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John Sebit Benansio
AERD-Alliance for Environment and Rural Development

Johnson J. Balli

Daniele Dendi
Rivers State University of Science and Technology

Stephanie N. Ajong

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John Sebit Benansio[1], Johnson Jiribi Balli[2], Daniele Dendi[3,6,7], Stephanie N. Ajong[3,4], Nic Pacini[5,8], Luca Luiselli[3,6,7]

[1]AERD – Alliance for Environment and Rural Development P.O. Box 445, Juba South Sudan; Email: sebitbenansio@gmail.com
[2]Department of Fisheries Science, University of Juba, P.O.Box 82, Juba, South Sudan; Email: j.jiribi@yahoo.com
[3]IDECC – Institute for Development Ecology Conservation and Cooperation, via G.Tomasi di Lampedusa 33,00144 Rome, Italy. Emails: d.dendi@ideccngo.org; l.luiselli@ideccngo.org
[4] Department of Fisheries, Lagos State University, Ojo, Lagos, Nigeria. Email: ajong.stephanie@gmail.com
[5] Department of Environmental Engineering, University of Calabria, Arcavacata di Rende, Italy; Email: nic.pacini@unical.it
[6]Department of Applied and Environmental Biology, Rivers State University of Science and Technology, P.M.B. 5080, Port Harcourt, Nigeria;
[7]Département de Zoologie, Faculté des Sciences, Université de Lomé, B.P. 6057 Lomé, Togo
[8]University of Leicester School of Geography, Geology and the Environment, LE1 7RH, UK

Abstract.

A survey conducted in Terekeka, Mangalla and Gemeiza, payams of Central Equatoria in South Sudan using face-to-face interviews, structured questionnaire and focused group discussion provided information on income generating strategies of fishing communities. These included: full time or part time fishing, small-scale farming, cattle breeding and firewood collection. Stationary gill nets were the dominant type of fishing gear, followed by monofilament, hook and long line, cast nets, spears and harpoons. Fishing vessels included planked canoes, steel boats and fibreglass. The best fishing months were August, September, followed by May. Main species caught included large bodied potamodromous predators adapted to channel habitats, as well as floodplain migrants. Overall, the fish community appeared to be at equilibrium, with no evidence of impacts due to excessive catch efforts. The good health of the local fishery is related to the high resilience of South Sudanese aquatic ecosystems, as well as to the low potential of fish capture in a country disrupted by war and lack of security. Our results support the view that Sudd swamp fish communities significantly contribute to Nile River biodiversity.

Key words: *fishing communities, fish diversity, fishing impact, White Nile River, fishing-down*

Introduction

Despite humanitarian efforts backed by the international organizations (FAO, UNDP, UNEP, etc.) and significant gross domestic product increase in several West African countries, recent reports confirm that food insecurity has been steadily rising in Sub-Saharan Africa, where the number of undernourished people reached 236.5 million by 2017 (+25% within the preceding 12 years; FAO 2018). The situation is particularly critical in South Sudan, a Low Income Food Deficient Country inhabited in mid-2014 by an estimated 11.9 million people (FAO 2015), with a *per capita* GDP of around 1,500 US$ (World Bank 2021, data referred to 2014). By late 2014, about 38.3 percent of the population was considered food insecure and the country was at *level 3 (and above)-Emergency*, as defined by the Integrated Food Security Phase Classification (FAO 2015). South Sudan is reputed having one of the highest population growth rates in the world (ca. 3%, according to different estimates), only mitigated by the fact that about 2.3 million people fled the country between 2013 and 2015, mainly to Sudan and to Uganda, pushed by famine and ethnic violence.

The research we describe was conducted in 2014, while the country was under a long-lasting armed conflict. A C*omprehensive Peace Agreement* had been signed in 2005 after 22 years of civil war, but the region experienced a new outbreak in December 2013 (a *Revitalised Peace Agreement* was then signed on the 12th of September 2018). By 2018, the country was at peace but with nearly 2 million people internally displaced, lack of safe transport facilities, disruption of markets, and forced interruptions of humanitarian assistance over vast portions of its territory. Cattle raiding and disruption of traditional seasonal livestock migration patterns affected one of the primary economic activities while the country witnessed a pronounced reduction in food production capacity and a decrease in cereal output (FAO 2015). Beside the conflict, the region has been recently affected by anomalous droughts and high temperatures, symptoms of climate change that have given origin to an increase in maize and wheat prices across most of Africa (FAO et al. 2018). Data collected in South Sudan over the last 15 years indicate that a reduction in the growing season and anomalous dry spells exacerbated food insecurity, already critical because of conflict. South Sudan was recently listed among the 5 countries in the world that were expected to be worst hit by on-going climate change (Climate Change Vulnerability Index 2017).

When livelihoods become insecure or fail entirely, fishing remains often the sole source of protein to sustain rural populations. It is a consolidated fact that in much of inland Africa and Asia, fishing is a largely underestimated source of food (Deines et al. 2017, Dugan et al. 2010) and represents a "safety net" for the rural poor (Heck et al. 2007, Jul Larsen et al. 2003), which becomes essential for survival during conflicts and/or droughts. Famine relief operators are well aware of this, and rely on the availability of fish and wild foods to compensate the lack of other sources of nourishment especially during the rainy season (FEWS NET 2019), when bad roads disrupt relief operations.

