Vol. 14(12), pp. 410-421, December 2020
DOI: 10.5897/AJEST2020.2892
Article Number: EEA00D565661
ISSN: 1996-0786

http://www.academicjournals.org/AJEST

African Journal of Environmental Science and Technology

Full Length Research Paper

Mining the past for a better future of African waters: Historical changes in the fish and fishery of Lake Bam (Burkina Faso) before rehabilitation

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Received 22 July, 2020; Accepted 7 December, 2020

Terrestrial waters provide multiple goods and services to human kind, but they have been severely diminished by increasing human exploitation of water and the landscapes surrounding aquatic communities. This research illuminates such dynamics in the recent history of exploitation of the Lake Bam fishery in Burkina Faso. To do so, from 2009 to 2015 we collected data on the ecology, exploitation and governance of the Lake Bam fishery. Direct sampling of fish documented the erosion of fish diversity and the reduction of fish size and the number of landings. Interviews with leaders of riverside community suggest a halting and uncertain transition in the governance of natural aquatic resources from the traditional (pre-colonial) approach to a republican (European democratic) one. The number of fishermen exceeds the fishery's carrying capacity, but the number of fishermen continues to rise, driven by the low level of opportunities in alternative livelihoods. National and international awareness regarding the lake's ecological and socio-economic importance has driven restoration projects that can benefit from these findings.

Key words: Water, fishery, sahel, ecological awareness, exploitation, governance.

INTRODUCTION

Aquatic ecosystems provide many services that contribute to human well-being and poverty alleviation. In developing countries, inland fisheries are extremely important since they are sources of animal protein, employment and income for rural populations (Millennium Ecosystem Assessment, 2005). Worldwide the settlement of large cities along river courses over the past millennia indicates that human life has long been strongly linked to aquatic ecosystem services (Baron et al., 2002). While the deficient management of freshwaters has led to their overexploitation and disturbance (Malmqvist and Rundle, 2002; Humphries and Winemiller, 2009), there is an

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increasing awareness to promote their conservation. The conservation of freshwaters requires their monitoring and assessment of the extent to which they are impacted. To Karr (1981) fish are commonly used to assess the overall health of aquatic ecosystems and their fisheries. Thus, determining the current status of fish communities gives information on the status of the body of water the communities occupy.

This bio-metric approach was adapted and applied in many areas in the world: Guinea (Hugueny et al*.,* 1996), South Africa (Kleynhans, 1999; Rashleigh et al*.,* 2009), Argentina (Crettaz‐Minaglia and Juarez, 2020), Brazil (Gonino et al*.,* 2020), Nigeria (Ali et al*.,* 2017), Europe (Schmutz et al*.,* 2007; Blabolil et al*.,* 2017; Ergönül et al*.*, 2018; Specziár and Erős, 2020), Côte d'Ivoire (Aboua et al*.,* 2012), India (Basavaraja et al*.,* 2014). It relies on the principle that fish respond to stress on aquatic ecosystems, and that these responses (Table 1) are sustained for a relatively long period of time, e.g. a time period long enough to suggest impacts and potential responses relevant to management policy. A range of relevant research (Table 1) has documented how indicators, such as the level of catch, the species mean adult length, the number of species, the type of species, the number of diseased and deformed fishes are used to assess the quality of a freshwater and the fishery that it offers. However, the lack of reliable data and information on fish and fisheries is a reality in Burkina Faso (Ouédraogo, 2010). For example, the main reliable document available on the lake Bam fishery that is Coenen (1988) is so old that it is likely not so relevant to policy. In and of itself it is not scientific research, but more of a collation of information summarized in a report as part of preparation for a fishery development project undertaken by the FAO. The other available documents are some reports that were prepared in 2005 as part of a lake rehabilitation project. To address this lack of data based on rigorous sampling and analysis, the present work aims to describe the historical changes in Lake Bam fishery in terms of fish community assemblage, commercial total landings and aquatic habitat quality. For the first time it documents the fish species in the lake and the fishing community.

MATERIALS AND METHODS

The study area

Lake Bam is located in the northern part of the country next to Kongoussi, the capital city of the Province of Bam (Figure 1). This largest natural water body in Burkina Faso is included in the catchment of the Nakanbé River, the second most important tributary of the Volta River. Because the lake is fed exclusively by runoff during the rainy season, its size varies from 600 ha during the dry season to 2600 ha during the rainy one. Currently the lake volume is said to be depleted as a result of mismanagement of its resources (Ouédraogo, 2010), and a project for its rehabilitation was officially launched in March 2017 (APPEAR, 2018) and is currently being implemented.

Data collection

Three methods were used to gather all available information about the Lake Bam. A survey of literature was conducted for historical data to itemise the above-mentioned indicators concerning Lake Bam. Then, selected stakeholders and experts were interviewed. Using a variety of fishing gears (cast nets, electric fishing, gillnets and long lines), fish were sampled to provide an overview on the fish community. The sampling of fish and the interviews were implemented from June to August 2009. This initial round of research was followed by the collection of complementary data from the fishermen and local community leaders.

The interviews

Interviews provided a survey of data based on the experience and knowledge of local fishermen. To do so, a workshop was held with 25 fishermen whose age ranged from 25 to 60 years. As aged people often are better informed by their long experience than youths (Leopold et al*.,* 2008), we interviewed a retired fisherman, approximately 85 years-old, with some 60 years fishing experience on Lake Bam. The objective was to collect historical data on the use of fishing gear, the fishing community, fish landings and species composition. When sampling for fish in Lake Bam, these questions were also raised in discussion with local, currently active fishermen who were part of the sampling team.

The management of the lake continues to shift from traditional to republican regimes. The original, historical regime was established and run by the traditional communities that are led by the Naba and the Tengsoba. Its authority is based on customary beliefs and animist religion. The second regime was introduced by the colonizing power from Europe and is supposed to be supported by the evidence derived from scientific analysis of natural resources and the communities that exploit those resources. To gather information about lake management under the traditional regime, we interviewed two villagers who represent the traditional authority of their villages:

(i) Naba Tigré: living in the village of Zimtanga, he is the Chief of the Canton of Datinga, an administrative area that is supposed to regroup more than 100 villages and that includes about 90 % of the lake water area and the surrounding upland catchment.
(ii) Tengsoba Yaalé: the Tengsoba is the person traditionally responsible for natural resources management in the Mossi ethnic group, including the area of Bam. According to the local fishermen we interviewed, Tengsoba Yaalé represents the traditional authority in the management of Lake Bam. He is living in Bam Village, which is located about 10 km away from Zimtanga.

