 4% semi-active gear, while in the much smaller and shallower Lake Mtanza, where one could often wade across even the deepest parts in the dry season, 82% was active, 7% passive and 11% semi-active. Other factors, such as the need for agricultural work (clearing, hoeing, planting, harvesting), and the risk of a district clampdown on "illegal" gear, do come into play in gear choice.

Catch composition is dominated by a few species, or species groups, but is highly dependent on the connectedness of the lake (Fig. 3). During the very strong flood peak of late April 2002 (6.41 m on the Mloka stageboard, i.e. about 5 m above the dry season level), the Rufiji River was 10–15 km wide and all the lakes connected and had inflows from the Rufiji River for anything between 13 and 45 days (Table 3). Over the following five months, the catch composition, expressed as number of individuals caught, was very similar across all the lakes (Fig. 3(a)), and could be divided broadly into four groups:

- Cichlidae (13–29%), almost entirely *Oreochromis urolepis* (99%);
- Alestidae (14–35%; except for Lake Umwe, which had only 3%) composed of *Brycinus affinis* (60%), a mix of *Brycinus imberi* and *Alestes stuhlmanni* (21%), and *Hydrocynus vittatus* (19%);

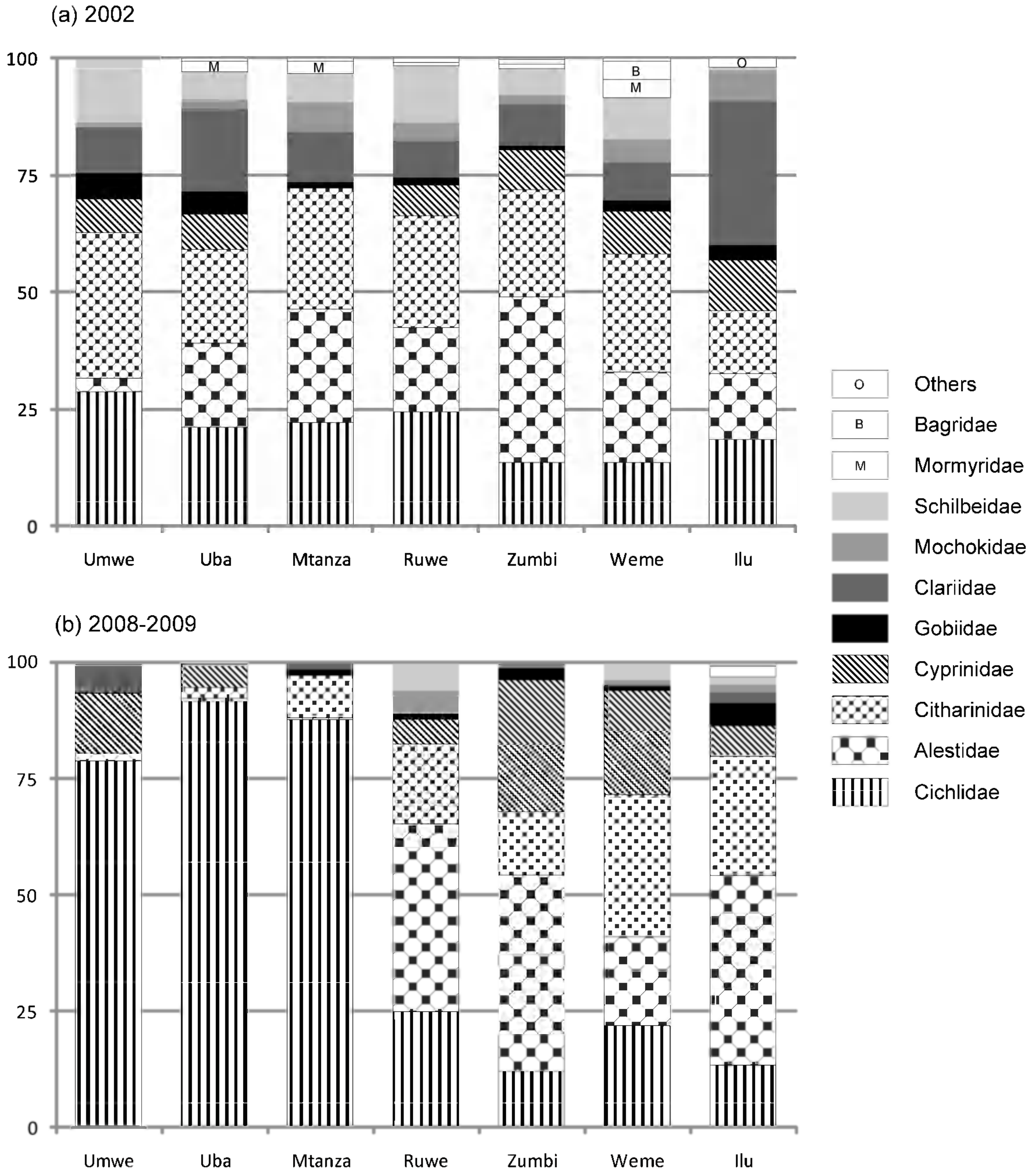

Fig. 3 Catch composition for the various lakes in: (a) 2002 (May to November), and (b) 2008 (July–August)/2009 (February–March), expressed as the % of total catch (number of fish) per family.