South Sudan has vast aquatic resources with some 13 million hectares of inland waters distributed between the Nile River, its tributaries, and the vast network of side channels, oxbow lakes and seasonally inundated riverside swamps that develop within its floodplain. The Nile Basin includes 97.5% of the country and comprises the White Nile coming from the Great Lakes, the Bar El Sobat originating in Ethiopia and the Bahr El Ghazal joining the main river from the West. During the dry season, beside the White Nile, which is the only perennial river, the country can rely on the vast wetlands comprised within the Sudd Swamps. The rivers and swamps undergo pronounced seasonal pulsing, during which the Sudd can expand, on an average year, from 10 000 km^2 to more than 35 000 km^2, depending on rainfall (FAO 2016). The Sudd, whose 57,000 km^2 core area has been declared Ramsar site in 2006, is a key repository of Nile biodiversity, hosting 470 species of birds, >100 mammal species, >100 fish species, including 8 dwarf fish species (Cichlids and Cyprinids) endemic to the Sudd (El-Moghrabi et al. 2006). It is estimated that more than 1 million people, mainly included within the Dinka, Nuer and Shilluk ethnic groups, base their livelihoods on its resources and modulate their seasonal activities according to flood levels. Due to the lack of security, little recent information is available on the status of the fisheries resources available to them.

Fisheries contribute to meeting the millennium development goals of many countries in the world through employment, provision of nutritious food, generation of revenues for local and national governments from licenses and taxation on landings, from export revenues, and from various upstream and downstream multipliers (Béné 2006; Heck et al. 2007). In 2013, it was estimated that as many as 1,732,208 Sudanese households (comprising South Sudan) were directly dependent on capture fisheries for their food security (CAMP 2013). In South Sudan today, fisheries provide a substantial, yet underestimated contribution to overall nutrition and promotion of healthier lives (Sustainable Development Goal 3: *Ensure healthy lives and promote well-being for all at all age*), mitigate poverty (Sustainable Development Goal 1: *End poverty in all its forms everywhere*) and ensure quality education (Sustainable Development Goal 4: *Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all*).

In South Sudan, the fisheries sector is portrayed by thousands of poor, small-scale fishers, using rudimentary gear and living in isolated fishing camps in *Typha* and *Papyrus* thickets along the White Nile and Sudd swamps (Benansio 2013), with no infrastructural support (Miller 2008). Low infrastructure, poor fisheries organization and lack of training and capacity building contribute to high post-harvest losses (Taege and Benansio 2009). It can be estimated that in 2014, there were approximately 35,000 fisheries operators in South Sudan, of which 10,000 engaged in full-time fishing, with as many as 50,000 more looking after fish processing, transporting, wholesaling and retailing (UNIDO 2015, BKP 2013).

The river counties of Mangalla, Terekeka and Gemeiza (= Gemeiza) are the most productive fishing clusters within Central Equatoria, an ecoregion of high fish productivity (Taege and Benansio 2009). As in much of the rest of Africa, the majority of the local fisher-folk is composed of farmer-fishers, and even cattle ranchers-fishers, who fish part-time to diversify their sources of income, as a risk spreading activity. Direct information is less than scanty, and overall the fishery sector of South Sudan is characterised by lack of credible data on all aspects of resource management and development because of limited institutional capacity (BKP 2013). Fishing activities and their output are severely undervalued. Given the widespread insecurity, official capture fisheries were estimated to range between 40,000-45,000 t for the whole country (FAO 2015), which is far lower than the 75,000 t estimated fish capture potential for the Sudd alone mentioned by Witte et al. (2009a). However, next to official figures, fish capture estimates based on recent local sources raise this to a larger amount, comprised between 150,000 and 300,000 tons per year nationwide, which would raise the value of capture fisheries to1.5 billion South Sudanese pounds, equivalent to 555 million US$ (Miller and Benansio 2011, UNIDO 2013). Besides the size of the fish catch, poor product quality and wasting during transport significantly limit the potential value of South Sudanese fisheries. Lack of cooling facilities in the fishing areas and transport limitations imply that most of the fish going to be marketed ends up being sun-dried, salted or smoked using traditional methods with substantial product loss.

A large diversity of fishing gears is used, including gill nets, hooks and lines, long lines, seine nets, cast nets, hand nets, basket and wire mesh traps (locally known as *Egwa*), and spears (Witte et al. 2009b, BKP 2013). Different types of fishing vessels are used, including *sharoaq* long canoes, *felukas*, and *Murkab Al-Hadeed* fishing boats (FAO 2018). The fishing gear, including nets of 5-8 inch mesh size are deployed to catch mainly Nile tilapia and *Heterotis*; large Nile perch is fished using 70-100 inches nets; catfishes (*Clarias*, *Bagrus* and *Synodontis*) are caught using lines and hooks; Mormyridae are fished using 4 inch mesh (BKP 2013). Several other fishes are caught while aiming at these preferred species Catches are limited by poor quality equipment, the poor state of fishing vessels, scarce availability of replacement parts and difficulty in keeping fishing equipment in working conditions. The market value of fresh fish can be as low as <0.3 US$/kg (BKP 2013); fish is mainly caught for subsistence purposes and sold only when in excess. For similar reasons aquaculture is very poorly developed, to the extent that the national output for 2016 was estimated at 20 t only (FAO 2018), despite the high natural resource potential. No systematic assessment of fish stocks is made and no information is collected concerning water pollution and its potential impacts on fish quality and availability. Under present conditions, apart for a yearly fish licence fee (115 SSP = 0.5 euro) and a largely ignored 3600 SSP annual trading licence (BKP2013), the system can be considered an unregulated and unrestrained open-access fishery with no effective enforcement of regulations that could moderate access, and characterised by a general lack of control of the fishing methods used.

