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Spatial and seasonal fish community patterns in impacted and protected semi-arid rivers of Burkina Faso

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ABSTRACT

This research evaluates fish assemblages in both impacted and protected areas in tropical seasonal small rivers in Burkina Faso. The study zones were, respectively, in the much-impounded area of Koubri close to the capital city Ouagadougou and in the protected Ranch of Nazinga along Burkina's southern border with Ghana. The impacts on these assemblages were evaluated in terms of seasonal changes in fish and the disruption of dams as an opportunity for fish to migrate. Burkina Faso is a leading country in reservoir creation in Africa and this is the first time the impacts of these reservoirs as fish barriers have been evaluated. Analyses of comparative seasonality, electric and traditional fishing equipment are provided. A total of 35 fish species were recorded in the 14 reservoirs impacted by intense agriculture and commercial fishing. In contrast, the protected area of Nazinga recorded 48 species with a higher frequency of intolerant species, e.g. *Sarotherodon galilaeus*. Altogether 56 species within 16 families were recorded. Average fish size for most of the species was significantly smaller in Koubri than in Nazinga. Accidental dam breaks have impacted fish assemblages in a manner similar to dam removal. Habitat improvement and unobstructed migration to the main river have increased the number of species in comparison to the previous situation of impoundment by 30%. The results of this research make important contributions to the integration of information concerning fish ecology and land use in semi-arid areas of Africa.

1. Introduction

Overuse of rivers, lakes, and wetlands by human exploitation has been so extensive that the degradation of these resources is recognized worldwide (Baron et al., 2002; Malmqvist and Rundle, 2002). The most important drivers are deforestation (Toham and Teugels, 1999), agriculture (Horrigan et al., 2002), cattle breeding (Agouridis et al., 2005), urbanization (Awomeso et al., 2010), river channelization (Jungwirth et al., 2005), roading and traffic (Geneletti, 2003), water withdrawal (Freeman and Marcinek, 2006), mining (Byrnes et al., 2004), damming (Ovidio and Philippart, 2002; Arthington et al., 2006), fishing (Allan et al., 2005), impoundment (Gourène et al., 1999; Quinn and Kwak, 2003; Arthington et al., 2006), introduction of invasive species (Gophen et al., 1995), and spread of diseases (Paugy et al., 1999). The impacts include alteration of river morphology, pollution, changes in water flow regime, loss of water and wet areas, changes of habitat, fragmentation of hydrological and biotic connections and erosion of biodiversity.

In conjunction with biological research, there is an increasing trend for development policies to consider, even mandate, the protection and restoration of aquatic habitats and their surrounding terrestrial ecosystems (Gleick, 1998; Gustafson et al., 2000; Bouwer, 2000; Thomas and Durham, 2003). Consequently, the removal of dams has been incorporated into river restoration programmes for developed and temperateclimate countries such as Austria (Tockner et al., 1998) and the USA (Bednarek, 2001; Doyle et al., 2003a). The preliminary aim of dam and weir removal is restoration of the longitudinal connectivity of rivers (Bednarek, 2001).

Nevertheless, there is insufficient consideration by the developed world of dam removal in West African policy, despite the loss of fish species after dam construction began in West Africa (Gourène et al., 1999). However, accidental dam breaks offer opportunities to investigate the biological re-connection of rivers. In a semi-arid country such as Burkina Faso some 1400 dams have been built to create water reservoirs, ranging in size from one to 25,000 ha, stocking some 82% of the nation's surface water (Conagese, 2001). These reservoirs act as water storage buffers

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for domestic and commercial uses, such as irrigation and cattle breeding. However, the hydrology of these reservoirs is very highly variable in space and time, which possibly affects fish ecology. These dams are built with no consideration as to their ecological impacts on rivers. However, statutory instruments, including the *Code de l'Environnement* (Assemblée Nationale, 1997a), the *Code Forestier* (Assemblée Nationale, 1997b), and the water law (Assemblée Nationale, 2001), as well as development strategies for integrated water resources management (MAHRH, 2003) have required maintaining high levels of river ecosystem quality and integrity. This makes the quality of fish ecosystems a key issue linking science and policy in Burkina Faso. It also raises the questions regarding baseline level of quality and how these are used to both predict future trends and support policy reformulation. As no reference list of fish species in Burkina Faso exists, we used the protected area of the Ranch of Nazinga ('Nazinga'), located in the Nakanbe river catchment, to compare fish assemblage structures between impacted and less impacted areas. This is the first time that human impacts like reservoirs or land use on fish have been evaluated and electro fishing was undertaken in this country.

The objectives of this study are:

- to publish a fish species list for the upper Nakanbe River catchment;
- to assess the effect of dam disruption on fish migration in seasonally-intermittent small rivers in West Africa;
- to analyse fish assemblages, abundance and size structure for impacted and less impacted river sections in Burkina Faso.

2. Study areas

All over Burkina Faso, water flow in rivers and reservoirs is regulated by the spatial-temporal distribution of rainfall. The dry season lasts from October to June and the rainy season from July to September. The area of Ouagadougou, Burkina Faso's capital city, receives 750 mm of rainfall annually, the rainiest month being August (35% of the precipitations). Usually the water reservoir water level progressively reduces and is lowest in June (Traore et al., 1994). Depending on the rain spatial-temporal distribution of rainfall, it takes several days to fill the reservoirs and spill over. The combination of direct solar radiation and high temperatures (20–40 °C) results in a massive loss of water due to evaporation rates averaging more than 2000 mm/year (Baijot et al., 1994). Consequently, some reservoirs are only temporarily full, then drain completely and remain dry until the next rainy season. These unstable, highly variable hydrological trends are illustrated for selected years in Fig. 1.

For this study, we selected two study areas in the upper part of the big Volta River catchment, to sample fish and environmental data, (1) the impacted region of Koubri in the south of the capital city Ouagadougou, and (2) the protected and less impacted river reaches at Nazinga Ranch at the Burkinabe border to Ghana (Fig. 2). The Koubri and Nazinga areas are located in the catchment of the Nakanbe River, a main tributary of the Volta River. The administrative area of Koubri is 555 km^2 large and is inhabited by 44,780 people. Koubri lies between the latitudes 12°07′35″N and 12°07′05″N and the longitudes 01°16′57″W and 01°26′08″W (Google Earth) 40 km to the southeast of Ouagadougou at highway N5. Around Koubri we targeted 14 reservoirs and their connecting small rivers. The reservoirs were constructed between 1962 and 1988 and range in size from 5 to 430 ha (Table 1). On the main course of the Nariale River are located the bigger reservoirs of Segda, Arzoum Baongo and Naba Zana. On the left or Northeast bank the following reservoirs are found: Tanvi, Napagbtenga, Badnogo, Toyoko, Mogtedo, Zeguedse and Zakin, and on the right or Southwest bank: Gonse, Poedogo, Kagamzinse, and Wedbila. Note that the names of the reservoirs could change depending on the source of information. The Nariale itself is an intermittent and seasonal tributary of the Nakanbe River that is 526 km long. The Nakanbe is the second most important river of Burkina Faso, but it is runs dry from December to July (Traore et al., 1994); this means it transforms in a series of unconnected pools with virtually no flow between them.