- Citharinidae (13–31%), predominantly *Citharinus congicus* (79%) and *Distichodus petersii* (21%, but there might be a mix with *Distichodus rufigiensis* in some lakes); and
- A number of other families (28–54%), mostly "catfish", such as *Clarias gariepinus* (8–31%), *Schilbe moebiusii* (5–13%, except Lake Ilu only 1%); Bagridae (maximum 4% in Lake Weme) with *Bagrus meridionalis* (90%) and *B. orientalis* (10%); Cyprinidae (maximum 28% in Lake Zumbi), essentially *Labeo congoro* and the occasional *Barbus oxyrhynchus*; Mochokidae (maximum 7% in Lake Ilu), mainly *Synodontis rukwaensis*, Gobiidae (maximum 6% in Lake Umwe) with mostly *Glossogobius giurus* (66%) and *Favonigobius reichei* (34%); Mormyridae (maximum 4% in Lake Weme); three species of *Anguilla* (*A. mossambica*, *bengalensis* and *bicolor*).

In 2008, the highest flood peak since 2002 (5.65 m on the Mloka stageboard, 0.76 m lower than

Table 3 Flood characteristics for the seven "hydraulic years" (1 October year N to 30 September year $N+1$) monitored with the height of the flood peak on the Mloka stageboard; number of days the different lakes received inflow from the Rufiji River; the percentage of lake volume that this inflow represented; and the total number of inflow days over the 7-year period.

Hydraulic year	Flood peak at Mloka (m)	No. of days inflow from Rufiji River / inflow as % of lake volume						
		Umwe	Uba	Mtanza	Ruwe	Zumbi	Weme	Ilu
2001–2002	6.41	13d 84%	25d 71%	17d 85%	32d 88%	38d 57%	45d 69%	43d 77%
2002–2003	4.83	0	0	0	0	d 0.5%	5d 40%	23d 14%
2003–2004	5.36	0	0	0	0	d 19%	14d 67%	19d 68%
2004–2005	4.61	0	0	0	0	d 1%	5d 48%	1d 5%
2005–2006	5.45	0	0	1d 0.8%	0	8d 15%	9d 56%	5d 37%
2006–2007	5.59	0	0	1d 2.6%	0	51d 56%	29d 77%	52d 78%
2007–2008	5.65	0	0	10d 13%	4d 7%	19d 40%	23d 48%	51d 80%
Number of inflow days in 7 years		13	25	29	36	127	130	194

Table 4 Numbers of fish caught per lake, number of "species" (or species groups such as Mormyridae or *Anguilla* spec.) in the catch (May–September 2002 and combined for July–August 2008 and February–March 2009), and conductivity in the lakes (August 2002 and October 2008).

	Umwe	Uba	Mtanza	Ruwe	Zumbi	Weme	Ilu
Fish catch 2002	6752	6789	1261	3660	2375	6557	2048
No. of "species"	16	13	14	15	18	16	14
Conductivity (μS/cm)	3432	313	153	165	156	98	110
Fish catch 2008–2009	749	25 670	2140	48 099	5458	19 853	55 338
No. of "species"	11	6	6	16	16	17	16
Conductivity (μS/cm)	19 700	1, 332	255	206	219	85	115

the 2002 flood peak), connected almost all lakes again (except Uba and Umwe) with Lake Ruwe reconnecting for the first time since 2002 (Table 3). The catch composition of the lakes that connect every year—Zumbi, Weme and Ilu—is rather similar in 2008 (Fig. 3(b)) compared to 2002, though some groups such as Clariidae and Schilbeidae were more abundant in 2002. The same is true of Ruwe, even though it only connected for a few days in 2008. In contrast, Lake Mtanza, that connected in four years out of seven (but, on two occasions, this was only during a single day), has a catch composition that resembles that of the badly-connected lakes Uba and Umwe, with a strong dominance of Cichlidae, almost exclusively *Oreochromis urolepis*.

In 2008–2009, the biggest difference in catch composition between the badly-connected and small lakes Uba, Umwe and Mtanza, in comparison to much larger lakes Ruwe and Zumbi, and the much better connected Weme and Ilu, is in the Alestidae and the Citharinidae, which have virtually disappeared from the former (Fig. 3(b)).

When one compares the number of "species" in the catches (Table 4) in 2002 with those in 2008–2009, a similar picture emerges, with a strong decline in the number of species in lakes Uba and Mtanza, in spite of similar or much larger sample sizes. Lake Umwe has kept quite a high diversity in spite of a very small sample size in 2009, but that lake has very different characteristics from the other lakes (e.g. very high conductivity, Table 4), and fishing for human consumption has been abandoned in it for several years. In July–August 2008, there was no fishing activity, and the February–March 2009 sample was in fact an experimental fishing exercise by the fish recorders themselves. According to the locals interviewed in April 2008, "there are no fish in Umwe because it receives only rain water; the lake is shallow because of the drought that has lasted for 4 years now; there are a lot of algae and the fish taste foul". The other lakes seem to have kept their diversity even though the sample sizes (except for Zumbi) are not really comparable. Conductivity has also gone up substantially in Lake Uba (Table 4). Conductivities in Lake Ruwe fluctuated between 400 and 550 μS/cm before the 2008 reconnection brought it down again. Conductivities in the well-connected lakes Weme and Ilu are always close to those in the Rufiji River, which fluctuate between 80 and 110 μS/cm.

IPHF and connectivity

Looking at the income per hour of fishing in 2008–2009 (Fig. 4), some trends are discernable with IPHF significantly higher in lakes Ruwe and Ilu than in Umwe, Uba and Zumbi. The IPHF in Ilu is also higher than in Mtanza. However, the IPHF in comparatively well-connected Lake Zumbi is significantly lower than in Mtanza, Ruwe, Weme and Ilu.