In this contribution, we characterise inland fisheries in the Sudd Swamps by combining a dual objective: 1. assess fish community composition of the captured fish stock, and 2. describe socioeconomic status and fishing practices among fisher communities. We discuss the data within the context of potential fishing impact on the diversity of Sudd Swamp fisheries and their contribution to the fish diversity of the Nile River. This work contributes rare data on fishing resources from a troubled and hitherto virtually unexplored central African region, in which fishery resources provide a much needed last resort to the on-going food emergency.

Materials and Methods

Location and climate within the study area

The present study was carried out along the White Nile - the branch of the Nile originating from the equatorial lakes, in a reach situated North of the capital Juba, within the surroundings of the western and eastern corridors of the Bandingilo National Park (*ca.* 10,000 km^2). After leaving the city with a 50 km steep run along an incised straight channel, the White Nile reduces its slope and becomes progressively more braided as it starts coming closer to Mangalla (= Mangalla), from where it enters the Sudd Swamps. In this region, the main river is locally known as Bahr El-Jebel (the Mountain River), name which refers to the cataract and rocky runs that characterise the riverbed upstream of the capital. Our study reach is comprised within the counties of Mangalla, Terekeka and Gemeiza (= Gemeiza), in Terekeka State (part of former Central Equatoria; Figure 1). The small town of Mangalla (N 05^0 11’53.50” and E 031^0 46’1.64”) lies on the eastern bank of the Nile, with a population of 3,997 (SSNBSC 2010), while the city of Terekeka (N 05^0 27’15.55” and E 031^0 45’26.78”), on the western bank, hosts 144,373 inhabitants (SSNBSC 2010), and Gemeiza (N 05^0 44’27.38” and E 031^0

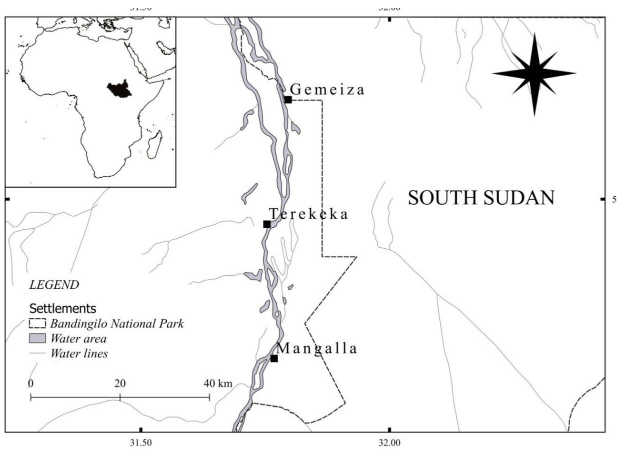

Figure 1: Map of South Sudan, showing the three study sites situated along the White Nile.

47'10.21") on the western bank has a population of 7,558 inhabitants (SSNBSC 2010).

Situated at an altitude decreasing from 449 to 441 m a.s.l., with average daily temperatures between 21 and 39°C, our study area enjoys an average long-term precipitation comprised between 1000 and 900 mm/year, decreasing from South to North. The climate is moist tropical, characterised by an extended rainy season with two peaks, the first one in May-June and the second one between July and August. The rainfall pattern is intermediate between the equatorial (2 rainy seasons) and the tropical one (1 rainy season) as this southern portion of the Sudd is close to the limit of the annual northerly migration of the Intertropical Convergence Zone (ITCZ) driving monsoonal precipitation.

Hydrology

The stretch between Mangalla and Gemeiza, 55 km in river length, was selected for our study because of its reputed high fishing potential at national scale, after consultations with the Department of Fisheries of Central Equatoria and with the Senior Fisheries Officer of the National Ministry of Livestock and Fisheries Industry. As suggested by studies conducted in other tropical regions (for example: Baran et al. 2001), the reason for this high production potential is likely to reside in the main hydrological characteristics of our study area, i.e.: extensive seasonal flooding over vast areas.

While entering the Sudd at Mangalla, the White Nile reaches its maximum average discharge: 36 km^3/year (1940-1977 data; FAO 2019). Thereafter, its flows disperse across the floodplain swamps, where evapotranspiration rates in excess of 1600 mm/year greatly reduce water levels (Rebelo 2016). Measured outflows at Malakal, 480 km further North, at the other end of the Sudd, are about half of estimated inflows at Mangalla. The Sudd outflow includes the combined discharge represented by the Bahr El-Jebel and the Bahr El-Ghazal (the Gazelle river), the western branch of the Sudd, which contributes almost negligible flow, in addition to local tributaries active only during seasonal rains (Sutcliffe 2009). The Sudd region, from Mangalla to Malakal, and with a width of 1300 km across, comprises a catchment area of 1.48 million km^2 (Mohamed et al. 2005) that was originally occupied by a huge shallow lake (Green and Al Moghraby 2009); as much as 90,000 km^2 in this area can become submerged during exceptional floods (Dumont 2009).

During the rainy season, local temporary tributaries tend to contribute sudden high flows and heavy silt loads to the Bahr El-Jebel. On average years, water logging caused by the rains precedes slightly the river flood peak, which tends to reach Mangalla in early September, at the end of the rainy season. The maximum extent of flooding in the central Sudd takes place in January (Rebelo 2016). From Mangalla to Gemeiza, the active floodplain (5-10 km across) is contained between incised banks only few meters tall, marking the limit of the 'Acacia forest' on either side and progressively tapering off northwards. The three sites selected for our survey are about 20 km apart and comprise relatively similar habitats. The river is slow-flowing, with low and steadily decreasing bed inclination (only about 10 cm/km). Islands, braided channels and oxbow lakes become progressively more numerous as the river meanders northwards beside riparian swamps dominated by floating hippo grass *Vossia cuspidata* Roxb., papyrus *Cyperus papyrus* L. and the ever present water hyacinth *Eichhornia crassipes* Martius (Solms-Laubach). Beyond the floating vegetation belt, rooted papyrus alternates with tropical reed *Phragmites karka* Retz. and southern cattail *Typha domingensis* Pers. distributed according to depth of flooding (Sutcliffe 2009) in a mosaic of depressions and alluvial deposits. As in the rest of the Sudd, in places this riparian vegetation forms an intricate and sometimes inaccessible jungle colonised by climbers (Green and El-Moghraby 2009).