The sampling of fish

In early July 2009, we sampled fish with long lines, gillnets, cast nets and electric fishing. The specimens were classified into species according to Lévêque et al*.* (1990, 1992); their total length (TL) and body weight (W) were measured. Fish were sampled in the lake itself, as well as in the main and secondary tributaries a few hours after it had rained. The rain aided our sampling since fish often become concentrated at the brook mouths and migrates upstream as soon it rains (Bénech and Quensière, 1987).

Data analysis

To highlight the historical changes in the fishery, we organized the data into the following categories: climatic and hydro-morphologic features, the governance of the lake and its resources, fishing

Table 1. Effects of environmental stresses on fish and fishery.

Indicators	Trends	Sources	Remarks
Level of catch	Falling level of total catches	Welcomme, 2001; Allan et al. 2005	
	Falling level of catches per unit of fishing effort	Welcomme, 2001; Albaret and Laë, 2003; Rice and Rochet, 2005 ; Ruangrai, 2006; Sheaves et al., 2012	If the number of fishermen does not decrease.
Mean length	Disappearance of large size species	Welcomme, 2001; Albaret and Laë, 2003 ; Allan et al., 2005	At community level. Example of large size specie: *Heterobranchus* sp.)
	Falling mean size or weight	Welcomme, 2001; Albaret and Laë, 2003; Piet and Jennings, 2005; Allan et al., 2005	At species level
Number of species	Declining number of species	Welcomme, 2001; Albaret and Laë, 2003; Allan et al., 2005; Sheaves et al., 2012	
Type of species	Decline and disappearance of higher trophic levels	Welcomme, 2001; Albaret and Laë, 2003	The highest trophic levels species are predators (Ex: *Lates niloticus*, *Hydrocinus forskahalli)*
	Increase of lower trophic levels	Murawski, 2000; Welcomme, 2001	Ex: phyto-planktophagous species like *Oreochromis niloticus*
	Decrease of intolerant species and increase of tolerant species	Welcomme, 2001	Tolerance means ability to withstand harsh conditions
Diseases and deformed fishes	Increasing proportion with disease, tumours, fin damage, and other anomalies	Karr, 1981	May lead to mortality of fishes

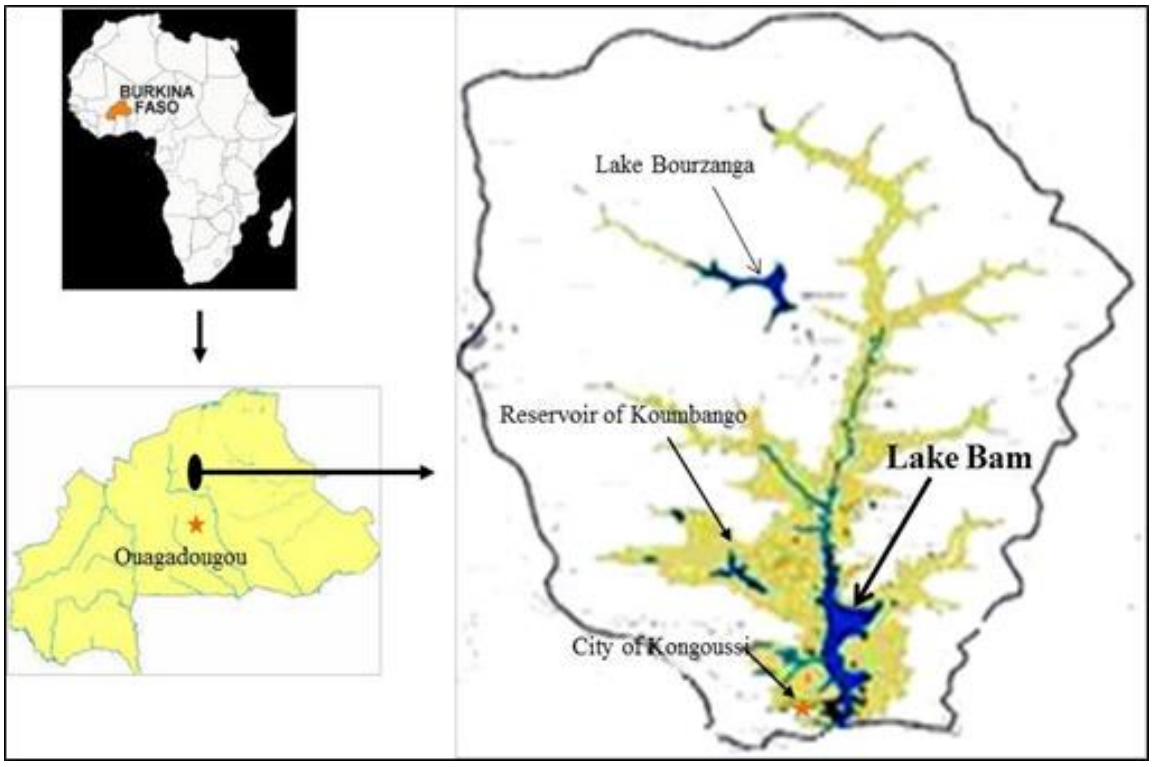

Figure 1. The study area: Lake Bam catchment is shown on the right-hand map.

pressure and the fishery production, changes in the fish community, restoration actions. We then analysed the dynamic trends of these entities over time.

RESULTS

Climatic and hydro-morphologic features

The lake relies exclusively on rain to be filled, but the annual rainfall shows a general decreasing trend over the past century. From 878 mm in 1927 it dropped to 572.6 mm in 2008. Figure 2 illustrates a clear 35% decrease of the rainfall trend from 1927 to 2015 despite the missing of data from 1980 to 1989.