The study area of Koubri could be divided into four water sections according to the number and size of barriers (Fig. 2). On the main Nariale at Segada, Section 1 is a free-flowing river segment of 1.5 km length. Water continuously flows in that section until the middle of the dry season. In this least impacted part of the area fish have free access to the main Nakanbe River. Sections 2 and 3 are mainly the big upstream river reservoirs of Arzoum Baongo and Naba Zana (Table 1). They are similar in dimensions and are both 98% impounded, the remaining parts being small river segments of <1 km long, depending on the water level in downstream reservoirs. Thus, Sections 1–3 are contiguous during the period of highest water level. Section 4 regroups the remaining smaller reservoirs and minor small rivers on both left and right hand banks of the main Nariale. The small rivers of Section 4 flow for only 1–4 h after a rain or when upstream reservoirs are filled and spill over. Their wetted width varied from 2 to 150 m, their depth up to 2 m and their length from 100 to 5600 m. Direct visual observations in 2008 confirmed that the earliest date of spill over was July 06 for the reservoirs Naba Zana, Gonse, Kogse and Mogtedo and the latest date was September 10 for Napagbtenga. In the meantime, Zeguedse spilled over July 20 and Poedogo and Arzoum Baongo 25 July. Following a reservoir being filled, the water flows in the downstream waters for a 1–10 h after it rained on the catchment of the reservoir. Then the small rivers break into pools.

The protected Nazinga Game Ranch is located in the South of Burkina Faso at the frontier with the Republic of Ghana and lies between the latitudes 11°03′04″N and 11°12′47″N and the longitudes 01°23′25″W and 01°43′00″W (Google Earth) 60 km west of the city Po and highway N5. It is 91,300 ha large and was created in 1979 on a forested area that is managed since 1953. The main management objectives are to protect and conserve the wildlife for limited hunting and fishing and to maintain the ecological balance (Adouabou et al., 2004; UICN/PACO, 2009). Eleven reservoirs of 18–60 ha large were created between 1981 and 1987 with the sole objective to provide the wildlife with water, especially in the very dry season. These naturalised reservoirs give fish the possibility for lateral and longitudinal migration and enhance their survival, because it is possible to pass the weirs during rainy season. The area is well protected: there are no human habitations and trespass is controlled. Agriculture, cattle breeding and deforestation are forbidden. Although fishing is allowed from December to April, it is strictly controlled.

3. Methodology

The sampling took place in Koubri during three periods: the rainy season (August 2008), the beginning of the dry period (October and December 2008) and at the end of the dry season (June 2009). In Nazinga it took place at the beginning of the dry period (November and December 2009). During the rainy season the sampling of fish took place after the reservoirs started spilling over. In tandem we also sampled and measured information on anthropogenic pressures and environmental descriptors.

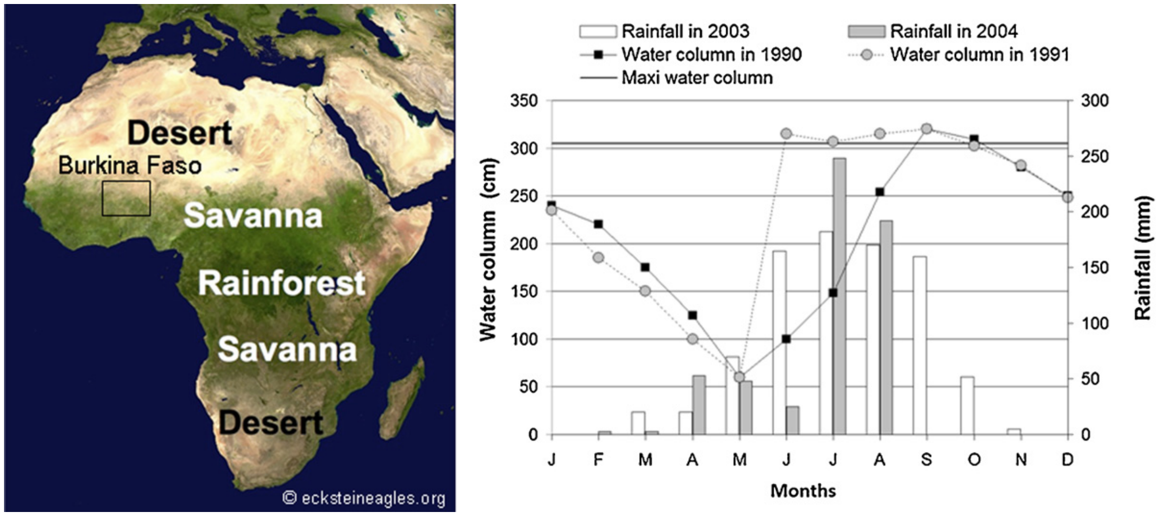

Fig. 1. Climatic and hydrological conditions in Burkina Faso: on the left hand side, climatic zones of entire Africa. On the right hand side, rainfall in the capital city of Ouagadougou, 20 km far from Koubri in 2003 and 2004 (after Direction de la Météorologie, 2010) and hydrological profile of Reservoir No. 3 of the same city in 1990 and 1991 (after Traore et al., 1994).