During high river flows, floodwater is released towards the floodplain through spill channels that cut through the river banks, and a multitude of depressions of various size start filling up forming temporary wetlands. Extensive flooding tends to start further North, above Bor, where slope becomes <2 cm km^{-1}, the valley opens up, and vast portions of land are submerged all year round. Only later in the flooding season, progressively, flooded areas expand southwards. As the floodplain becomes submerged, water starts moving slowly northwards across the vegetation, in parallel to the main channel (Sutcliffe 2009).

Local human population

Between Mangalla and Gemeiza, fishers reside in small villages and single homes along the river, and congregate in fishing camps during their daily activities. No major differences were evident between the settlements surveyed. Fishers tend to gather in groups or associations. In former Central Equatoria, 16 associations existed, separate among fishers and fish traders, and most of them were active in Terekeka, Gemeiza and Tombe (BKP 2013), where they kept partial records of fish landings and interacted with fisheries officers and NGOs. Fishing has traditionally been a subsistence activity, considered as a secondary alternative to livestock keeping, main economic activity within the region. Commercial fishing picked up during the 1970s with the arrival of fishermen from West Africa and from northern Sudan, but then it was greatly disrupted by lack of security and political instability. The most favourable fishing period coincides with the flood recession period, from the end of the rainy season up to late November, while catches become strongly reduced during the first half of each calendar year. During this period, fishers tend to migrate, often as far as Uganda, to become farmers or conduct other business.

Sampling methods

A team of surveyors approached fishers and other fishing sector operators belonging to 20 communities, by visiting them at their work place, in fishing camps and in their proximity. Each study area was surveyed intensively during a period of two weeks in May, and again in July 2014. Some 340 semi – structured interviews were conducted: 84 in Mangalla, 125 in Terekeka, and 131 in Gemeiza, in the interviewee's own language, mostly local Arabic or Bari. The catches of a total of 20 fishermen in Mangalla, 23 in Terekeka, and 36 in Gemeiza were inspected and fish species were identified. The number of fish individuals was not recorded because of time constraints, whereas the presence/absence of each species in the catches of each fisherman was carefully recorded. For each species in each study area, we assessed the number of fishermen that captured it. Therefore, the percentage of occurrence of each species was used to describe a representative fish assemblage composition at each study area.

Semi-structured interviews and Focus Group Discussions (FGD) were conducted with local fishers' communities in order to: 1. assess local community education level; 2. obtain information on fish breeding season, seasonality of occurrence, season of highest catch efficiency; 3. obtain information on the economic importance of the various fish species; 4. Obtain details about fishing gear used and access to fishing vessel; 5. specify details about their main income generating activities, beside fishing. Interview methods followed the British Sociological Society's guidelines for ensuring appropriate ethical standards in projects involving data collection from people for research purposes. All respondents were assured that their identity would be kept anonymously, with no minors being involved in the survey. Interviews were conducted following verbal consent of participants. In each research area, we interviewed representative community leaders.

Fish community analysis

Patterns of species composition, evenness and dominance were compared between the three study areas using the following indices of species assemblage (Magurran 1988):

(1) number of species observed;

(2) Dominance: 1–(Simpson's index), with values ranging from 0, when all species are equally abundant, to 1 when one species dominates the entire community);

(3) Simpson's diversity index: 1–(Dominance index), with values also yelding from 0 to 1;

(4) Shannon's index (ranging from 0, for communities with only a single taxon, to high values, for communities characterised by many taxa but each having few individuals);

(5) Buzas and Gibson's evenness (Harper 1999);

(6) Chao-1 index.

For each index, upper and lower confidence intervals were generated by bootstrapping, with 9,999 random samples, each with the same total number of individuals as in each original sample being generated (Harper 1999). Principal Component Analysis (PCA) was used to portray the distribution of fish species presence/absence and abundance in a multivariate space (Hammer 2012). The selection of the factors was based on Kaiser's criterion, retaining all factors with *eigenvalue* ≥ 1.

The data distribution of each variable was tested for normality by the Shapiro–Wilk test, and when normality was rejected ($P < 0.05$), data were log transformed before performing parametric statistics. The frequency of use of (i) fishing gears, (ii) boats, and (iii) boat ownership, was compared among study areas by observed-versus-expected χ^2 test. Alpha was set at 5%, and all tests were performed with PAST 4.0 statistical software.

Results

Fish assemblage composition

The survey yielded 19 fish species belonging to 17 families and 9 orders. Four species (*Clarias gariepinus* Burchell, *Distichodus nefasch* Bonnaterre, *Oreochromis niloticus* L., and *Gymnarchus niloticus* Cuvier) appeared in most catches (Table 1). Other species, belonging to the genera *Tetraodon, Schilbe, Citharinus* and *Heterobranchus*, occurred rarely, and only at single sites, with a scattered distribution. Saturation curves indicated that fish diversity, with a species richness averaging 15 to 17 species per site, was accurately surveyed in all study areas (Figure 2A), and the diversity profiles of the three areas were substantially similar (Figure 2B). The diversity indices used in this study did not show any remarkable difference across sites (Table 2). In terms of taxonomic diversity and abundance, factor scores of the PCA analysis (determinant of correlation matrix = –1.876) showed that study areas 1, 2 and 3 were very similar (Figure 3). Factor 1 (eigenvalue = 3.895) explained 97.1% of the total variance, Factor 2 explained just 2.1% of the total variance (eigenvalue = 0.864). The three study areas were arranged along the latitudinal gradient by factor 2 (Figure 3).