There is therefore no straightforward correlation between connectedness and IPHF. In fact, when one considers the evolution of IPHF in Lake Zumbi between November 2005 and March 2009 (Fig. 5), the IPHF varies little around its average of 0.23 ± 0.05 US$/fisher/hour and there is no obvious correlation with connectedness. Significant differences in IPHF are only recorded between the very low values in late 2005 and early 2006 (after only two days of connection in March 2005, representing an inflow of about 1% of the lake volume at the time) and some of the high values between July and September 2006 (after an inflow in April 2006 of about 15% of the lake volume at the time), and, in particular, the exceptionally high value of May 2007 (after the very substantial inflow during a total of 51 days between December 2006 and March 2007, representing about 56% of the lake volume at the time). July and October 2007 and March 2008 (during another substantial

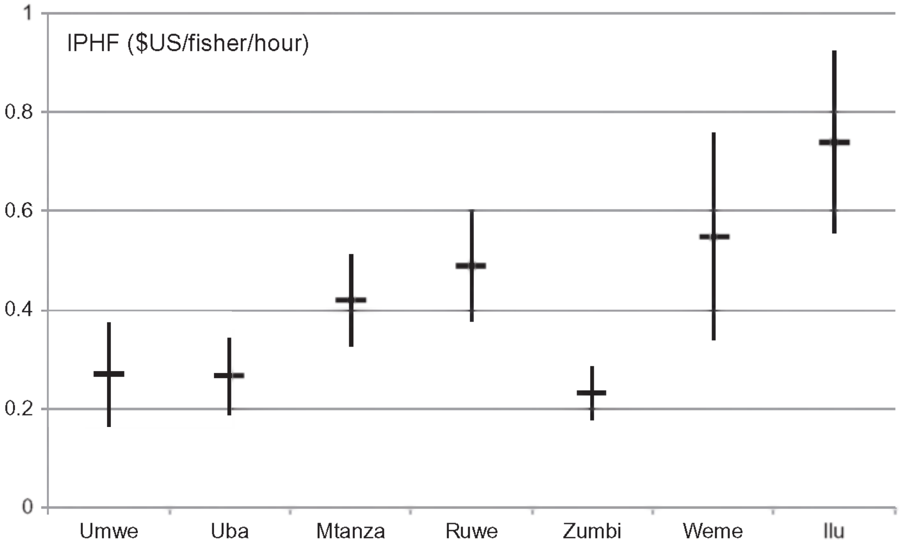

Fig. 4 Average income per hour of fishing (IPHF in US$ per fisher per hour), with 95% confidence limits, in the various lakes for the combined surveys of July–August 2008 and February–March 2009.

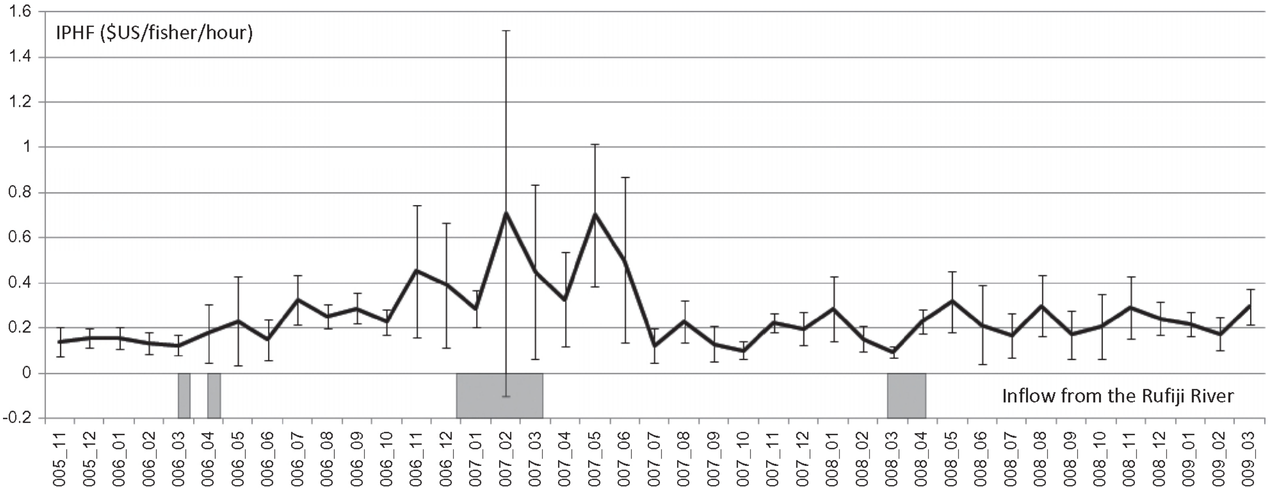

Fig. 5 Average income per hour of fishing (IPHF in US$ per fisher per hour), with 95% confidence limits, for Lake Zumbi between November 2005 and March 2009. The inflows from the Rufiji River are marked in grey.

inflow during 19 days and representing about 40% of the lake volume at the time, Table 3) also have significantly lower IPHF than during the aforementioned high IPHF months.

IPHF and fishing mode (type of gear and mesh size)

Income per hour of fishing is obviously not independent of the type of gear used. One does not expect that leaving a 88.9 mm mesh size gill net out for three hours will result in the same yield as four fishers spending three hours beating on the water and pulling a large 50.8 mm mesh seine net between two canoes. In Lake Zumbi, during the low IPHF period of November 2005–March 2006, fishing gear was almost exclusively illegal and predominantly active, so there was little scope for improving IPHF by a more intensive technique (Table 5). In May and June 2006, after the connection in early March and between 12 and 20 April 2006, there is a predominance of legal fishing (active and passive) and IPHF stays low. Between July and November 2006, when IPHF goes up a notch (significantly so in some of the months), active illegal fishing is again the dominant mode. In December 2006, illegal fishing was still dominant, but mostly passive. Between January and April 2007, during a series of substantial inflows, IPHF stays high while the fishing becomes predominantly legal and passive. The highest IPHF was achieved in May 2007 (significantly higher than in 10 out of the 12 months between November 2005 and October 2006, and than in 16 out of 21 months between July 2007 and March 2009), just after disconnection in May and was exclusively through active legal fishing (data from eight canoes only). From July 2007, when IPHF goes down to its average level of around 0.2 US$/fisher/hour, passive fishing techniques were predominant, and, in 17 out of the 19 months until March 2009, legal techniques were dominant.