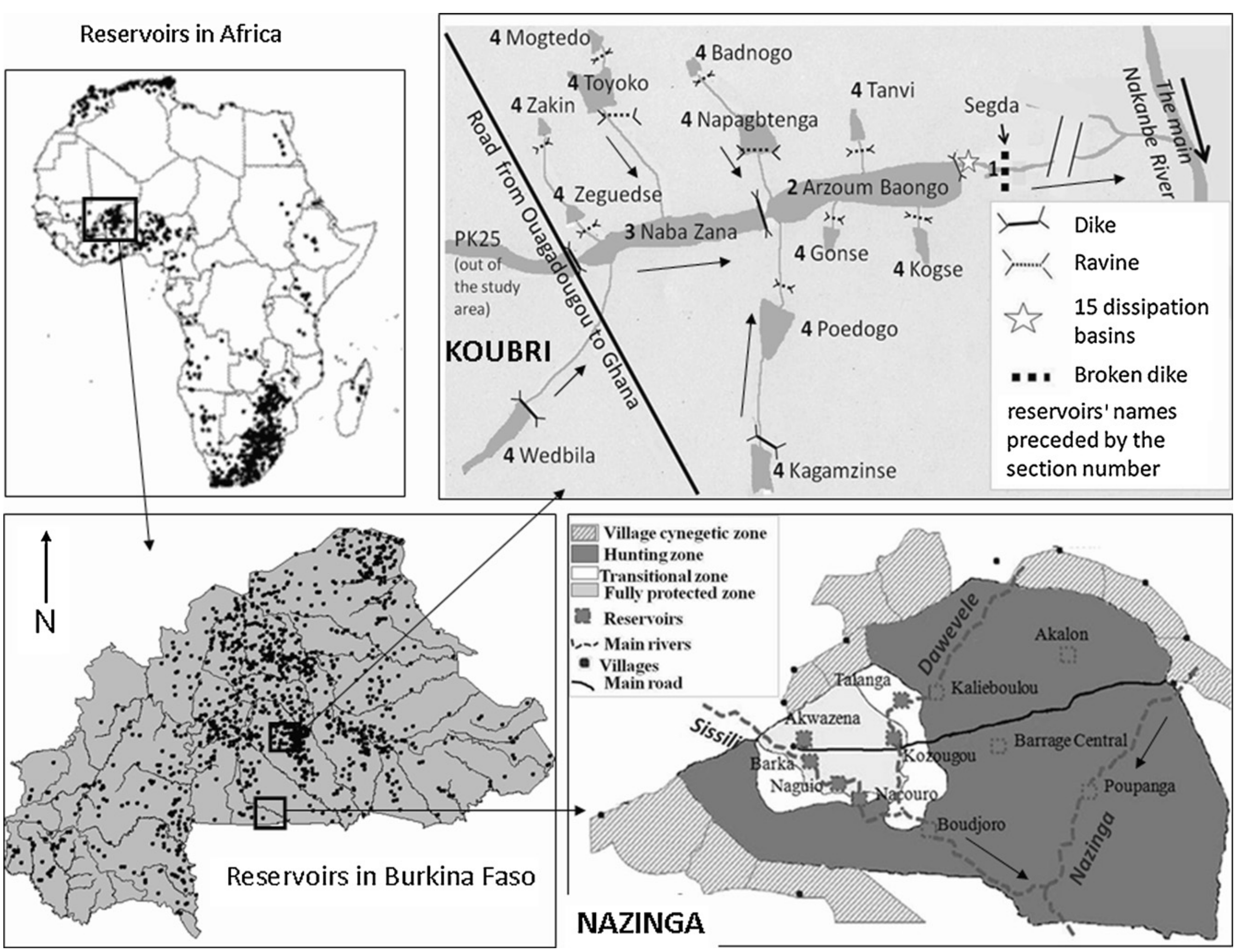

Fig. 2. Spatial distribution of reservoirs in Africa and Burkina Faso. The geographical position of the study areas of Nazinga and Koubri. For Koubri the location of reservoirs and sections (bold figures) are indicated.

Table 1
Overview of our four chosen sections and description of targeted reservoirs of Koubri (information was provided by the local fishermen and Brother Adrien St Benoit of the Monastery of Koubri, he planned and built 13 of the 16 reservoirs).

Koubri section	Reservoir name	Max. size (ha)	Year of creation	Year of disruption	Last year of rebuilding	Hydrology
Section 1	Segada	12	1978	2004	Not repaired	Free flowing, frequently dries
Section 2	Arzoum Baongo	420	1986	2004	2004	Never dries, 7 tributaries
Section 3	Naba Zana	300	1972	2004	2004	Never dries, 3 tributaries
Section 4	Napagbtenga	208	1962	1991	Unreported	Never dries; spills over every 5 years
Section 4	Poedogo	198	1982	2004 and before	2004	Never dries
Section 4	Wedbila	100	1978	Never	–	Often dries; is currently being extended to 159 ha (3)
Section 4	Toyoko	47	1976	Never	–	–
Section 4	Kogse	30	1984	1998	1998	Frequently dries
Section 4	Kagamzinse	23	1979	Never	–	Dries every year
Section 4	Tanvi	18	1977	2004	2004	Frequently dries; spills over every 4 years
Section 4	Zeguedse	16	1988	2004	2004	Dries every year
Section 4	Gonse	12	1985	1985, 1997, 2003	2003	Dries every 5 years
Section 4	Badnogo	10	1982	2004	2004	Frequently dries
Section 4	Mogtedo	6	1960	Never	–	Frequently dries
Section 4	Zakin	5	1984	Twice	Repaired	Dries every year

3.1. Collection of data on environmental descriptions and anthropogenic pressures

The sites were sampled representatively with different morphological characteristics, to distinguish different types of habitat (e.g. lentic or lotic); therefore we qualitatively estimated the flow velocity by visual observation. At each sampling (fishing) site we used a measuring tape to measure the width of randomly selected river transects, depth and distance from the nearest bank. The substrate of the fishing sites was described using the dominant choriotop (pelal, psammal < 2, akal 2–20, microlithal 20–63, mesolithal 63–200, macrolithal 200–400, megalithal > 400 mm). We were not able to measure key physico-chemical parameters, due to logistical difficulties organising the necessary equipment in Burkina Faso and budget constraints affecting any import of this equipment.

Anthropogenic pressures were qualitatively defined using categories, for example damming, rain fed agriculture, irrigated vegetables farming, water abstraction, sand mining, fishing, deforestation, cattle breeding, roads and human settlements. Data on land use was obtained from local village development plans in the rural area of Koubri—referenced in this paper as Commune Koubri (2005). Information was also searched on the internet and field trips were undertaken to confirm the accuracy of this data, as well as collect additional information for the protected area of Nazinga. Data on water reservoirs were extracted from a database compiled by the Water Resources Department, Ministry of Agriculture, Water and Fish Resources. We then consulted in the field with resource personnel to verify existing data and collect additional material.

3.2. Sampling of fish

Fish were sampled in lentic and lotic waters using mainly two types of equipment: electric fishing (EF) and three types of traditional gear—cast net (CN), gill nets (GN) and long lines (LL). In the "traditional" fish sampling method we used a multifilament CN of 10 mm stretched mesh size, 2.45 m long, 13.20 m in circumference. We also used two types of monofilament for the 30 m × 1.5 m GN. One type had a stretched mesh size of 60 mm and 40 mm for the other type. The two GN were aligned to make one final GN, effectively creating a third version of GN to utilise. The traditional LL was made of hooks ranging in number from 8, 11 and 12 to 56 hooks each. The hooks were arranged alternately with two successive hooks 0.5 m distance apart and using soap as bait. Three long lines were utilized.

Two professional local fishermen were recruited to construct the CN, GN and LL equipment and then use them to fish the selected lotic and lentic waters. The GN and LL were set in the daytime at 4:30 PM, lifted the next day at 8:00 AM and occasionally on the same day set in the morning and lifted in the afternoon. Although the GN and LL were set close to each other, the catch from each type of fishing equipment accounted for one sample (i.e. the GN catch was one sample and the LL catch another sample). We threw the CN eight times at each fishing site, counting as one sample. The "alternative" and louder method was EF with a portable generator – Honda, model GXV50 – assembled by H. Grassl (www.hans-grassl.com) in Germany. The electric fishing team – four trained members of the Ouagadougou Fisheries Department – waded in the water to sample. The EF was used in the daytime only, one run in each EF site, accounting for one sample. Before the EF took place, we set a stop net (mosquito net) at the upper part of the site to prevent fish from escaping from the sample. The surface area of EF sites was visually estimated by two members of the fishing team. Fish were sorted into species according to Lévêque et al. (1990, 1992) and Lévêque (2006). The fish were counted, weighed and their total length was measured. In 2009, we spent four days at the Royal Museum for Central Africa, Tervuren, Belgium to discuss species determination.