Table 1: Taxonomical composition, and relative fish abundance at the three study sites. Percentage presence of each species in fishers' catches was used as estimate of relative abundance. Symbols: * = endemic, [vu] = vulnerable, [DD] = Data Deficient, [thr] = threatened, [RE] = regionally extinct

					Terekeka		Mangalla		Gemeiza	
Order	Family	Species	migration	diet	n=23	%	n=20	%	n=36	%
Characiformes	Alestidae	*Alestes baremoze* [RE]	potamodromous	omnivore	6	26.1	4	20	9	25
Characiformes	Alestidae	*Hydrocynus forskahlli* [VU]	potamodromous	piscivore	18	78.3	17	85	21	58.3
Characiformes	Citharinidae	*Citharinus citharus* [thr]	potamodromous	detritus/plankton	1	4.3	0	0	0	0
Characiformes	Distichodontidae	*Distichodus nefasch*	potamodromous	micro/macrophytes	20	87.0	14	70	33	91.7
Cichliformes	Cichlidae	*Oreochromis niloticus*	main channel	planktivore	21	91.3	19	95	32	88.9
Cypriniformes	Cyprinidae	*Labeo niloticus* *	main channel	detritivore	4	17.4	1	5	7	19.4
Lepidosireniformes	Protopteridae	*Protopterus aethiopicus*	floodplain resident	insect/piscivore	6	26.1	7	35	9	25
Osteoglossiformes	Arapaimidae	*Heterotis niloticus*	main channel	insectivore	13	56.5	11	55	26	72.2
Osteoglossiformes	Gymnarchidae	*Gymnarchus niloticus* [DD thr]	floodplain migrant	insect/piscivore	21	91.3	19	95	29	80.6
Osteoglossiformes	Mormyridae	*Mormyrus caschive* * [VU]	potamodromous	insectivore	3	13.0	7	35	5	13.9
Perciformes	Latidae	*Lates niloticus*	main channel	piscivore	15	65.2	13	65	27	75.0
Polypteriformes	Polypteridae	*Polypterus senegalus*	floodplain migrant	invertivore	9	39.1	5	25	13	36.1
Siluriformes	Bagridae	*Bagrus bajad*	floodplain migrant	invert/piscivore	16	69.6	17	85	31	86.1
Siluriformes	Clariidae	*Clarias gariepinus*	floodplain migrant	invert/piscivore	22	95.7	19	95	35	97.2
Siluriformes	Clariidae	*Heterobranchus bidorsalis* [VU]	main channel	omnivore	0	0.0	0	0	2	5.6
Siluriformes	Malapteruridae	*Malapterurus electricus* [VU]	main channel	piscivore	0	0.0	4	20	0	0
Siluriformes	Mochokidae	*Synodontis schall*	floodplain migrant	invertivore	15	65.2	12	60	23	63.9
Siluriformes	Schilbeidae	*Schilbe intermedius*	potamodromous	invert/piscivore	0	0.0	1	5	0	0
Tetraodontiformes	Tetraodontidae	*Tetraodon lineatus* [DD thr]	main channel	molluscivore	0	0.0	0	0	1	2.8

Table 2: Diversity indices at the three study sites. Lower = lower 95% confidence limit of the estimate after 9,999 random bootstraps; Upper = upper 95% confidence limit of the estimate after 9,999 random bootstraps.

	Terekeka	Lower	Upper	Mangalla	Lower	Upper	Gemeiza	Lower	Upper
Taxa richness	15	15	15	16	16	16	16	16	16
Dominance	0.087	0.083	0.101	0.085	0.081	0.100	0.086	0.083	0.096
Simpson	0.913	0.899	0.917	0.915	0.899	0.919	0.914	0.904	0.917
Shannon	2.527	2.429	2.565	2.565	2.457	2.609	2.544	2.469	2.584
Evenness	0.834	0.757	0.866	0.813	0.729	0.849	0.795	0.738	0.828
Chao-1	15	15	16	17	16	19	16	16	17

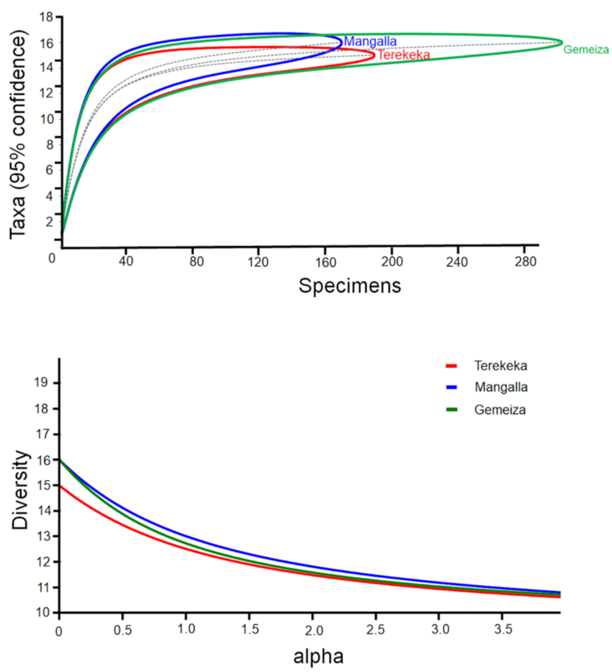

Figure 2: (upper graphic) Saturation curves (95 % confidence intervals after 9999 bootstraps) and (lower graphic) Diversity profiles (95 % confidence, after 9999 bootstraps) illustrating fish community diversity in the three study sites. "Specimens" refers to individual catches made by fishers.