Rainfall in the Sahel region is usually scarce and patchily distributed. According to Ouédraogo (2010), the sparse, upland vegetation and the patchy, intense patterns of precipitation contribute to strong soil erosion, and these results in the transportation of significant quantities of sediments to the lake. With about 500,000 m^3 of sediments deposited every year, the lake lost one third of its water volume, as measured by depth, between 1963 and 2006. If this trend continues, lake water storage capacity will vanish, and the lake will disappear in a quarter of century. The elderly villagers who participated in this survey said that, the lake is increasing in area as it becomes shallower and shallower. They illustrated this by showing areas that formerly surrounded the lake where they were farming maize, sorghum and millet some 3-5 decades ago. But the pieces of land on which they used to farm are now flooded by August, the middle of the rainy period that lasts from June to September. Furthermore, the lake loses large quantities of water due to (i) the heat that resulted in high evaporation (ii) abstraction of large quantities of water for irrigation. The surface water temperature ranges from 18 to 42°C, and the evaporation rate is about 7 mm/day (Pouyaud, 1986). As a result, the lake water surface declines by 1.5 m over the course of the year, a significant decrease for a lake that is 2-3 m deep during the rainy season.

Water management within Lake Bam catchment

In arid regions like the Sahel, people have historically dug small size ponds to store water to be used during the dry season. Today, larger reservoirs are created and many others are under construction as the demand for water increases year-by-year. According to a national list of water bodies developed a decade ago, the lake catchment currently hosts 45 reservoirs; all sizes included (Figure 3).

The dams are not supplied with migratory devices, e.g. fish ladders, the absence of which, in all probability impedes the migration of fish. Furthermore, upstream reservoirs have to be filled before the water flows into the lake, which delays the filling of the lake as compared to what it was in the past.

Pollution and degradation of habitat

According to the fishermen, fish mortality is gradually increasing as water levels increasingly decline during the fish community's most vulnerable period, from April to June, the variable and unpredictable end of the dry season before the rainy season starts. Firstly, this may be due to increasing pollution concentrations in the water column as pollution rates in runoff increase at the same time that the lake's volume decreases. Observations on the river banks during the dry season, confirmed by Google maps, show the presence of large, irrigated, vegetable farms in the immediate surroundings of Lake Bam. The same irrigated lands used to grow vegetables during the dry season are rain-fed farms of sorghum and of other cereals during the rainy season from July to October. Local experts of agriculture explain that the farmers use large quantities of fertilisers and pesticides. Inadequate government oversight or control results in overuse of these chemicals, and the excess is washed into the streams and the lake during the rainy season. Secondly, the area surrounding Bam is grazed by a significant population of livestock, estimated at more than 100 000 animals, all types included (Ouédraogo, 2010). Animal nutrient deposition across the landscape is washed by runoff to Lake Bam, thereby increasing the nutrient input (Derlet et al., 2010). The fishermen observed that, in entering the lake to drink water, the cattle stir up bottom sediments, making the water more turbid, and defecate, increasing the organic loading of the water column, the decomposition of which increases oxygen demand. The resultant hypoxia during the period of lowest water levels may increase stress and mortalities in fish.

Changes in the fishery governance

The traditional management approaches

Elderly and traditional authority leaders explained that before colonisation in the early 20^{th} century, riverside people managed the lake according to their own rules, values, and understandings. That traditional belief system is consecrated by more than 12 holy sites existing in and around the lake along the shore area. From time to time, sacrifices were offered to prevent harm to the community, such as drowning, floods and diseases, and to ensure fruitful usages of the resources (such as fish and water), and for the wealth of people in general. The offerings can include one or many of the following items: traditional beer, sesame, bean cakes, black bullock, black goat, black hen, donkey, dog and horse. The dog and the horse replace human being which was formerly used as a sacrifice. Additional items may be required depending on

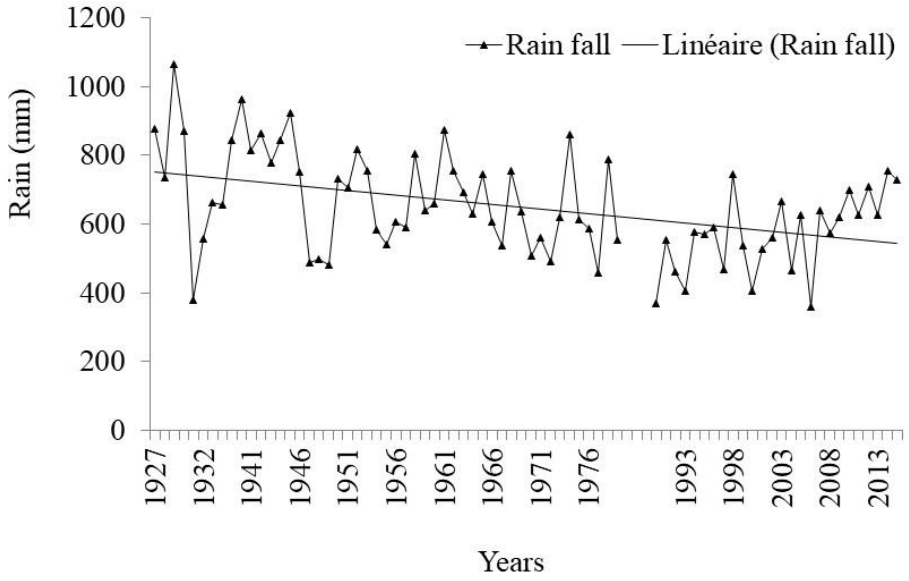

Figure 2. Annual Rainfall trend from 1927 to 2015 in Bam area.