In general, the EF and traditional methods were applied to the same sections and habitats. There was only one exception during the rainy season when the EF did not take place, because of delays preparing the equipment due to processing by the customs office. It was the first time such equipment had been imported into the country. We analysed the fish species richness, assemblage and abundance for impacted and less impacted sections of the lotic and lentic water bodies. In addition both fish length and catches per unit of fishing effort (CPUE) were compared for the dry and wet seasons (i.e. beginning of rainy season, rainy season and the after rainy season) and the different fishing gears. The CPUE is defined as the fish biomass and number of fish caught per throw of cast net and per hectare of water electric fished. We used mean values, standard deviation (SD) and the Mann–Whitney test ($p < 0.05$) to compare catches. Statistical analyses were done by using SPSS software.

Fig. 3. Pictures of different types of dams in Koubri.

4. Results

4.1. Anthropogenic pressures in Koubri

A diverse set of anthropogenic activities are the main drivers that impact water quality and quantity in the area of Koubri. In particular damming, rain-fed agriculture, irrigated vegetables farming, water abstraction, sand mining, fishing, deforestation, cattle breeding, roads and human settlements Koubri is crossed by seasonal small rivers with only 1.5 ha of water surface in total. On these small rivers were built 86 reservoirs with a total area of 1862 ha. We note that less official but more reliable local estimates gave a lower total number of reservoirs. With a density of 8.8 reservoirs per 100 km^2, Koubri is probably the most extensively impounded area in comparison to the national average of 0.5 reservoirs per 100 km^2 in Burkina Faso. In these reservoirs, intensive fishing pressure produces 10 tons of fish per year. Unfortunately prohibited fishing methods are commonly used.

The dams of Koubri have two types of spillway, either a central spillway or a lateral type. The central spillway is built with concrete and is sufficiently high to obstruct fish migration (2–3.5 m high). The lateral type of spillway is rare and not so high, therefore having little influence on fish migration. However, it diverts the water flow from its natural course, creating a 'new' reach whose junction to the natural river becomes a ravine, possibly delaying or preventing fish migration. The big dam of Section 2 has a lateral type of spillway and is equipped with 15 dissipation basins that fish may use as ladders. Section 3 has a central type of spillway that is 1.8 m high, possibly obstructing or delaying upstream river migration. Although it also has four sets of fish ladders, their functional performance is questionable. In Section 4, Wedbila and Kagamzinse have a central type of spillway that is built with concrete, 3 m high and probably obstructing fish migration. The other dams have a lateral type of spillway. Most of the dams have been periodically destroyed by floods and crocodiles, with 16 breaks occurring between 1998 and 2004 as reported by local people. In fact reservoir designers had mentioned that 13 of the 15 reservoirs were not built according to the proper standards, which may explain the frequency of breakages. In addition, the dams are relatively old. Fig. 3 shows the broken Segda reservoir, the fish ladders of Naba Zana, the dissipation basins of Arzoum Baongo and a lateral type of spillway.

Much water is abstracted from reservoirs for a variety of purposes, but mainly for drinking water supply and irrigation. Irrigated gardens have been built along the river banks and vegetables are produced primarily for consumption in Ouagadougou city. There is almost no control over the extensive use of pesticides and fertilizers. More than 18,000 ha of land are used by intensive rain-fed agriculture with no particular erosion control measures. In 2005, half of the land surrounding the reservoirs was occupied by agriculture and nearly 40% by agro-forestry. In this region more than 536,000 domestic animals are extensively reared. In 2004 officially 865 m^3 of wood were sold, but this is a clear underestimation. It is

Table 2
Number of samples and caught individuals for Nazinga and Koubri (all gears together), divided per type of water, season and section.

Study area			Number of samples	Number of individuals
Nazinga	Status	Less impacted	88	4016
	Water type	Reservoirs	215	7585
		Brooks	41	5900
	Season	End of the dry season	53	3177
		Rainy season	170	3792
Koubri		Start of dry the season	33	6516
	Section	1	19	4214
		2	54	4626
		3	59	2226
		4	124	3541

also used for other domestic needs like house construction and fire wood. The area of Koubri is relatively well provided with country roads and crossed by a national road improved with asphalt. More than 2000 m^3 of sand are extracted yearly from the study area and transported by trucks to the neighbouring city of Ouagadougou but personal observation suggests that this is also a clear underestimate. We counted nine important sand mining sites and many minor ones spread across the area and detected that the soil is taken from both the base and banks of the reservoirs to make bricks. In Koubri 68% of the sampled (fishing) sites were dominated by mud, 31% by sand and the rest by stones and blocks of concrete.

4.2. Fish species assemblages at the impacted and less impacted sites

We took 256 fish samples from the impacted area of Koubri and 88 samples in Nazinga (Table 2). In both areas and for all seasons combined, we caught 17,501 fish specimens and recorded a total of 16 families of fish distributed across 56 species (Appendix A and Table 3). Nearly all species were significantly smaller in Koubri than in Nazinga (Table 4).

While the protected sites had 48 species, the impacted area had 35 (Table 3). Regarding all fishing equipment used in the surveys in Koubri, altogether we took 19 samples (4214 specimens) from Section 1; 54 samples (4626 specimens) from Section 2; 59 samples (2226 specimens) from Section 3 and 124 samples (3541 specimens) from Section 4. The species richness decreased from 32 (Section 1)–28 (Section 4)–25 (Section 2) to 23 (Section 3). In all sections the most abundant species were *Barbus ablabes* and *Barbus macrops* (35 and 14% of the specimens, respectively). The tilapia group (*Sarotherodon galilaeus*, *Tilapia zillii* and *Oreochromis niloticus*) and *Clarias gariepinus* were also abundant. *Schilbe* sp., *Bagrus docmak*, *C. petcherici*, *H. fasciatus*, and *M. rume* were more frequent in Section 1 than in any other section. *H. forskalii* was caught only in Section 1 and *H. membranaceus* and *P. bovei* in Sections 1 and 2 only. But *Protopterus annectens* was nearly 1% in Section 4 but absent anywhere else.

As shown in Table 3 in the protected area of Nazinga, no species dominated as much as was found in the impacted waterbody, where there were 22 dominant species (23% of the total abundance), e.g. *S. galilaeus*, *Brycinus nurse* and *B. macrops*. In Koubri we found only nine species (6%) that could be qualified as intolerant to habitat degradation, large size and/or top predatory. The rare species were *Mormyrops anguilloides*, *Polypterus senegalus* and *Malapterurus electricus* (<1%). Tolerant species were dominant (*B. ablabes* 43% and *B. macrops* 19%), followed by *S. galilaeus* (9%), *T. zillii* (7%) and *O. niloticus* (4%).