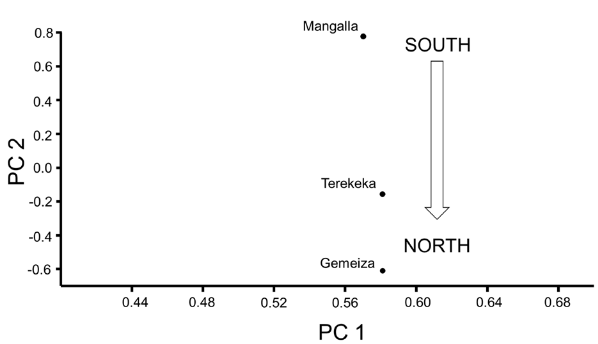

Figure 3: Scores of the first two factors extracted from a principal component analysis (PCA) of fish species by study site.

Interviews with fishermen

In each study area, only a minority of the fishers were fishing full-time and most had an alternative occupation as main income generating strategy (Appendix 1). Rural economic activities in the study area include fishing, livestock grazing, illegal hunting/poaching of wildlife, charcoal production, collection of reeds and other building materials, fuel, production of crafts and hunting are important aspects in the rural economy. Most fishers were illiterate or with low formal education, very few had tertiary education (Appendix 2).

Use of fishing gears showed significant differences within and among study areas (χ^2 test, $P < 0.01$). Stationary gill nets were most common in Terekeka, whereas hooks and long-lines were preferred in both Mangalla and Gemeiza (Table 3). *Sharoaq* planked canoes were the main type of fishing vessel in all study areas (χ^2 test, at least $P < 0.01$), followed by *Murkab Al Hadeed* steel boats and *felukas* (Table 4). Most fishers shared a vessel with other members of the community, while fewer owned their own (Table 4). Because of the flood pulse, the fish catch is highly seasonal, and tends to be plentiful at the end of the rainy season when fish tend to abandon the floodplain returning towards the main channel. Typically this is also the period when transport becomes difficult because roads are impassable and the produce cannot be easily marketed. Fishing effort peaked during the wet months (May to September, Figure 4) and was significantly uneven among fishers' communities (χ^2 test, $P < 0.01$).

Discussion

Fish community composition as reflected in fishers' catch

Fish capture data presented in Table 1 indicate very little difference between sites despite the vari-

Table 3: Main type of fishing gear utilised by fishers in the three study areas. Numbers reflect the sample size of interviewed fisherfolks using a given fishing gear

	Terekeka	Mangalla	Gemeiza
Stationary gill nets	19	17	26
Cast Nets	4	7	6
Hooks and long-lines	17	19	33
Spears and Harpoons	6	4	11
Monofilament gill nets	16	18	23

Table 4: Synopsis of the data recorded from interviews with fishers concerning the type of vessel used during fishing activities and ownership. Numbers reflect the sample size of interviewed fisherfolks reporting the type of used fishing vessels and the type of ownership of their used fishing vessels

	Terekeka	Mangalla	Gemeiza
Fishing vessel			
Planked canoe (*sharoaq*)	16	7	56
Steel boat (*murkab el hadeed*)	9	1	12
Fibreglass boat (*feluka*)	5	0	2
access to boat/canoe and ownership			
No access	4	11	17
shared	16	14	26
hired/rented	9	12	13
owned	12	4	21

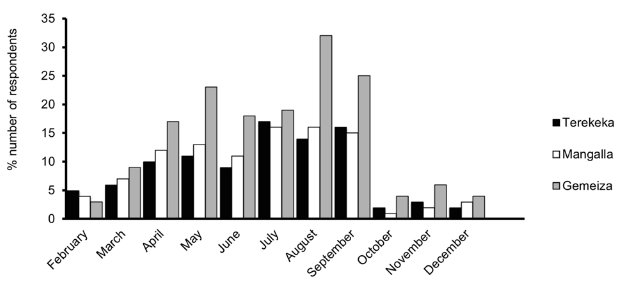

Figure 4: Seasonality of fish capture effort intensity at the three study sites.

ety of fishing gear and vessels used. As underlined in Materials and Methods, potential between-site differences in the structure of aquatic and riparian habitats are masked by the complexity of the overall habitat mosaic that characterises the wider area. The second axis of multivariate plot (see Figure 3), indicates that species distribution varies with latitude, a factor that is likely to be related to the change in valley morphology and in flooding patterns, as reported in the description of the study area; this evidence has however low explanatory power. Our fish species list (Table 1) reflects fishers' preference for large marketable fish, and the selectivity of the fishing gear used. The list is not representative of the diversity found in the greater region drained by the White Nile. As many as 68 species were listed by Hickley and Bailey (1987) caught by electro-fishing among floodplain swamps above Bor (further North), where 23 species were caught in the seasonal floodplain, while as many as 63 were found in permanent wetlands, highlighting the importance of permanently flooded habitats.