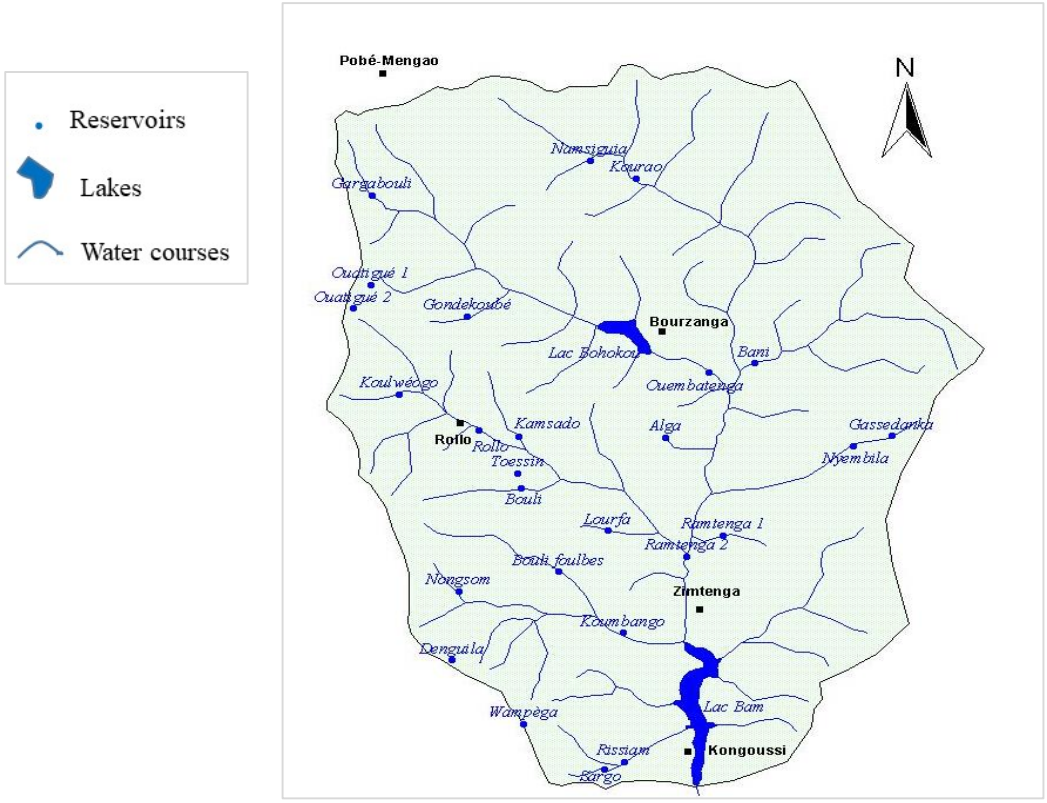

Figure 3. Spatial distribution of reservoirs, lakes and water courses in Lake Bam catchment area (Source: Government of Burkina Faso, 2009).

the circumstances of the sacrifice. Sacrifices for the benefit of the entire community were ordered by a group of wise people, and the Chief of the Canton had to provide the ingredients. To do so, he used to send people

Figure 4. The fishermen association asked the Tengsoba Yaallé of Bam village for sacrifice for fruitifull and peaceful fishery (Photos R. OUEDRAOGO, 23 May 2013).

to walk around and to catch any animal that roams freely. On 23rd May 2013, we witnessed a sacrifice event that the fishermen of Lake Bam asked Yaalé to proceed for fishing to be productive (Figure 4).

In former times, the rules were legitimized and enforced by a group of wise people led by the Tengsoba and acknowledged and followed by the community in general. By this approach the Lake and the other natural resources were managed. For instance, when declining water levels broke the lake into separate pools, some pools were designated to be open to domestic animals, some for domestic needs, but all were managed for fish conservation. During this period fishing and hunting for crocodiles were strictly forbidden, a ban that generally protected aquatic biodiversity. Clearing large areas of land cover of vegetation was subject to the approval of the Tengsoba. Medicinal trees, trees producing edible fruits and holy forests were always strictly protected. Hunting and cutting trees were seasonally restricted. During the protection period, no wildlife animal could be killed, because they were thought to be pregnant. But killing wildlife such as snakes for human protection was allowed and even encouraged.

Anyone who witnesses a violation event was expected to report to the authority. A range of punishments were applied for different offences, but a person who repeatedly violates the rules was gradually marginalised. For instance, this person was not properly greeted by anybody in the community. The ultimate sentence was the drowning of the guilty person in the lake. Not only was finding the dead body extremely difficult, but the person was then qualified as donkey; and as animal and could not benefit from a proper funeral. This extreme condemnation was greatly detested in the community.

The republican management approaches

In the early to mid-20th century, the French colonial administration introduced new rules governing natural resources. The elderly respondents in our interviews reported some republican management policies that they

could not understand, nor accept:

(i) Overnight, local people lost the ownership of the lake, which was now allocated to the State. But the new owner was not present to implement their rules.
(ii) For leisure purposes the French colonisers cleaned the lake banks from vegetation. Then they used to cross the lake with a motorised boat, to swim and to fish.
(iii) No foreign fisherman was allowed to catch fish in the lake, and rules for foreigners willing to undertake any activity other than fishing existed. But the coloniser invited professional fishermen from the neighboring Republic of Mali to fish in the lake without seeking the agreement of the indigenous people.
(iv) Six to seven decades ago the colonial administration introduced a fishing tax or licence of 6000 FCFA/year/ fisherman, the equivalent of 9.15 Euro or the price of two 4-year old bulls or two new bicycles. This was much higher than what the average, indigenous citizen could afford. For comparison, at that time, the colonial administration introduced a national Head tax for all citizens. The entire city of Kongoussi, the biggest agglomeration next to the lake had to pay only 15 FCFA/year (that is, 0.02 €). But this amount was seldom met by the city, meaning that the fishing tax was unreasonably high.

Today the Naba Tigre, Chief of the Canton of Datinga, and the Tengsoba are both calling for a reorientation of the lake management to better accommodate and integrate traditional authorities within what is, ostensibly, a republican regime. To explain previous failures to accomplish this, the Naba, points out that the republican system tries to involve the traditional authority but from a wrong perspective. He is frequently invited for meetings regarding the lake, which regrettably he has no strong authority to manage, because he manages people but not natural resources. In addition to his invitation, he has suggested that the Tengsoba also be solicited, because he is the most appropriate for managing natural resources following the traditional approach. According to the Tengsoba, the government or any other governing body has to provide them with the ingredients for sacrifice for the community's benefit. This is necessary because the Naba can no longer order the free catching of animals for sacrifices. People still respect and believe in the Tengsoba power as they often come to him for assistance.

The exploitation of fish resources

Historically, riverside people were fishing for subsistence using elementary gear. Commercial fishing was introduced in Bam in 1953 by the French colonial administrator, who invited some professional fishermen from the River Niger in the Republic of Mali to fish the lake. With a much longer fishing tradition than what existed at that time in Burkina Faso, they brought more efficient gear, such as cast nets, gill nets, long lines and canoes. Their number reached 30 some years later, but they left the lake more than a quarter of a century ago. In addition to their role as trainers for local people with little previous history of fishing, these fishers were providing fish products to local markets and to Ouagadougou the main city of the country that is 110 km far in the South. Half a century ago about 100 persons were fishing in the lake. Today there are about 650-700 fishermen inhabiting the 36 riverside villages.