Altogether we took 41 samples from the small rivers (lotic) and 215 from the reservoirs (lentic) of Koubri using all types of fish sampling equipment. The small rivers exhibited 35 species and the reservoirs 28. All species caught in the reservoirs were also found in the small rivers. Seven species were found in the small rivers but not in the reservoirs: *B. docmak*, *Ctenopoma petcherici*, *Hydrocinus forskalii*, *M. anguilloides*, *Mormyrus rume*, *Pollimyrus isidori*, and *P. senegalus*. Some species turned up in our samples (nearly) equally in the reservoirs and in the small rivers. That was the case for *Barbus* sp. and the tilapia (*S. galilaeus*, *T. zillii*, and *O. niloticus*). However, some others were more abundant in lotic than lentic waters. This was the case for the Schilbeidae family. For instance 99% of the 208 individuals of *S. intermedius*, 93% of the 162 *S. auritus* were caught in rivers. We also note that *C. nigrodigitatus* and *H. membranaceus* were much more frequent in the lotic than in the lentic waters. Also the *C. gariepinus* and the Mormyrid species like *H. pictus*, *H. bebe* and *M. senegalensis* tended to be more abundant in the small rivers than in the reservoirs. The tilapia fishes (*S. galilaeus*, *T. zillii* and *O. niloticus*) tended to be more frequent in the reservoirs than in the small rivers.

4.3. Sampling method and seasonal shifts in fish species abundance, biomass and length

Thirty-one species were caught in Koubri with EF (6400 specimens), 30 with CN (6852 specimens), 10 with GN (188 specimens) and 4 with LL (45 specimens).

EF caught 5 species that CN did not and CN caught 4 species that EF did not. All species caught by GN or LL were also caught with EF or CN. EF and CN have similar efficiency in showing the fish species assemblage; the efficiency of GN and LL is very low. The mean lengths of fish caught with EF and with traditional gears remained similar (Mann–Whitney test, $p < 0.05$). Also in comparing the sampling seasons, no significant difference was observed in mean abundance by Electro Fishing and the mean sampled biomass.

Fish species richness, which was 16 at the end of the dry season, increased to 28 species in the beginning of the rainy season. Then, it reached a peak at the beginning of the next dry season (30 species). During the end of the dry season we could not find specimens of *H. membranaceus*, *P. annectens*, three of the eight mormyrid, all schilbeid, all charachid and all bagrid fishes. They appeared during the rainy season.

The number and biomass of fish caught per unit of fishing effort decreased from the end of the dry season to the rainy season (Table 5). The mean abundance was 6.2 fish (SD 7.2) per CN throw at the end of the dry season, 3.7 fish/throw (SD 9.5) during the rainy season and 12.4 (SD 12.9) at the beginning of the dry season. The mean biomass (g) of fish caught by a throw of CN was 232 g (SD 179) at the end of the dry season, 176 g (SD 348) during the rainy season and 567 g (SD 1058) at the beginning of the dry season. It was significantly higher at the end of the dry season than during the rainy season, significantly lower during the rainy season than during the start of the dry season. It was not significantly lower during the start of the dry season than when that season ends.

Table 3
Relative frequency of fish species in Nazinga and in the entire area of Koubri (Section: 1 = free-flowing section, 4: tributaries, 2 = Arzoum Baongo reservoir upstream Section 1, 3 = Naba Zana, reservoir upstream Section 2).

Species	Nazinga	Koubri			
		Section 1	Section 4	Section 2	Section 3
Sarotherodon galilaeus	12.45	9.23	12.7	4.49	8.44
Brycinus nurse	10.99	2.02	0.82	0.4	2.65
Barbus macrops	10.8	14.4	19.3	16.7	20.9
Oreochromis niloticus	7.6	1.9	5.84	8.31	6.5
Barbus ablabes	7.23	34.7	37.2	51.1	43.6
Clarias gariepinus	5.58	5.77	3.76	0.99	1.41
Tilapia zillii	5.47	6.26	13.6	5.26	8.08
Chelaethiops bibie	3.57	1.57	1.1	0.58	1.64
Auchenoglanis occidentalis	3.46	0.05	0.28		
Schilbe intermedius	3.39	4.84	0.58	0.04	
Labeo senegalensis	2.93				
Alestes dentex	2.82				
Synodontis schall	2.17	0.33	0.06	0.58	1.04
Schilbe mystus	2.04	0.83	0.76		
Marcusenius senegalensis	1.97	0.12	0.45	0.09	0.42
Lates niloticus	1.88	1.38	0.06	4.36	0.56
Petrocephalus bovei	1.83	0.19		0.72	
Hemichromis fasciatus	1.74	2.18	0.02	4.85	1.38
Mormyrus rume	1.67	0.19		0.09	0.03
Alestes baremoze	1.56	0.97	0.09	0.22	0.03
Hydrocinus forskalii	1.12	0.14			
Heterobranchus bidorsalis	0.92				
Polypterus endlicheri	0.69				
Labeo coubie	0.69				
Brycinus macrolepidotus	0.66				
Synodontis punctifer	0.64	2.75	0.04	0.4	0.37
Hyperopisus bebe	0.57	0.76	0.09		0.25
Synodontis clarias	0.55				
Bagrus bajad	0.5				
Heterotis niloticus	0.43				
Brienomyrus niger	0.34		0.04	0.04	
Bagrus docmak	0.3	0.21			
Citharinus citharus	0.23				
Hemichromis letourneauxi	0.18	1.21	0.86		1.92
Mormyrus hasselquistii	0.16				
Hippopotamyrus paugyi	0.14				
Labeo niloticus	0.14				
Distichodus rostratus	0.11				
Synodontis velifer	0.09				
Hydrocinus vittatus	0.09				
Malapterurus electricus	0.07	0.02	0.02	0.09	0.14
Micralestes elongates	0.05				
Hemisynodontis membranaceus	0.05	0.95		0.09	
Synodontis comoensis	0.05				
Synodontis filamentosus	0.02				
Synodontis vermiculatus	0.02				
Heterobranchus longifilis	0.02				
Mormyrops anguilloides	0.02	0.02	0.02	0.27	0.03
Hippopotamyrus pictus		1.19	0.63		0.37
Siluranodon auritus		3.56	0.26		0.03
Chrysichthys nigrodigitatus		1.47	0.06	0.04	0.03
Ctenopoma petcherici		0.21			
Ctenopoma kingsleyae		0.57	0.22	0.04	
Pollimyrus isidori			0.41		
Polypterus senegalus		0.05		0.09	
Protopterus annectens			0.76	0.09	0.2
Number of species	48	32	28	25	23

At fish community level (all sampled fishes and all species), the average fish length during the rainy season was 66 mm (SD 47), 61 mm (SD 35) at the beginning of the dry season and 50 mm (SD 24) at the end of the dry season (Fig. 4). The mean length was significantly higher during the rainy period than the start of the dry season, significantly higher at the beginning of the dry season and also significantly higher when the dry season starts than at the end of the dry season (Mann–Whitney test, $p < 0.05$ for the three comparisons).