Despite the moderate species diversity (in relation to the number of fish species caught in former published surveys; e.g.: Hickley and Bailey 1987) that characterises the fish catch recorded in our survey, we note that the fish community composition indicates a rather well-equilibrated fish community, characterised by the presence of a moderately large proportion of predators such as *C. gariepinus*, *G. niloticus*, *Hydrocynus forskahlli* Cuvier, *Bagrus bajad* Forsskål, and *Lates niloticus* L. (for greater detail see Appendix 3). General patterns governing the size structure of predator/prey systems (Hatton et al. 2015), as well as relationships existing between biomass and body size in fish communities (Sprules and Barth 2016), highlight that the proportion between large bodied species, many of which are piscivorous in the adult phase, and "coarse" fish, is an indicator of the potential strength of top-down control in fish communities. Size structure has been highlighted by empirical observations carried out on intensively exploited African riverine fisheries (Allan et al. 2005 and references therein); such studies evidenced how fishing effort impacts on the size structure of communities altering the original pattern. The "fishing down the food-web" syndrome became a universally accepted conceptual model introduced to describe changes in fish composition that occur when increasing fishing pressure selects out large-bodied species, mostly fish predators, whose slow reproduction rate typically does not cope with the rate of uptake by fishers (Régier and Loftus 1972, Pauly et al. 1998). As fishing effort increases, predators reduce their body size and eventually become extinct altogether. A similar "fished-down" community has been illustrated for the Ouémé River in Benin (Allan et al. 2005), a river occupied by smaller, faster growing and faster reproducing species, represented by low trophic levels characterised by high productivity in relation to biomass. Fishing-down and the consequent release of top-down control that ensues lead to consequences for primary and secondary productivity that may alter the physical structure of ecosystems.

In our catch data, the high frequency of large species (i.e.: >80 cm potential maximum length), that are predators in the adult phase, indicates that fishers are actively selecting for large-bodied taxa and their frequency is greater than what we would expect in a natural community where predators typically represent a minor fraction while small individuals and species greatly outnumber large species and individuals. Large bodied fishes have not become over-exploited yet indicating that the local fishery may be experiencing a capture effort below overfishing and there are no signs of "fishing-down".

The presence of several other species, such as the ones highlighted below, confirm the good health of the Sudd fishery. *Synodontis schall*, present in all our sites and once very common in the upper Nile, has become rare in Khartoum fish market; similarly *Alestes baremoze* Joannis, and the Nile endemic *Mormyrus niloticus* Bloch & J. G. Schneider common in our survey, have been extirpated altogether from the lower Nile in Egypt, where as much as one third of the original fish fauna is threatened or already extinct (Neumann et al. 2016). Our list also contains endemic species such as *Labeo niloticus* L., the vulnerable endemic *Mormyrus caschive* L., the vulnerable *Malapterurus electricus* Gmelin, and the rare threatened large-bodied *Tetraodon lineatus* L.

Relevance of the Sudd to Nile River fish diversity

According to the most recent surveys, the Nile River catchment, in its portion comprised between Jinja (Uganda) and the Mediterranean, hosts 150 fish species, including 133 autochthonous, 7 introduced, and 10 populations defined to be "aberrant", i.e.: potentially representing new taxa (Neumann et al. 2016). This relatively modest estimate, when compared to other large tropical rivers, is attributed to the current, as well as to past periods of long lasting aridity within much of the Nile's basin (Darwall et al. 2011). In reality, despite its great catchment size and river length, less than 30 fish species survive along most of the main course of the mighty river (Darwall et al. 2011) and most of the Nile's extant freshwater diversity is comprised in its upstream branches: the Blue Nile in Ethiopia and the White Nile coming from South Sudan. The White Nile alone, including the Sudd could host as many as 100 species (Howell et al. 1988); this dated estimate still needs further confirmation that has been impossible to get because of political instability and lack of safe access to sites in South Sudan.

South Sudanese freshwaters are of difficult access and yet highly productive (Miller and Benansio 2011); the flood pulse, which inundates vast portions of the Nile floodplain revitalises a diverse array of aquatic ecosystems, creates refuge for the reproduction and growth of wetland species and at the same time makes the region impenetrable. The great abundance and variety of South Sudanese freshwater ecosystems is matched by plentiful and diverse inland fisheries resources.

As many as 80% of the 123 fish species present in Sudan and South Sudan, including 23 of the 43 extant Nile Basin endemics, are considered data deficient and their status needs further assessment (Neumann et al. 2016); information exists only concerning species of commercial interest (i.e.: FAO 2018). Experts suspect that minor tributaries draining the outer regions of the Sudd could host several endemic species collected only rarely, and very probably some undescribed taxa (Neumann et al. 2016).

Conclusions

South Sudanese freshwaters represent a precious repository of Nile fish species that have become uncommon elsewhere in the basin. The relatively diverse population hosted there is a consequence of the high diversity of freshwater habitats, their relatively well-preserved state, and low fishing effort.

The weakness of the fishing sector portrayed by our survey, exacerbated by poor roads, lack of storage infrastructure and insecurity because of conflict, and the difficulty of accessing the vast and widespread fisheries resources is a factor that reduces the fishers' impact in comparison to large river fisheries in West Africa, such as the Ouémé and the Niger.

The results of our survey, with its moderately large species diversity and the presence of large-bodied predatory species underline this situation as these can be considered good indicators of fish community health and fishery resource potential. As shown by Brooks et al. (2016), in African continental waters fish species richness is significantly related to fish yield and to reduced yield variability. Following a large increase in Lake Victoria outflow in the early 1960s, the Sudd entered a long-term expansion period that greatly benefited its ecology and fisheries (El-Moghrabi et al. 2006), and that partly could be influencing the resilience of the wetland ecosystem still today. The alarming status of freshwater biodiversity worldwide (Reid et al. 2018) confers a global significance to the relatively pristine resources held in the South Sudanese upper Nile. Our brief survey of fish catches supports the view that South Sudan is likely to represent a precious repository hosting most of the original aquatic biodiversity of the Nile Basin that has become overfished and polluted along most of its course (Witte et al. 2009b, El Sayed 2017, El Sheekh 2017).