That the difference between using predominantly legal *versus* illegal gear is not without impact on the fish population can be seen from a comparison between the average size of *Oreochromis urolepis* in different situations. In the "crisis" period (only a very short connection and a very high level of "illegal" fishing) between November 2005 and December 2006 in Lake Zumbi, average fish size was 17.74 cm (95% confidence limits 17.52–17.95 cm, $N = 2590$), while during the "more relaxed" fishing (regular substantial connections, predominantly "legal" fishing) in 2008 and 2009, average size was 23.87 cm (95% confidence limits 23.33–24.41 cm, $N = 1251$). This difference of 6.1 cm may not seem impressive, but, for *O. urolepis* in Lake Mtanza, using the *LW* relationship derived by Richmond *et al.* (2006) ($W = 0.014 \times L^{3.1191}$, $R^2 = 0.9894$, $N = 128$), the average weight of the fish increases from 0.110 to 0.275 kg.

Fishing pressure

The data set does not contain any information on total fishing effort, e.g. the total number of canoes operating in any lake at a given time; however, an indirect measure of fishing pressure (Welcomme 1999) can be derived from the average fish size in the catches (as was done for *Oreochromis urolepis* to compare two fishing periods in Lake Zumbi after the small connections of 2005 and 2006 *versus* after the large connections of 2007 and 2008). When comparing the size of *O. urolepis* across all lakes for the combined July–August 2008 and February–March 2009 surveys (Fig. 6), the fish in Lake Zumbi are significantly larger than those in all other lakes. Average size in lakes Mtanza, Ruwe and Weme is significantly larger than that in lakes Umwe and Ilu. Fish in Lake Uba are significantly smaller than those in all other lakes, and, at

Table 5 Dominant fishing modes according to the distinct IPHF levels identified from Fig. 5, expressed as a percentage, and the total number of records (semi-active fishing is marginal over this time period, with only 14 records in total, and only 2 months with more than 1 record, so not included in the table).

	Active Illegal	Active Legal	Passive Illegal	Passive Legal	*N*
November 2005–April 2006	69	2	25	5	64
May and June 2006	29	35	6	29	17
July–November 2006	78	5	12	5	41
December 2006	14	0	71	14	7
January–April 2007	13	31	5	51	39
May and June 2007	0	80	13	7	15
July 2007–March 2009	16	17	24	43	255

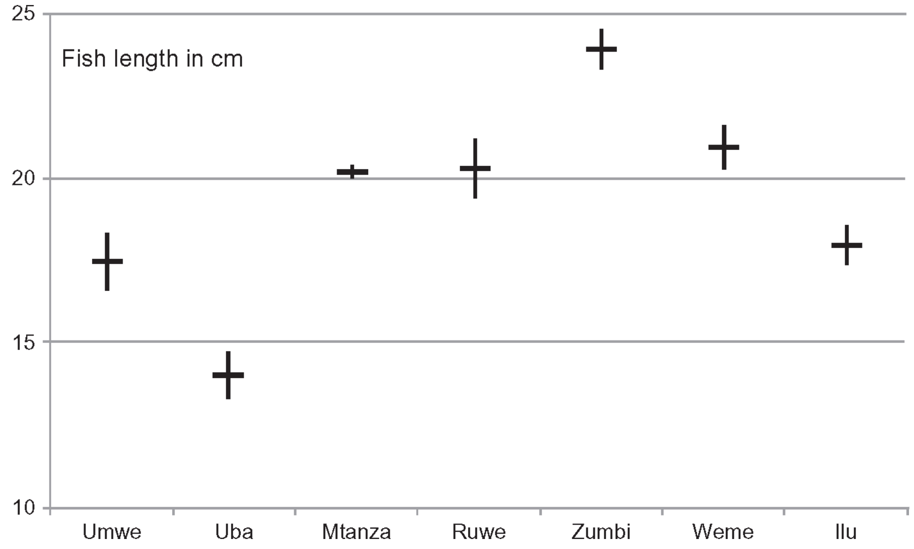

Fig. 6 Average size of *Oreochromis urolepis*, with 95% confidence limits, in the various lakes for the combined surveys of July–August 2008 and February–March 2009.

14.1 cm, the average weight of the fish caught is only 0.054 kg.