The fishermen mentioned a remarkable decrease of catches over the past 70 years. From about 50 kg of fish per day in 1950 the landings of a fisherman dropped to 2.3 kg in 1987 and to 0.5 kg in 2009. The total landing of the lake was estimated at 175 t in 1990, 150 t in 2000 and about 80 t in 2009 (Ouédraogo, 2010).

Historical changes in the fish community

The fishermen described the historical changes in the fish community as they witnessed or heard from elder people. Six decades ago, the fish community was dominated at about 60% by two species: *Clarias gariepinus* and *Heterotis niloticus*. They were followed by *Polypterus* sp., *Synodontis* sp., *Auchenoglanis occidentalis*, *Protopterus annectens* and the tilapia group which together contribute at 35 % to the fish community. *Alestes* species and *Brycinus* specie were rare, as together they contributed to about 5% to the fish community. *Barbus* sp. appeared during that period.

Three decades ago, *C. gariepinus* and *H. niloticus* were still dominant, *Polypterus* specie, *Synodontis* specie, *P. annectens* and the tilapias frequent*, Alestes* specie and *Brycinus* specie were relatively frequent as compared to *Barbus* specie which was rare. The mormyrid family, *Hydrocynus* specie, *Heterobranchus* specie and *Malapterurus electricus* appeared at that time. *Heterobranchus* specie was somehow frequent, and very large specimens were often caught. *Lates niloticus* was twice introduced but never established. The only written document about the Lake Bam fish community Coenen (1988) mentioned 21 species in the commercial landings but estimated that the lake was hosting 30 species regrouped in 11 families. *Sarotherodon galilaeus* was dominant (39.1%), followed by *Oreochromis niloticus* (16.3%), *Brycinus nurse* (9.9%), *Marcusenius senegalensis* (9.1%), *Schilbe intermedius* (8.9%), *Auchenoglanis occidentalis* (5.6%) and *Synodontis schall* (4.2%); the other species contributed 6.9%.

In 2009, some fifty-two sampling events yielded 2533 fish, regrouped in 20 species and 9 families. Two species strongly dominated: *Sarotherodon galilaeus* (30.2 %) and *Enteromius ablabes* (26.3%). They were followed by *Chelaethiops bibie* (6.5%) and *Enteromius macrops* (5.9%). *Oreochromis niloticus, Clarias gariepinus*,

Coptodon zillii and *Hemichromis letourneauxi* contributed at 4% each. Together the 11 remaining species contributed a total of 15%. The fishermen pointed out that nowadays *Heterotis niloticus* and *Heterobranchus* sp. still exist, but they are extremely rare and seasonal (Table 1).

In 2009 the maximum total length (TL in mm) was 119 for *S. galilaeus*, 85 for *E. ablabes*, 310 for *C. gariepinus* and 160 for *O. niloticus*. Table 2 shows the species list, the relative frequencies and the size of fish in Lake Bam. A comparison of data in Coenen (1988) and ours shows that a likely loss of 8 species and a decrease in fish mean weight over 20 years (Table 3).

Social impacts of the lake and its resources

Today, there are 650-700 fishermen inhabiting the 36 riverside villages. But only 3-5 of them rely more or less exclusively on fishing for their daily livelihood. It means that most fishermen are also involved in other economic activities, such as rain-fed agriculture, irrigated agriculture, livestock breeding, selling of goods, artisanal mining of gold, etc, and only take up fishing as an additional income source. Such occasional fishermen often lack the experience or knowledge to fish sustainably. In contrast to former times, forbidden fishing methods are currently commonly used. They include nets of small mesh size, unsuitable long lines, beach seine, poisoning, etc.

In addition, about 600 women are involved in the post-harvest segment of the fishery. They sell fresh fish, smoke fish that they later sell, fry and cook fish in small restaurants. Seasonality is observed in the fishery. During the rainy season, the fishers are all involved in rain-fed agriculture that is labor-intensive. Therefore, they allocate the least time to fishing by tending to use passive gear, such as gillnets and long lines. The fishermen also indicated that by this time, as there is much water in the lake, fishing is rather less productive. During the dry season, as water levels decline and concentrate the fish the fishing becomes more intensive. The fishermen tend to fish more when money-demanding social events are planned: festivals (e.g. Christmas), funerals, when children return to school in October after the long holidays, etc. The fishermen affirmed that without fishing, they would have to sell their crops or domestic animals to meet the cash needs of these occasions.

Previously, the fish production of Lake Bam was collected by fishmongers coming from Ouagadougou and sold in that city. Today, it is exclusively sold in local markets and even has to meet the competition from fish imported from Asia, Côte d'Ivoire and other countries and sold in the areas surrounding the lake. This means that the lake fishery is less and less competitive, and perhaps is so depleted that it has to be completely rehabilitated through significantly higher levels of investment and effort.

The restoration actions undertaken in Lake Bam

To support rehabilitation of Lake Bam, significant attention is given to lake conservation. In 2009 the lake was allocated the status of a Ramsar site - a recognition of its international ecological importance (Government du Burkina Faso, 2009). To protect the lake, trees are being planted on the banks and stony walls (bunds) built on the brooks to slow down the transportation of sediment into the lake (Figure 5). The first stony walls were built by a Germany-funded project dedicated to restore the soils of the areas to improve agriculture. Today, many NGOs and associations now pursue projects that prioritize the lake's protection. Some brooks whose 2.5 m deep accelerated runoff rates and erosion are now filled of sand and used for agriculture.

The lake is currently being rehabilitated under a project that was launched 03 March 2017 (APPEAR, 2018). The restoration project has two phases. The first step consists mainly, in erecting a 25 cm high wall at the downstream edge of the lake, in intensifying the irrigated farming of vegetables, protecting the lake resources, studying the possibility of dredging and enhancing the fishery. As for fish, the project planned to farm fish for restocking, and to provide the fishing community with equipment for fishing and processing fish. But noticeably no fish related research activity is planned (MAH, 2012). The second step will consist in dredging the lake, if feasible, to increase the lake's depth and water storage capacity.