At population level, the length of the larger-size species tended to increase from the end of the dry season to the rainy one and to decrease from that season to the beginning of the dry period. The frequency distribution of species length shows that for most species, small-size individuals were infrequent in any season. However, they were more frequent at the beginning of the dry season for *C. gariepinus* and *S. galilaeus* at the end of the dry season for *T. zillii* (Fig. 4). The size of many species such as *T. zillii*, *S. galilaeus*, and *B. ablabes* was significantly lower at the end of the dry season than during the rainy period and also significantly lower at the beginning of the dry season than at its ending time. For these species, excluding *T. zillii*, the size was significantly lower during the rainy season than at the start of the dry season. However, the seasonal

Table 4
Comparison of fish size in Koubri and Nazinga: mean total length (TL, mm) of major species and values of *p* (Mann–Whitney test).

Species	Area	*N*	Mean TL (mm)	SD (mm)	Value of *p*
L. niloticus	Koubri	62	103.10	34.95	<0.05
	Nazinga	66	189.32	72.52	
S. galilaeus	Koubri	504	98.42	47.42	<0.05
	Nazinga	531	113.73	37.91	
C. gariepinus	Koubri	256	100.92	92.05	<0.05
	Nazinga	233	226.28	105.80	
H. fasciatus	Koubri	96	49.72	10.61	<0.05
	Nazinga	76	99.12	25.37	
H. forskalli	Koubri	5	59.00	22.19	<0.05
	Nazinga	31	247.74	71.97	
B. macrops	Koubri	1232	52.11	10.58	<0.05
	Nazinga	472	51.19	14.23	
B. nurse	Koubri	113	71.64	18.20	<0.05
	Nazinga	476	108.22	27.33	
T. zillii	Koubri	283	94.58	33.39	>0.05
	Nazinga	239	94.44	32.05	
S. intermedius	Koubri	183	105.49	39.27	>0.05
	Nazinga	146	108.41	55.43	

Table 5
Comparison of abundance and biomass (Mann–Whitney test and mean values incl. standard deviation (SD)) for seasonal catches per throw (CN) and site (EF).

	End dry season		Rainy season		Start dry season		Values of *p*	
	N	Mean (SD)	*N*	Mean (SD)	*N*	Mean (SD)		
CN abundance (ind./throw)	24	6.21 (7.19)	111	3.68 (9.52)	19	12.36 (12.85)	E. dry vs. rainy	<0.05
							Rainy vs. S. dry	<0.05
							E. dry vs. S. dry	<0.05
CN biomass (g/throw)	24	232.00 (178.96)	111	175.79 (347.87)	19	566.63 (1058)	E. dry vs. rainy	<0.05
							Rainy vs. S. dry	<0.05
							E. dry vs. S. dry	>0.05
EF abundance (ind./ha) per site	16	1971.44 (1414)	–	–	12	2393.50 (1543)	E. dry vs. rainy	–
							Rainy vs. S. dry	–
							E. dry vs. S. dry	>0.05
EF biomass (kg/ha) per site	16	3.38 (2.09)	–	–	12	14.08 (24.81)	E. dry vs. rainy	–
							Rainy vs. S. dry	–
							E. dry vs. S. dry	>0.05

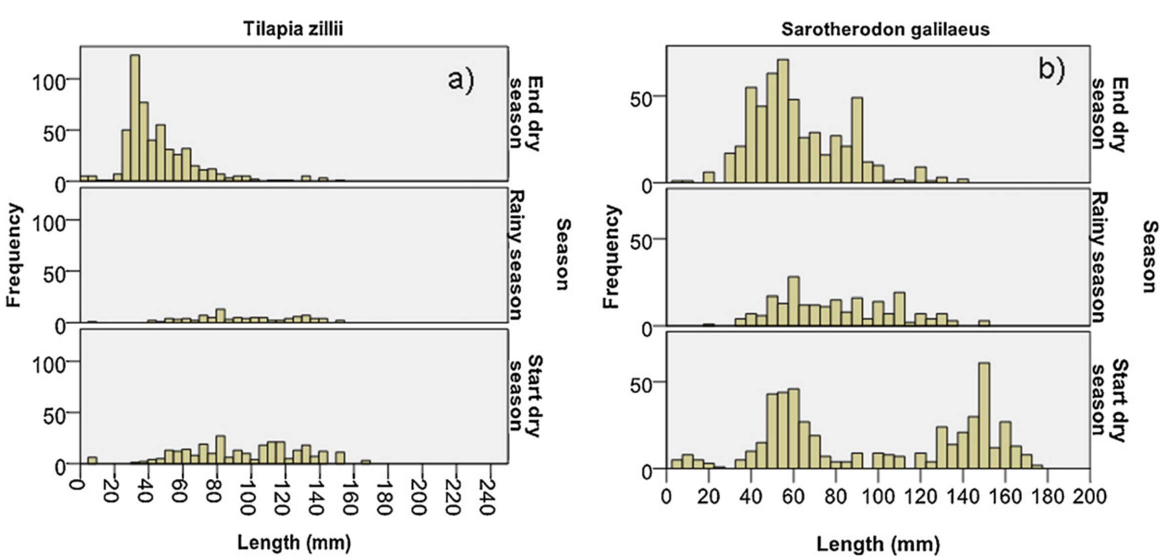

Fig. 4. Seasonal changes in fish size, length frequency distribution of selected fish (*Tilapia zillii* and *Sarotherodon galilaueus*) in Koubri.

Table 6
Comparison of the length of major species between seasons in Koubri: mean total length and values of p (Mann–Whitney test); SD: standard deviation, E.: end; S.: start).

Species	End dry season		Rainy season		Start dry season		Values of p	
	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)		
Tilapia zillii	525	45.10 (21.47)	95	94.19 (29.82)	283	94.58 (33.39)	E. dry vs. rainy	<0.05
							Rainy vs. S. dry	>0.05
							S. dry vs. E. dry	<0.05
Sarotherodon galilaeus	536	62.00 (22.00)	220	80.31 (27.26)	504	98.39 (47.41)	E. dry vs. rainy	<0.05
							Rainy vs. S. dry	<0.05
							S. dry vs. E. dry	<0.05
Barbus ablabes	1044	40.31 (12.57)	1908	46.97 (11.08)	2906	45.76 (11.62)	E. dry vs. rainy	<0.05
							Rainy vs. S. dry	<0.05
							S. dry vs. E. dry	<0.05
Clarias gariepinus	15	152.60 (69.19)	66	254.66 (61.55)	256	100.37 (92.48)	E. dry vs. rainy	<0.05
							Rainy vs. S. dry	<0.05
							S. dry vs. E. dry	<0.05
Lates niloticus	4	96.50 (6.35)	3	77.33 (47.61)	62	103 (34.95)	E. dry vs. rainy	>0.05
							Rainy vs. S. dry	>0.05
							S. dry vs. E. dry	>0.05

variation in the length of some species (e.g.: *L. niloticus*) did not follow this trend, as shown in the details of Table 6.