DISCUSSION

In the Lower Rufiji, the past decade has been characterized by an unprecedented series of dry years with 2003, 2004, 2006 and 2007 totalling less than 600 mm rainfall in Utete (all four are among the 10 driest years since 1923), and 2000, 2001, 2002 and 2005 all totalling less than 730 mm, well below the long-term average of 860 mm (1923–2008). This local drought was accompanied by a series of low flood peaks, which led to severe food insecurity in the Rufiji District, requiring the distribution of some 500 t of food aid in 2003 and 2006 (A.B. Mwakalinga, unpublished data). The western floodplain was especially hard hit, partly because the 1997–1998 El Niño-related floods (Erftemeijer and Hamerlynck 2005) deposited vast quantities of sand in the lowest-lying and normally fertile areas around the main river bed, and also because a man-eating lion (Baldus 2004) caused people to abandon their farms south of the river. These became overgrown and have only recently been re-opened to cultivation. In addition to agricultural food insecurity, the fish provisioning ecosystem service was affected, as can be seen from the low income per hour of fishing (IPHF) in Lake Zumbi during late 2005 and early 2006 (Fig. 4), in spite of the near ubiquitous use of active illegal fishing gear, requiring a major physical effort by the fishers, probably because of the reduced connectivity of the lake. In addition, Lake Uba, which used to provide drinking water for Ikwiriri town, has become too saline, necessitating the establishment of boreholes to supply its 15 000 inhabitants. The characteristics of Lake Mtanza, in spite of occasional short connections, have changed (e.g. it became increasingly covered with *Pistia stratiotes*) and fisheries virtually came to a halt there (since September 2007) even before the lake dried out completely in August 2010. Fishing in Lake Umwe was halted before 2008, because the fish tasted foul. The three badly-connected and small lakes (Uba, Mtanza and Umwe) also lost a major part of their fish biodiversity across a range of flood-dependent species, most prominently in the Alestidae and the Citharinidae, including the vulnerable *Distichodus petersii* (Hanssens 2006). The fishery in those lakes is very strongly dominated by a single species, *Oreochromis urolepis*, which seems to be highly tolerant of a wide range of conditions. Still, such a reduction in biodiversity may indicate a loss of resilience in the system, with an increased risk of regime shift (Folke *et al.* 2004). As one progresses from west to east, the lakes become more vulnerable to salinization (Table 4), probably because of the proximity of saline groundwater. The smallest lakes are also at risk of drying out completely. This happened to Lake Mtanza in 1996, and to Lake Uba in the 1930s (after which a canal was dug to reconnect it to the floodplain); in August 2010 both lakes were again dry.

The number of species in the Rufiji floodplain fishery is lower than in other tropical systems, e.g. in Bangladesh (Craig *et al.* 2004), but the range and the temporal and spatial variability in fishing areas, techniques, equipment, as well as in the social and economic spectrum of the fishers and the traders, and in their resource-use calendars, is still overwhelming. This precludes a traditional stock and maximum sustainable yield approach, even if near-unlimited research funds for experimental fishing would be available. More pragmatic and indirect approaches to the links between hydrological characteristics and fish yield, such as the one expounded here, are therefore justified. The longevity of the linear and still largely unchallenged estimate of 40–60 kg fish yield/ha flooded derived from (reliable?) catch statistics in tropical floodplains by Welcomme (1975) shows how difficult it is to improve on simple black-box correlations.

The survey method used here does not allow an estimate of total effort. Theoretically, this could be reconstructed through the levy on fishing raised by the lake-adjacent villages, but, as one village leader expressed it, "*the cost of sending someone to collect the fees is higher than the income generated*". The levy records are therefore unlikely to be reliable or complete. Visual estimates of the number of canoes operating, or of the set nets in a lake, can give some indication of activity, especially when fishing activity is virtually non-existent, as has happened in lakes Mtanza and Umwe over the past few years. However, according to Welcomme (1999), fish size is one of the most powerful variables for the qualitative evaluation of fishing effort in complex, tropical, multi-species fisheries in inland waters. Thus, an indication of fishing pressure can be derived from the average size of the *Oreochromis urolepis*, generally the most abundant fish in the catches, but especially so in the "badly" connected lakes Uba, Umwe and Mtanza, where water levels are low and catchability is high. The significant differences in size of *O. urolepis* in the various lakes and its variability over time demonstrate that only Lake Uba was heavily overfished in 2008–2009, and that substantial reconnections, such as those that occurred in Lake Zumbi in 2007 and 2008, allow the fishers to reduce fishing pressure in comparison to the low-connectivity period of 2005–2006. Indeed, when fishing mode does not change, the IPHF will be determined by the interplay between lake productivity and catchability. During the "crisis" situation in Lake Zumbi at the end of 2005, IPHF was low and constant in spite of a high effort by individual fishers. After the small connections in March and April 2006, IPHF increased. As catchability increases at lower water levels, an increase in IPHF with constant (type of) effort and an increasing water level (of about 3.5 m), as occurred at that time, most likely indicates an increase in productivity that can probably be explained by the inflow of the river water with its associated nutrients and biological elements (e.g. fish intending to spawn in the floodplain lakes). The same holds, and to an even greater extent, during the connections in late 2006 and early 2007, as, between January and April, there was a major shift in fishing mode from illegal to legal and, again, an increase in lake levels of 3.6 m. The seemingly aberrantly low IPHF for Zumbi in July–August 2008/February–March 2009 of Fig. 4 is therefore an indication of sustained productivity under lower-intensity fishing. In fact, in that period, fishing in the similar-sized but much less well-connected Lake Ruwe was 100% illegal and over 90% active, while in the very well-connected Lake Ilu the high IPHF is achieved with over 25% legal (but active) fishing techniques. Maintaining the flood pulse is therefore the key to a healthy species-rich fishery in the floodplain lakes of the Rufiji that provides some income to fishers at an acceptable level of effort.

During the period under study, the district fisheries department implemented various management measures, such as imposing annual levees on canoe owners, regular clampdowns on illegal gear and mesh size, enforced closure of the lakes to fishing (March–June 2010), the introduction of a productive "tilapia" from fish farms and, most recently (2010), an increase of the minimum mesh size from 63.5 to 76.2 mm. As there is no indication that the Rufiji lakes are overfished, with the exception of Lake Uba, at least not in post-connection situations such as prevailed in 2002 and 2008, in spite of the ubiquitous use of "illegal" gear types and mesh sizes, these interventions do not seem to be evidence-based and may be related to a misperception and what is referred to as the "overfishing narrative" by Abbott and Campbell (2009) in relation to the "issue" of the use of mosquito nets for fishing in the Upper Zambezi floodplains. Compliance with fisheries regulations are a complex matter, and fines and the confiscation of nets have limited impact (Eggert and Lokina 2010). Also, as can be seen from the survival and continued productivity of *Oreochromis urolepis* in increasingly saline, shallow and murky lakes, such as Uba (the water often looks about as green as pea soup), there seems to be absolutely no need to introduce new species into the system and, should the introduction be successful, the negative impacts are likely to be substantial (Canonico *et al.* 2005).