DISCUSSION

The present study does not intend to make an extensive or detailed description of the fishery of the lake or to conduct solid statistical analysis but to address general trends that serve as a warning on the lake's status. This study confirms the need for reform of natural resource management in Burkina Faso. The replacement of the traditional management system by the republican one is not effective (Yelkouni, 2012), and in the intervening limbo the lack of clear governing responsibility and accountability has only exacerbated the misuse and decline of the Lake Bam resources. As concluded by GTZ (2002), two legitimised approaches to the management of the lake, and its resources exist in the area and should be sensibly integrated.

The fish of Bam exhibit typical features of a degraded and depleted fish community. We found that the lake exhibits an erosion of fish diversity, confirming what many authors believe (Horrigan et al., 2002; Albaret and Laë, 2003; Freeman and Marcinek, 2006). Vulnerable, large size and intolerant species such as *H. niloticus, Heterobranchus* sp. and *Lates niloticus* (Froese and Pauly, 2019) gradually declined significantly and have been replaced by pygmy ones; e.g. *E. ablabes, E. macrops* and *C. bibie* as well as tolerant, resilient and

Table 2. Lake Bam fish species list, relative frequencies (%) and size in 2009.

Species	Frequencies	TL (mm)			Weight (g)			Remarks
		Mean	Maxi	Mini	Mean	Maxi	Mini	
Alestes baremoze	1.31	80.88	120.00	40.00	5.67	18.20	1.70	
Auchenoglanis occidentalis	0.36	184.78	230.00	163.00	65.50	113.50	48.30	
Brycinus nurse	0.36	68.11	90.00	50.00	3.86	7.60	2.00	
Chelaethiops bibie	6.50	38.49	49.00	15.00	0.51	0.90	0.10	
Clarias gariepinus	4.00	184.15	310.00	120.00	47.84	250.00	8.10	
Coptodon zillii	4.00	72.39	125.00	40.00	9.94	30.20	1.20	
Enteromius ablabes	26.35	37.46	85.00	17.00	0.62	11.00	0.10	
Enteromius macrops	5.90	49.19	75.00	30.00	1.32	4.00	0.20	
Hemichromis fasciatus	3.45	38.22	50.00	31.00	1.14	2.20	0.50	
Hemichromis letourneauxi	4.00	42.79	65.00	30.00	1.48	4.30	0.50	Seen in our catches in 2009
Hippopotamyrus pictus	0.04	59.00	59.00	59.00	1.90	1.90	1.90	
Marcusenius senegalensis	0.87	94.00	120.00	70.00	6.84	13.60	2.00	
Oreochromis niloticus	4.00	82.93	160.00	14.00	15.67	75.40	0.50	
Petrocephalus bovei	2.65	53.81	70.00	38.00	1.57	3.70	0.50	
Polypterus senegalus	0.08	143.50	152.00	135.00	16.90	18.70	15.10	
Sarotherodon galilaeus	30.2	51.13	119.00	30.00	3.28	36.90	0.60	
Schilbe intermedius	0.44	69.82	90.00	50.00	3.27	7.40	0.90	
Siluranodon auritus	3.41	82.35	111.00	49.00	4.32	9.60	0.70	
Synodontis punctifer	0.52	66.08	111.00	45.00	3.95	13.50	1.20	
Synodontis schall	1.51	65.66	110.00	45.00	4.20	16.00	1.10	
Heterotis niloticus								Seldom seen by the fishermen
Heterobranchus sp.								

Table 3. Lake Bam fish community evolution from 1987 to 2009.

Criteria of comparison	Species	1987	2009
Number of species		**± 30**	**± 22**
Species composition (%)	*Sarotherodon galilaeus*	39.1	30.2
	Oreochromis niloticus	16.3	4.00
	Brycinus nurse	9.9	0.4
	Marcusenius senegalensis	9.1	0.9
	Schilbe intermedius	8.9	0.44
	Auchnoglanis occidentalis	5.6	0.4
	Synodontis schall	4.2	1.5
	Other species	6.9	62.3
Mean weight (g) of major species	*Sarotherodon galilaeus*	23	3.3
	Oreochromis niloticus	16.3	14.8
	Schilbe intermedius	9.9	3.9

less vulnerable ones like *S. galilaeus* (Ouédraogo, 2010). Also, the small length of species characterises the degradation of the carrying capacity of the Lake Bam fishery (van Zwieten et al., 2011). Bam fishes are much smaller than those of many other areas of Burkina Faso (Ouédraogo, 2010) (Table 3).

As for the fishing community, the lake now hosts about 14 times more fishermen than what the FAO would have recommended, e.g. 2 fishermen/km^2. According to van Zwieten et al. (2011) a fisherman daily lands 7 to 28.8 kg of fish in Lake Volta (Ghana) depending on the gear used; in Bam he currently lands only half a kilogramme. Such a low production level cannot sustain the involvement of foreign, professional fishermen and

Figure 5. A stony wall built by the fishermen on a small tributary of the lake in 2015 in the area of Song-N-Med-Beenga, close to Bam village) (Photo R. Ouédraogo, 25 Oct. 2015).

scarcely supports the part-time fishermen currently fishing in Lake Bam. In Bam the number of local fishers may have increased over time as the perceived profitability of fishing outweighed other factors, such as other economic activities, policy measures and the existence of restrictions (Charles, 2000). As they no longer catch much fish, the emigration of foreign, professional fishermen was expected, just as it happened in other bodies like Lake Higa (Ouédraogo et al., 2015). Actually, in Burkina waters, fishing efforts are not really regulated and limited. This is in line with one of the objectives of the fishery policy, that is, to provide employment to rural people (MAHRH, 2010). But this might not be in line with sustainability.

Fish can die as a result of a wide variety of natural and unnatural causes. In Nigeria, Solomon-Wisdom and Olatunde (2014) found a strong and positive correlation between fluctuation in physicochemical parameters and fish mortality. The level of Lake Bam water seasonally fluctuates substantially as a result of natural and human factors, which may affect greatly the fish and fishery (Baijot et al., 1994; Kabré and Illé, 2000; Patrick, 2016).) Lake Bam's location at the headwaters of a river catchment makes it naturally vulnerable to such threats. As posited by the River Continuum Concept (Vannote et al., 1980) and demonstrated by Meyer et al. (2007) and Konan et al. (2013) fish diversity is lower in upstream river and reaches and increases as one moves downstream. This is also consistent with the suggestions of Haigh and Krecek (1991) and Neiland and Béné (2008). As with other aquatic ecosystems (Carpenter and Brock (2004) and Solomon-Wisdom and Olatunde (2014) increasing trends of yearly fish mortality is convincing evidence that the lake is in an advanced state of physical and biotic decline, requiring large-scale measures to rehabilitate it.