5. Discussion

The study showed seasonal and spatial variation in fish species richness, despite significant environmental stress in an impoverished area of West Africa. In the impacted and highly populated area, we found most fish in sections where the fish were able to migrate to habitats for specific spawning and juvenile life stages. The largest fish were also found there. In both study areas of Koubri and Nazinga, we recorded 35 and 48 species, respectively (Fig. 5). All together we caught 56 species in the Nakanbe catchment. The sampling effort was different and up to 20% higher in the impacted river reaches. The species richness decreased in the most impacted sections to 40%. More than 40 years ago, Roman (1966) reported 121 species in the upper part of the Volta River. Considering this we have already lost 50% of them in general and 80% in heavily impacted areas, which leads us to the belief that we will lose more in the future due to an increasing human population, especially around the cities, and increasing fishing pressures. In this study we were able to describe a number of major impacts to rivers in Burkina Faso, which were not obvious before this study. For example, damming, rain-fed agriculture, irrigated vegetable farming, water abstraction, sand mining, (over) fishing, deforestation, cattle breeding and human settlements, which goes hand in hand with water pollution.

We have evidence of some species which disappeared. Baijot et al. (1994) reported the presence of *Gymnarchus niloticus* in the Nagbangre reservoir close to our study area of Koubri. *G. nilotichus* was not found in our survey. In addition, Villanueva et al. (2006) mentioned the existence of *G. niloticus* and Labeo sp. in the Bagre reservoir (100 km below to traverse Koubri), but we did not find either of these species. The downstream small river reservoir of Bagre is most likely the starting point of fish migration into our Koubri study area of Koubri. From Koubri to Bagre there is no permanent water, but nevertheless fish would be able to migrate after taking advantage of the dam breaks at Segda.

The dominance of small-size species in Koubri, such as *Barbus* spp., confirms that the area has been impacted (Karr, 1981; Welcomme, 2001; Tejerina-Garro et al., 2005). By contrast, the abundance of large-size species intolerant to habitat degradation

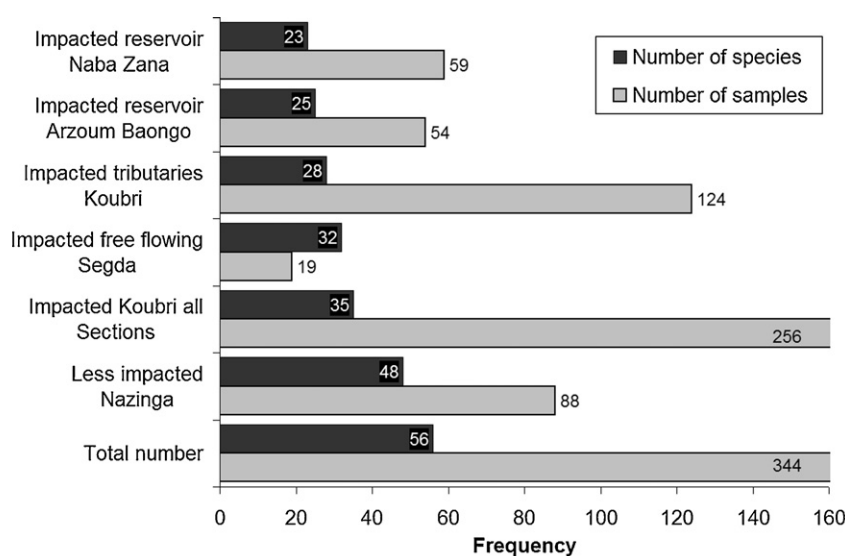

Fig. 5. The number of fish species caught in comparison to the total number of samples for impacted areas of Koubri (Section 1, Segda; Section 2, Arzoum Baongo; Section 3, Naba Zana; Section 4, Tributaries) and Protected Ranch of Nazinga.

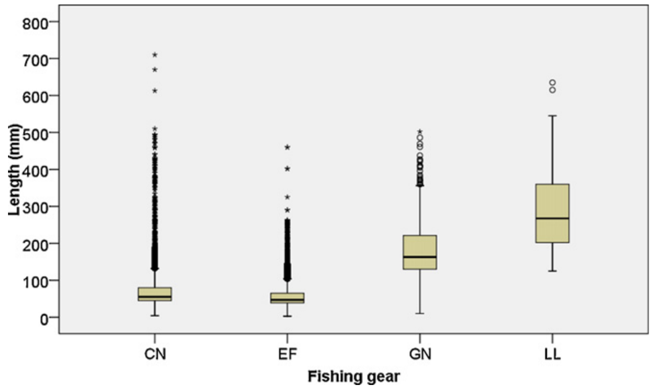

Fig. 6. Mean total fish length (bar—median, dots—extreme values, stars—outliers) of all caught individuals per sampling gear (castnet, CN; electric fishing, EF; gillnet, GN; longlines, LL).

in Nazinga suggests that this area is less impacted. The seasonality of most of the waters in Koubri may have contributed to the dominance of smaller-size species as found by Fernandes et al. (2010) in some Brazilian tropical waters. These species take advantage of the topographic roughness and habitats for protection against the water current when migrating (Lévêque et al., 1988). Consequently, the pygmy species are abundant in any section of Koubri. Large-sized species are unable to do this and large migratory species like *C. gariepinus*, *L. niloticus*, the Schilbeidae and the Mormyridae were more abundant in Section 1 than in any other section.

The decrease in species richness from Section 1 to 2 and from Section 2 to 3 suggests impacts on fish migration. The high richness of Section 4 can be explained by three factors: (1) this section presents both lotic and lentic waters, a combination that was not observed in any other section; (2) the ravines and the lateral type of spillway may not act as complete barriers to fish migration; (3) frequent accidental dam breaks have enabled an exchange and movement of fish between sections (Doyle et al., 2003b). Therefore, the accidental dam breaks in Burkina and the intentional removal of dams in developed and wet countries (Bednarek, 2001; Hart et al., 2002; Kocovsky et al., 2009) have comparable effects.

The use of appropriate fishing gear and sampling in appropriate periods are necessary to show the diversity in aquatic biota communities (Rozsa and Minello, 1997; Jawad, 2006; Chapman and Chapman, 1993; Garcia et al., 2003; Medeiros et al., 2010). It appeared easier and more efficient to sample with CN than with the other three types of equipment (Fig. 6). EF and CN caught fish indiscriminately but EF was suitable for stony sites, shallow waters and small rivers where CN could not be properly used. In contrast, the traditional fishing gear could be used to some extent where EF could not, e.g. in waters with much vegetation cover (Eldon, 1968), in deeper and offshore waters when EF by wading is not possible (water depth > 60 cm). Penczak et al. (1998) found that EF was more effective than nets (gill nets and seines) and considered that electric fishing is better for estimating the fish density than species diversity and that nets should complement EF. In this study, however, CN and EF tended to have a similar efficiency. The cast netting was as efficient as electric fishing in showing fish structure. However, the two methods should be considered as complementary for future sampling and national monitoring programmes.