CONCLUSION

There are clear links between hydrological connectivity and the catch composition in the different lakes.

Small, badly connected lakes such as Umwe, Uba and Mtanza are most sensitive to the absence of regular connections. Catches in these lakes quickly become dominated by *O. urolepis* while only a handful of other species can maintain themselves. In the larger lakes, such as Ruwe and Zumbi, a reasonably full complement of species can survive for longer time periods, even with irregular connections. In addition to the loss of species, the productivity of the lakes seems to decline in the absence of connections, but user strategies compensate for this by increasing effort and reducing mesh size, thus sustaining a rather constant IPHF of between 0.2 and 0.6 US$ per fisher per hour of fishing, even in the overfished Lake Uba. Therefore, catch and, thus, income per unit effort are much more resilient than species composition. Still, in order to maintain income, fishers have to resort to the use of "illegal" gear and mesh sizes, potentially bringing them into conflict with the regulatory authority. Because of the active and labour-intensive nature of the fishing, this compensatory strategy also interferes with their capacity to do agricultural work.

The observed trends, which occurred during an unprecedented series (in the perception of the locals) of consecutive drought years, raise several issues in relation to the plans for the Stiegler's Gorge Dam, and other potential changes in the hydrograph (climate change, land-use change, increased abstraction upstream) that would reduce flood peaks and therefore negatively affect hydrological connectivity. First of all, fish biodiversity may be affected, with the potential extinction of *Distichodus petersii*, and of other species dependent on lateral movements from the river into the lakes. *Oreochromis urolepis* seems very well adapted to the extreme conditions in the non-connected lakes, but the loss of species in the system increases the risk of a fundamental change in the functioning of the ecosystems (Folke *et al.* 2004), the outcomes of which are hard to predict. Currently, the system seems rather robust, but it is thought (Hopson 1979) that the replenishment of the lakes with each reconnection is possible only through longitudinal migrations along the river because of the existence of a large and virtually unexploited "reservoir" in the numerous well-connected lakes of the Selous Game Reserve. However, this would also be affected by the construction of Stiegler's Gorge Dam. Even if the dam were to operate with sufficiently large, managed flood releases, the expected river bed degradation downstream (Galay 1983) may quickly annul their positive impact. This will not only affect the fisheries, but also the entire bundle of flood peak-associated ecosystem services, with potentially dramatic consequences for the already highly vulnerable local livelihoods. For example, before the "drought", the villages around the lakes produced several thousand litres of honey each year, an activity that came virtually to a halt, most probably because falling groundwater levels diminished the flowering of riverine forest trees.

Post hoc, the reaction of the authorities to the crisis situation seems misdirected: preventing people from adapting their fishing strategy in times of duress, while distributing food aid, seems rather absurd. With intense efforts (and there was no useful agricultural work to do anyway), fishers succeeded in extracting fish from both lakes Uba and Mtanza to support their livelihoods, as long as there was water in them. Having large dead fish rather than small dead fish in a dried out lake is not particularly biologically relevant. As soon as even a minimal flood reaches the lakes, the pre-crisis situation is rapidly re-established and the fishing mode is adapted to the new circumstances, while the unconnected lakes have in fact become virtual monoculture *Oreochromis* fish ponds whose management (and mesh size regulations) can probably be left to the users. The local government, instead of taking up its new role of technical adviser rather than implementer of development, still seems to restrict its intervention to policing, thus preventing a constructive dialogue on sustainable development options such as brushwood parks (Richmond *et al.* 2006) or fingerponds (Lamtane 2008) that can potentially improve productivity in the lakes.

The results of this comparatively cheap village-based monitoring of key environmental variables, such as water levels and fisheries, over a longer time scale than the usual PhD project, demonstrates that there is scope for increasing levels of shared understanding of ecosystem service delivery that can directly benefit users. It is useful and important to widen the monitoring and the research to bundles of interlinked ecosystem services from the user perspective as their response to varying scenarios is flexible. The development of the research master plan (Ochieng 2002) through a transdisciplinary approach (Tress *et al.* 2006) with strong participation of the local communities in the identification and prioritization of issues to be investigated through action-oriented research is now bearing fruit. It can be hoped that funds from, for example, the climate change kitty can be used to support such initiatives with more regular and wider-reaching feedback sessions to the resource-using communities rather than only for high level national, regional and global "work"shops. One item that could be on the agenda is a collective evaluation of the potential costs and benefits of a controlled opening to fishing on the eastern part of the Selous Game Reserve, in particular during the difficult pre-harvest seasons, in case of a succession of years of floods that do not connect to the floodplain lakes. Also, obviously any impact of management measures, such as further restrictions on gear and mesh size (currently based on the totally different Lake Victoria fishery), temporary closure of lakes (which only makes biological sense when there is a connection), and the introduction of supposedly high-yield varieties of cichlids, should be discussed in advance, investigated scientifically, experimented on a small scale, and applied only on a consensual basis. A consensus-building approach to community-based fisheries management has been successfully implemented in Bangladesh and the Mekong Delta (Sultana and Thompson 2004), and this "sharing power" approach can be applied to conservation and sustainable use issues in general (Borrini-Feyerabend *et al.* 2004).