Conclusions

The fish community of Lake Bam exhibits signs of collapse. Declining trends in species number, in species tolerance, in fish size and in fish landings as well as the hydro-morphological alterations of the lake confirm significant degradation of the aquatic ecosystem. These trends are linked to a history of poorly regulated fishing and land-use in the surrounding catchment, and such abuse of natural resources is only exacerbated by unchecked increases in the number of fishermen and the general use of unsuitable fishing methods, neither of which have reversed the decline in fish landings.

Part of the basis for such mis-management of the lake can be attributed to the failure to establish a unified system of governance with clear and unquestioned responsibility and authority for natural resource management. This confusion arises from the unresolved tension between a waning traditional system and a republican approach that so far has failed to establish strong links between the national and local governments. For the moment, it appears best to seek better ways to

improve both traditional and republican institutions, with perhaps more effort given to integrating their operations. This follows the suggestions of two leaders of the tradition authority and should be the basis for further testing ways to decentralisation governance in Burkina Faso.

While this research establishes a recent foundation of data, much research is needed to continue to build on this foundation and provide policy makers with rigorous data in planning and adapting efforts to rehabilitate the lake and its fishery. The history of failures in management to date stems in part from the absence of useful information or reliance on deficient and fragmentary data. Such an ambitious research-based development approach will require strong cooperation between 'developers' and researchers in the implementation of the rehabilitation project.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGMENTS

The authors are grateful to APPEAR programme (Austrian Partnership Programme in Higher Education and Research for Development), funded by the Austrian Development Agency (ADA) and implemented by the OEAD (Austrian Agency for International Cooperation in Education and Research) for funding this study. This study was performed as a part of the APPEAR-sponsored SUSFISH and SUSFISH-plus Projects (Sustainable Management of Water and Fish Resources in Burkina Faso, www.susfish.boku.ac.at) that aimed to ''strengthen in-country capacities for science, policy and practice to establish the basis for sustainable fisheries in Burkina Faso.

REFERENCES

Aboua BRD, Kouamélan EP, N'Douba V (2012). Development of a fish-based index of biotic integrity (FIBI) to assess the quality of Bandama River in Côte d'Ivoire. Knowledge and Management of Aquatic Ecosystems 404(8):19.

Albaret J-J, Laë R (2003). Impact of fishing on fish assemblages in tropical lagoons: the example of the Ebrie lagoon, West Africa; Aquatic Living Resource 16:1-9.

Ali FA, Ofori-Danson PK, Nunoo FKE, Idowu RT, Tayib Y (2017). Comparative Biotic Quality Assessment of two Tropical Reservoirs using Fish Based Index of Biotic Integrity. SDRP Journal of Aquaculture, Fisheries and Fish Science 2(1):47-59.

Allan JD, Abell R, Hogan Z, Revenga C, Taylor BW, Welcomme RL, Winemiller K. (2005). Overfishing of Inland Waters. BioScience 55(12):1041-1051.

APPEAR (2018): SUSFISH-plus project partners took part in the launching ceremony for Lake Bam restoration project. https://appear.at/en/news/article/2017/06/susfish-plus-project-partners-took-part-in-the-launching-ceremony-for-lake-bam-restoration-project/. Visited 10 March 2018.

Baijot E, Kabore K, Zerbo H (1994). Chapitre 5: Production exploitée et effort de pêche dans les retenues In Baijot E, Moreau J, Bouda S. 1994. Aspects hydrobiolgiques et piscicoles des retenues d'eau en zone soudano-sahélienne. Ede; Bruxelles. Centre Technique de Coopération Agricole et Rurale (CTA); Commission des Communautés Européennes (CEE) 250 p.

Basavaraja D, Narayana J, Kiran BR, Puttaiah ET (2014). Fish diversity and abundance in relation to water quality of Anjanapura reservoir, Karnataka, India. International Journal of Current Microbiology and Applied Sciences 3(3):747-757.

Baron JS, Poff NL, Hairston NGJr., Angermeier PL, Richter BD, Jackson RB, Dahm CN, Johnston CA, Steinman AD, Gleick PH (2002). Meeting ecological and societal needs for freshwater; ESA Report. Ecological Applications 12(5):1247-1260.

Bénech V, Quensière J (1987). Dynamique des peuplements ichtyologiques de la région du lac Tchad (1966-78) - Influence de la sécheresse sahélienne - Tome 1: texte. Thèse de Doctorat d'Etat es-Sciences Naturelles, Université des Sciences et Techniques de Lille Flandres Artois 662 p.

Blabolil P, Říha M, Ricard D, Peterka J, Prchalová M, Vasek M, Čech M, Frouzová J, Jůza T, Muska M, Tuser M, Drastík V, Sajdlová Z, Šmejkal M, Vejřík L, Matěna J, Boukal DS, Ritterbusch D, Kubečka J (2017). A simple fish-based approach to assess the ecological quality of freshwater reservoirs in Central Europe. Knowledge and Management of Aquatic Ecosystems 418:53.

Carpenter SR, Brock WA (2004). Spatial complexity, resilience and policy diversity: Fishing on lake-rich landscapes. Ecology and Society 9 p.

Charles AT (2000). Fishery Management, in Sustainable Fishery Systems, Blackwell Science. https://books.google.com.ng/books?hl=en&lr=&id=m5ZhxzdmMbEC&oi=fnd&pg=PR7&dq=Charles+AT,+(2000).+Fishery+Management,+in+Sustainable+Fishery+Systems,+Blackwell+Science.&ots=y0bc_nAg1c&sig=7f6Y4apH989ZwURcJlzK4UbhTsk&redir_esc=y#v=onepage&q=Charles%20AT%2C%20(2000).%20Fishery%20Management%2C%20in%20Sustainable%20Fishery%20Systems%2C%20Blackwell%20Science.&f=false

Coenen E (1988). Etudes des ressources piscicoles du Lac Bam. Rapport préparé pour le projet Elaboration d'un plan directeur pour le développement de la pêche au Lac Bam. Organisation des Nations Unies pour l'Alimentation et l'Agriculture, Rome 26 p.