A further confirmation of the preliminary results presented in this contribution would require a more detailed assessment of the fish community status including the collection of morphometric data and estimates of length at maturation of the dominant taxa.

Acknowledgements

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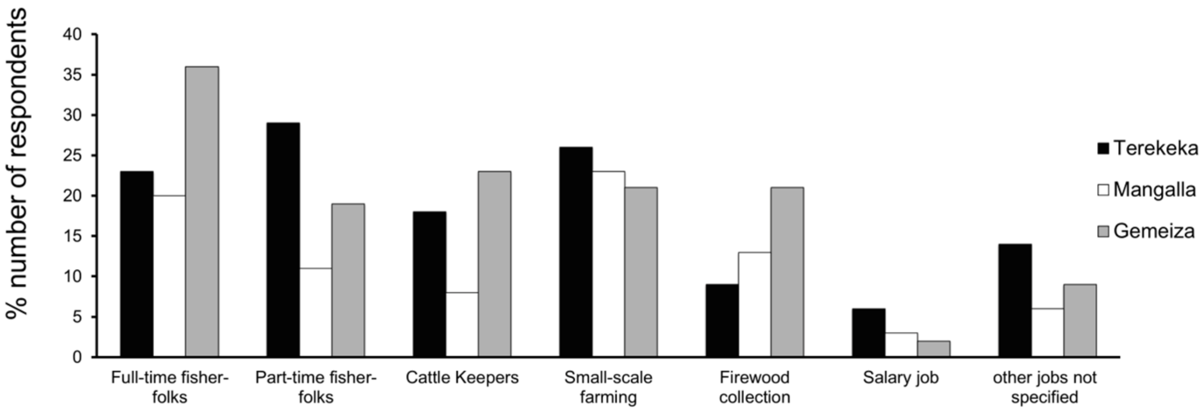

Appendix 1: Income-generating profile of the interviewed fishers expressed as percentage of total number of respondents per site. Sample size: Terereka n = 125; Mangalla n = 84; Gemeiza n = 131

Appendix 2: Education profile of the interviewed fishermen by study area

Educational Background	Terekeka	Mangalla	Gemeiza
Sample size	n=41	n=28	n=52
Never attended education	19	17	35
Primary education	14	9	11
Secondary education	7	2	6
Higher education	1	0	0

Appendix 3: Details about fish traits characterising the Sudd Swamp fish catch

Out of the 19 taxa reported in our survey, some of the commonest were caught in deep channels where resting places and hide outs are scarce. Permanence in the main channel requires strength and agility to withstand strong currents and body features that protect fishes from predation, such as: large size, presence of spines or coarse scale armours. For similar reasons, main channel fishes tend to be large-sized, and are often predators feeding on a highly nutritious food source. To this category belong, in order of frequency of abundance: *C. gariepinus*, *G. niloticus* (threatened, data-deficient), *H. forskahlli* (vulnerable), *B. bajad*, and *L. niloticus*. Out of these, only *L. niloticus* and *H. forskahlli* are typical potamodromous main channel adapted fish predators. Unlike the well-known Nile perch *L. niloticus*, which is widespread across the entire Nile basin, *H. forskahlli* is a poorly documented potamodromous tigerfish, found mainly in lowland river channels and in lakes, whose taxonomy is in need of revision (Goodier et al. 2011). Both species are highly sought for the preparation of traditional *feseekh* (salted fish), exported widely across northern Africa (FAO 2018). *Hydrocynus forskahlli* is heavily overfished and nearly extinct from the lower Nile.

Clariid catfishes tend to exhibit elongated bodies, fossorial habits and widespread distribution across Africa in both lotic and lentic biotopes (Winemiller et al. 2008); they are among the first that take advantage of floodplain inundation to migrate laterally and forage in seasonally connected wetlands and submerged riparian grasslands. Similarly, *G. niloticus,* an air-breathing electric predator, breeding in large floating nests in shallow floodplain swamps, tends to disperse across the floodplain at the arrival of river spates. Its large size and habits make it highly vulnerable to capture fisheries. It is considered data deficient and wild populations are possibly locally threatened by the degradation of riparian wetlands (Azeroual 2010), yet it was very common among the fishes caught in our studied river section, with frequencies going from 80 to 95%.

Bagrus bayad is a potamodromous nest guarding floodplain spawner provided with protective spines and sensory organs that demonstrate high adaptation to floodplain wetlands and shallow lakes that tend to migrate towards shallow waters and spawn at the arrival of the seasonal river spate.

Protopterus aethiopicus Heckel, another fossorial species, is a typical inhabitant of riparian zones of lakes and river floodplains of the Nile and Congo basins, with strict habitat requirements that is rarely found in main deep channels. Its ability to breathe air and survive droughts in slimy cocoons secreted from its own body has been known for a long time (Lockley 1949); it is also a highly appreciated species in the market.

Distichodus nefasch (formerly *niloticus*) was among the most frequent and abundant; this macro-herbivore, feeding on submerged water plants including *E. crassipes* roots and periphyton (Bailey 1994), is also found in large channels and can reach a highly respectable size (>80 cm, Daget and Gosse 1984), a characteristic that protects it from predation by birds and other fishes.

Other common floodplain migrants highly prized by fishermen include *Synodontis schall* Bloch & Schneider, and Nile tilapia, *O. niloticus*, highly adaptable omnivores. Together with Nile perch, Nile tilapia is the commonest and the most traded species caught in the Nile in Sudan (FAO 2018), generally abundant in the White Nile apart from poorer fishing seasons; both species are abundant also in the downstream sections of the Nile dams.

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