Acknowledgements Thanks are due to the fish recorders, J. Bwangwa, M. Makasamala, H.S. Mkina, M.A. Momboka, A.A. Mtabula, K.A. Mtumbei, Z.O. Ngageya, M.J. Nganamwa, A.S. Ngondo, J.O. Ngulangwa, H. Ngwambi, A.S. Pwetete, S.H. Sasa and M. Sobo; and the water level recorders, A.S. Pwetete, A.S. Magoga, A.J. Mbonde, A.S. Mupi, B. Mpendu, F.Y. Luwanda, F. Mbonde, H. Athumani, H. Mkumba, H.K. Machungu, K. Nguogani, M.S. Mketo, M. Mbonde, M. Mkongama, M.A. Lwambo, O.A. Ndanga, S.M. Selemani, A. Angaola, S.S. Kindinda, S. Abdallah, S. A. Magoba and T.A. Nduli; for their unrelenting efforts and accurate recordings. Credit is also due to F. Karanja, E.B. Chirwa, S.M. Sagara and R. Hogan, who set up the first fish survey; to J. Anderson who designed the database; to Vumilia who entered most of the data; to M.D. Richmond and M. Abdallah for local names for fish and gears; to Jan Mees for support and providing a home for the database in the VLIZ; and to various researchers who shared their knowledge: P. Erftemeijer, A. Mtweve, M. Cavalier, L. Brendonck, B. Vervaeke and A. Eijkelenburg. The REMP was funded by DGIS, The Netherlands, and implemented by the Rufiji District Council with technical support from IUCN. After the end of the REMP, the IRD and the Water and Land Programme of the French Ministry for Environment provided additional support.

REFERENCES

Abbott, J.G. and Campbell, L.M., 2009. Environmental histories and emerging fisheries management of the Upper Zambezi River Floodplain. *Conservation and Society*, 7, 83–99.

Baldus, R.D., 2004. Lion conservation in Tanzania leads to serious human–lion conflicts, with a case study of a man-eating lion killing 35 people. Dar es Salaam, Tanzania: GTZ Wildlife Programme in Tanzania, Wildlife Division, Tanzania Wildlife Discussion Paper 41.

Barbier, E.B., 1994. Valuing environmental functions: tropical wetlands. *Land Economics*, 70, 155–173.

Bayley, P.B., 1988. Accounting for effort when comparing tropical fisheries in lakes, river-floodplains and lagoons. *Limnology and Oceanography*, 33, 963–972.

Borrini-Feyerabend, G., *et al.*, 2004. *Sharing power: Learning by doing in co-management throughout the world.* Tehran, Iran: IIED and IUCN/ CEESP/ CMWG, Cenesta. http://www.iucn.org/about/union/commissions/ceesp/ceesp_publications/sharing_power.cfm.

Canonico, G.C., Arthington, A., McCrary, J.K. and Thieme, M.L., 2005. The effects of introduced tilapias on native biodiversity. *Aquatic Conservation and Marine Freshwater Ecosystems*, 15, 463–483.

Carpenter, S.R., *et al.*, 2006. Millennium ecosystem assessment: research needs. *Science*, 314, 257–258.

Costanza, R., *et al.*, 1997. The value of the world's ecosystem services and natural capital. *Nature*, 387, 253–260.

Craig, J.F., Halls, A.S., Barr, J.J.J. and Bean, C.W., 2004. The Bangladesh floodplain fisheries. *Fisheries Research*, 66, 271–286.

Dugan, P., Dey, M.M. and Sugunan, V.V., 2006. Fisheries and water productivity in tropical river basins: enhancing food security and livelihoods by managing water for fish. *Agricultural Water Management*, 80, 262–275.

Duvail, S., 2004. Water management and resource use in eastern African wetlands. *Pangea*, 41/42, 57–60.

Duvail, S. and Hamerlynck, O., 2007. The Rufiji River flood: plague or blessing? *International Journal of Biometeorology*, 52, 33–42.

Eggert, H. and Lokina, R.B., 2010. Regulatory compliance in Lake Victoria fisheries. *Environment and Development Economics*, 15, 197–217.

Erftemeijer, P.L.A. and Hamerlynck, O., 2005. Die-back of the mangrove *Heritiera littoralis* in the Rufiji Delta, Tanzania. following El Niño floods. *Journal of Coastal Research*, 42, 228–235.

Folke, C., *et al.*, 2004. Regime shifts, resilience and biodiversity in ecosystem management. *Annual Review in Ecology, Evolution and Systematics*, 35, 557–581.

Fullerton, A.H., *et al.*, 2010. Hydrological connectivity for riverine fish: measurement challenges and research opportunities. *Freshwater Biology*, 55, 2215–2237.

Galay, V.J., 1983. Causes of river bed degradation. *Water Resources Research*, 19, 1057–1090.

Hamerlynck, O., *et al.*, 2010a. The communal forest, wetland, rangeland and agricultural landscape mosaics of the Lower Tana, Kenya, a socio-ecological entity in peril. *In*: C. Belair, K. Ichikawa, B.Y. L. Wong and K.J. Mulongoy, ed. *Sustainable use of biological diversity in socioecological production landscapes. Background to the Satoyama Initiative for the benefit of biodiversity and human well-being*. Montreal: Secretariat of the Convention on Biological Diversity, Technical Series no. 52, 54–62.

Hamerlynck, O., *et al.*, 2010b. The large-scale irrigation potential of the Lower Rufiji floodplain, Tanzania.: reality or persistent myth? *In*: B. Calas and C.A. Mumma Martinon, ed. *Shared water, shared opportunities. Hydropolitics in East Africa*. Nairobi, Kenya: IFRA and Hekima College, 219–234.

Hanssens, M., 2006. *Distichodus petersii In: IUCN Red list of threatened species*. Version 2010.2 http://www.redlist.org [downloaded on 26 July 2010].