Our study showed that seasonal changes in fish populations and species richness varied in both lentic and lotic waters. During the dry season fish were concentrated in smaller volumes of water (i.e. waterholes). At the beginning of the rainy season – the start of spawning and migration – the quantity of water increased and fish species were dispersed (Winemiller and Jepsen, 1998; Arfi, 2005). While fish abundance initially decreases at the beginning of the rainy season, it then increases up to the end of the season and into the beginning of the dry season. In this period, the juveniles were very abundant, especially in the case of *C. gariepinus* (Offem et al., 2010). Our findings on the seasonal shifts of fish species diversity confirm previous studies. Seasonal changes in species composition and catches were also observed by Araoye (2009) in Lake Asa, Nigeria. Fish species diversity and assemblage are known to seasonally change in temperate waters (Carpentier et al., 2004; Deudero et al., 1999) as well in tropical ones (Rueda and Defeo, 2003; Dansoko et al., 1976; Laë, 1992; Pont, 1994; Garcia et al., 2003) in close relation with the flood periodicity and the availability of habitat and food items (Winemiller and Jepsen, 1998; Oueda et al., 2008).

In a tropical environment like Burkina, fish tend to migrate frequently and as soon as possible (i.e. very early in the rainy season) to colonize newly flooded habitats (Quensière et al., 1994). All species tend to look for them to use as spawning grounds and nursery habitat (Winemiller and Jepsen, 1998). Furthermore small rivers contain water only during the rainy season, which is the most productive period in terms of species diversity (Taylor et al., 2006), particularly for the abundance of species like *H. membranaceus*, *C. gariepinus* and families like the Mormyridae and the Schilbeidae. The reproductive season depends on the specific fish species biology. Whereas *T. zillii* spawn at the end of the dry season (El-Sayed and Moharram, 2007), the African catfish breeds during the rainy period (Offem et al., 2010). *S. galilaeus* and *O. niloticus* spawn anytime but in larger quantities during the rainy season (Bénech and Quensière, 1985). The seasonal frequency of juveniles followed mainly this trend with a small temporal bias towards the rainy season.

One interesting finding for Burkina is that all species migrate frequently and as far as possible in these tropical, seasonal, inland waters. Even *P. annectens*, a reputedly stationary species (Quensière et al., 1994), migrates if we assume that all fish caught in the small temporary rivers were migrating. Despite the fact that damming and impoundment are commonly known to have negative impacts on fish, some authors pointed out that fish can temporarily increase in diversity and abundance, especially in seasonal rivers (Lévêque et al., 1988; after Huenneke and Noble, 1996). By contrast, our results showed that the least negatively impacted water section of Koubri reflected the highest species abundance and biomass. This free-flowing section is connected to the main Nakanbe River and its hydrology is altered by upstream reservoirs in a way that seems beneficial to fish (Van Oel, 2009).

In general, the presence of dams is problematic for riverine ecosystems (Bednarek, 2001), but further studies could examine the hypothesis that dams create reservoirs used as fish habitat in seasonal and intermittent small rivers (Lake, 2003). However, improvements in the design of dams to allow fish migration, the regulation of the controlled use of the water stocked in the reservoir and wiser use of the land are required in order to preserve aquatic biodiversity. Furthermore the success of restoration (connectivity) is associated with increased or even permanent availability of water, of varied habitat and of upstream food prey, along with adjusted and controlled commercial and private fisheries. These conditions are not met in semi-arid areas where fishing is an important source of both income and protein, so fishing pressure can be very high. Therefore increased connectivity can help fish diversity and abundance. However, dam removal is too extreme, an African policy to enhance connectivity, as it is likely to immediately jeopardize the survival of both fish and the local population. Under these circumstances it is understandable that damaged dams are scheduled for rebuilding. A major goal will be developing a rigorous scientific basis to formulate policies that enhance fish migration without jeopardising livelihoods in semi-arid socio-ecosystems.

In addition, standardised monitoring programmes in the future should help to document changes in fish diversity before and after human impacts on aquatic ecosystems.

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Appendix A. Fish species list of Koubri and Nazinga (all catches together)

Families/species	Koubri	Nazinga	Families/species	Koubri	Nazinga
1-Anabantidae			9-Distichodontidae		
1-Ctenopoma kingsleyae	X		*30-Distichodus rostratus*		X
2-Ctenopoma petcherici	X		10-Malapteruridae		
2-Bagridae			*31-Malapterurus electricus*	X	X
3-Auchenoglanis occidentalis	X	X	11-Mochokidae		
4-Bagrus bajad		X	*32-Hemisynodontis membranaceus*	X	X
5-Bagrus docmak	X	X	*33-Synodontis clarias*		X
6-Chrysichthys nigrodigitatus	X		*34-Synodontis comoensis*		X
3-Centropomidae			*35-Synodontis filamentosus*		X
7-Lates niloticus	X	X	*36-Synodontis punctifer*	X	X
4-Characidae			*37-Synodontis schall*	X	X
8-Alestes baremoze	X	X	*38-Synodontis velifer*		X
9-Alestes dentex		X	*39-Synodontis vermiculatus*		X
10-Brycinus macrolepidotus		X	12-Mormyridae		
11-Brycinus nurse	X	X	*40-Brienomyrus niger*	X	X
12-Hydrocinus forskalii	X	X	*41-Hippopotamyrus paugyi*		X

Families/species	Koubri	Nazinga	Families/species	Koubri	Nazinga
13-Hydrocinus vittatus		X	*42-Hippopotamyrus pictus*	X	
14-Micralestes elongatus		X	*43-Hyperopisus bebe*	X	X
5-Cichlidae			*44-Marcusenius senegalensis*	X	X
15-Hemichromis fasciatus	X	X	*45-Mormyrops anguilloides*	X	X
16-Hemichromis letourneauxi	X	X	*46-Mormyrus hasselquistii*		X
17-Oreochromis niloticus	X	X	*47-Mormyrus rume*	X	X
18-Sarotherodon galilaeus	X	X	*48-Petrocephalus bovei*	X	X
19-Tilapia zillii	X	X	*49-Pollimyrus isidori*	X	
6-Citharinidae			13-Osteoglossidae		
20-Citharinus citharus		X	*50-Heterotis niloticus*		X
7-Clariidae			14-Polypteridae		
21-Clarias gariepinus	X	X	*51-Polypterus endlicheri*		X
22-Heterobranchus bidorsalis		X	*52-Polypterus senegalus*	X	
23-Heterobranchus longifilis		X	15-Protopteridae		
8-Cyprinidae			*53-Protopterus annectens*	X	
24-Barbus ablabes	X	X	16-Schilbeidae		
25-Barbus macrops	X	X	*54-Schilbe intermedius*	X	X
26-Chelaethiops bibie	X	X	*55-Schilbe mystus*	X	X
27-Labeo coubie		X	*56-Siluranodon auritus*	X	
28-Labeo niloticus		X			
29-Labeo senegalensis		X			

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