Hopson, A.J., 1979. Report on the freshwater fisheries on the Lower Rufiji River with particular reference to possible changes resulting from modifications to the environment by the proposed dam at Stiegler's Gorge. Rome: Food and Agriculture Organization of the United Nations, FAO Project Technical Paper 1.

Howard, G.W. and Hartley, K.L.S., 1998. How do floating aquatic weeds affect wetland conservation and development? How can these effects be minimised? *Water Ecology and Management*, 5, 215–225.

Jenkins, K.M. and Boulton, A.J., 2003. Connectivity in a dryland river: short-term aquatic microinvertebrate recruitment following floodplain inundation. *Ecology*, 84, 2708–2723.

Junk, W.J., 2002. Long-term environmental trends and the future of tropical wetlands. *Environmental Conservation*, 29, 414–435.

Junk, W.J., Bayley, P.B. and Sparks, R.E., 1989. The flood pulse concept in river–floodplain systems. *In*: D.P. Dodge, ed. Proceedings of the International Rivers Symposium. *Canadian Special Publication of Fisheries and Aquatic Sciences.*, 106, 110–127.

Lamtane, H. A., 2008. Fish ecology and yields from self-stocked fingerponds in East African wetlands. Thesis (PhD), University of London, King's College, UK.

Mwageni, E. *et al.*, 2005. Socio-economic status and health inequalities in rural Tanzania: evidence from the Rufiji Demographic Surveillance System. Accra, Ghana and Aldershot, Ashgate: INDEPTH Network 2005, 39–52.

Mwaitega, S.R., 2003. Limnological studies of floodplain lakes Ruwe and Uba, Rufiji River, Tanzania. Thesis (MSc), UNESCO-IHE The Netherlands/Institute of Limnology, Austria.

Mwalyosi, R.B.B., 1988. Environmental impacts of the proposed Stiegler's Gorge hydropower project, Tanzania. *Environmental Conservation*, 15, 250–254.

Mwalyosi, R.B.B., 1990. Resource potentials of the Rufiji River Basin, Tanzania. *Ambio*, 19, 1., 16–20.

Nicholson, E. *et al.*, 2009. Priority research areas for ecosystem services in a changing world. *Journal of Applied Ecology*, 46, 1139–1144.

Nilsson, C., Reidy, Dynesius, M., and Revenga, C., 2005. Fragmentation and flow regulation of the world's large river systems. *Science*, 308, 405–408.

Ochieng, C.A., 2002. Research master plan for the Rufiji floodplain and delta, 2003–2013. Rufiji Environment Management Project Technical Report 28 (downloaded from: http://coastalforests.tfcg.org].

Pains da Silva, H., Perty, A.C. and de Silva, C.J., 2010. Fish communities of the Pantanal wetland in Brazil: evaluating the effects of the Upper Paraguay River floodpulse on the Baia Caiçara fish fauna. *Aquatic Ecology*, 44, 275–288.

Pauly, D. *et al.*, 2002. Toward sustainability in world fisheries. *Nature*, 418, 689–695.

Pijnappel, H.W., 2002. Lakes of the Lower Rufiji floodplain, Tanzania. The water balance of Lake Lugongwe and the ecohydrological connectivity of the Rufiji lakes with the Rufiji River. Nijmegen, The Netherlands: University of Nijmegen, Department of Environmental Studies, Reports Environmental Studies 217.

REMP (Rufiji Environment Management Project), 2003. Index of Rufiji Environment Management Project Technical Reports. [Download from: http://coastalforests.tfcg.org].

Richmond, M.D., Wilson, J.D.K., Mgaya, Y.D. and LeVay, L., 2002. An analysis of small-holder opportunities in fisheries, coastal and related enterprises in the floodplain and delta areas of Rufiji River, Tanzania. Rufiji Environment Management Project Technical Report 25. [Download from: http://coastalforests.tfcg.org].

Richmond, M.D., Mohamed, A., De Villiers, A., Esseen, M. and LeVay, L., 2006. Smallholder fisheries enterprises trials. Final Report. Nairobi, Kenya: Samaki Consultants Ltd for IUCN.

Rufiji District Council, 1997. Rufiji District Socio-economic Profile. Utete, Tanzania.

Sultana, P. and Thompson, P., 2004. Methods of consensus building for community-based fisheries management in Bangladesh and the Mekong delta. *Agricultural Systems*, 82, 327–353.

Tress, B., Tress, G. and Fry, G., 2006. Defining concepts and the process of knowledge production in integrative research. *In*: B. Tress, G. Tress, G. Fry and P. Opdam, ed. *From landscape research to landscape planning. Aspects of integration, education and application*. Berlin: Springer, Wageningen UR Frontis Series, 13–26.

Turpie, J.K., 2000. The use and value of natural resources of the Rufiji Floodplain and delta, Tanzania. Rufiji Environment Management Project Technical Report 17.[Download from: http://coastalforests.tfcg.org].

United Republic of Tanzania, 2005. Poverty and Human Development Report 2005. Dar es Salaam, Tanzania: The Research and Analysis Working Group.

Ward, J.V., Tockner, K. and Scheimer, F., 1999. Biodiversity of floodplain river ecosystems: ecotones and connectivity. *Regulated Rivers: Research and Management*, 15, 125–139.

Welcomme, R.L., 1975. The fisheries ecology of African floodplains. Rome: FAO, CIFA Technical Paper 3.

Welcomme, R., 1999. A review of a model for qualitative evaluation of exploitation levels in multi-species fisheries. *Fisheries Management and Ecology*, 6, 1–19.

Welcomme, R., 2008. World prospects for floodplain fisheries. *Ecohydrology and Hydrobiology*, 8, 169–182.