Crettaz‐Minaglia M, Juarez RA (2020). Fish diversity and biotic integrity in a small stream of a temperate plain. Rendiconti Lincei. Scienze Fisiche e Naturali. https://doi.org/10.1007/s12210-020-00947-1

Derlet RW, Goldman CR, Connor MJ (2010). Reducing the impact of summer cattle grazing on water quality in the Sierra Nevada Mountains of California: a proposal. Journal of Water and Health 8(2):326-333.

Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) (2002). Back to Basics: Traditional inland fisheries management and enhancement systems in Sub-Saharan Africa and their potential for development. 212 p. http://cofad.com/download/back-to-basics.pdf

Ergönül MB, Breine J, Van den Bergh E (2018). A technical guide to develop a statistically valid fish-based index in compliance with the water framework directive: an evaluation for Turkish freshwaters. International Aquatic Research 10:303-319.

Froese R, Pauly D (2019). FishBase, World Wide Web electronic publication. www.fishbase.org, (02/2019). Visited 25 April 2019.

Gonino G, Benedito E, Cionek VM, Ferreira MT, Oliveira JM (2020). A Fish-Based Index of Biotic Integrity for Neotropical Rainforest Sandy Soil Streams-Southern Brazil. Water 12:1215.

Government of Burkina Faso (2009). Lac Bam. Zone Humide d'importance Internationale. Site Ramsar No. 1880. Superficie: 2 693 hectares. Date de désignation: 7 octobre 2009. Par le Gouvernement du Burkina Faso.

Haigh MJ, Krecek J (1991). Headwater management: problems and policies. Land Use Policy 8:191-205.

Horrigan L, Lawrence RS, Walker P (2002). How sustainable agriculture can address the environmental and human health harms of industrial agriculture. Environmental Health Perspectives 110:445-456.

Hugueny B, Camara S, Samoura B, Magassouba M (1996). Applying an index of biotic integrity based on fish assemblages in a West African

river. Hydrobiologia 331: 71-78.
Humphries P, Winemiller KO (2009). Historical Impacts on River Fauna, Shifting Baselines, and Challenges for Restoration. BioScience 59(8):673-684.
Kabré AT, Illé A (2000). Rétrécissement saisonnier des superficies d'eau, variation physico-chimique et production des pêcheries artisanales de Bagré. Centre-Est Burkina Faso. Tropicultura 18(3):130-135.
Karr JR (1981). Assessment of biotic integrity using fish communities. Fisheries 6:6. https://doi.org/10.1577/1548-8446(1981)006<0021:AOBIUF>2.0.CO;2
Kleynhans CJ (1999). The development of a fish index to assess the biological integrity of South African rivers. Water SA 25(3):265-278.
Konan KF, Bony KY, Edia OE, Kouame KM, Ouattara A, Gourene G (2013). Fish composition and structure along longitudinal gradient of a coastal river (Ehania River; south-east of Ivory Coast). International Journal of Biosciences 3(9): 195-207.
Leopold M, Herrenschmid J-B, Thaman R (2008). The relevance of traditional ecological knowledge for modern management of coral reef fisheries in Melanesia. Proceedings of the 11th International Coral Reef Symposium, Ft. Lauderdale, Florida, 7-11 July 2008. Session No 22.
Lévêque C, Paugy D, Teugels GG (1990). Faune des poissons d'eaux douces et saumâtres de l'Afrique de l'Ouest. Tome 1. Editions ORSTOM/MRAC. Collection Faune Tropicale 28:386.
Lévêque C, Paugy D, Teugels GG (1992). Faune des poissons d'eaux douces et saumâtres de l'Afrique de l'Ouest. Tome 2. Editions ORSTOM/MRAC. Collection Faune Tropicale 28:521.
Ministère de l'Agriculture et de l'Hydraulique (MAH) (2012). Etudes détaillées du projet de restauration, de protection et de valorisation du lac Bam. Rapport de synthèse. Version provisoire. Burkina Faso, Juillet 59 p.
MAHRH (Ministère de l'Agriculture de l'Hydraulique et des Ressources Halieutiques) (2010). Stratégie Nationale de Développement Durable des Ressources Halieutiques à l'horizon 2025. Ministère de l'Agriculture, de l'Hydraulique et des Ressources Halieutiques (2010). Ouagadougou, Burkina Faso. Burkina Faso, Septembre 2010, 44 p.
Malmqvist B, Rundle S (2002). Threats to the running water ecosystems of the world. Environmental Conservation 29(2):134-153.
Meyer JL, Strayer DL, Wallace JB, Eggert SL, Helfman GS, Leonard NE (2007). The Contribution of Headwater Streams to Biodiversity in River Networks. Journal of the American Water Resources Association 43(1):86-103.
Millennium Ecosystem Assessment (2005). Ecosystems and human well-being: wetlands and water Synthesis. World Resources Institute, Washington, DC. 80 p.
Murawski SA (2000). Definitions of overfishing from an ecosystem perspective. – ICES Journal of Marine Science 57:649-658.
Neiland AE, Béné C (2008). Tropical river fisheries valuation: background papers to a global synthesis. The WorldFish Center Studies and Reviews 1836, 290 p. The WorldFish Center, Penang, Malaysia 301 p.
Ouédraogo R (2010). Fish and fisheries prospective in arid inland waters of Burkina Faso, West Africa. Doctor Thesis. University of Natural Resources and Life Sciences, Vienna, Austria 132 p.
Ouédraogo R, Soara AE, Ouéda A (2015). Description du peuplement piscicole du lac sahélien de Higa, un site Ramsar du Burkina Faso, Afrique de l'Ouest. Journal of Applied Biosciences 95:8958-8965.
Patrick AES (2016). Influence of rainfall and water level on inland fisheries production: A review. Archives of Applied Science Research 8(6):44-51.
Piet GJ, Jennings S (2005). Response of potential fish community indicators to fishing. ICES Journal of Marine Science 62: 214: 225.
Pouyaud B (1986). Contribution à l'évaluation de l'évaporation de nappes d'eau libres en climat tropical sec. Exemples du Lac Bam et de la Mare d'Oursi (Burkina Faso) et du lac Tchad et d'Açudes du Nordeste brésilien. Éditions de l'ORSTOM ; Institut Français de Recherche Scientifique pour le Développement en Coopération. Collection ÉTUDES et THÈSES. Paris 244 p.
Rashleigh B, Hardwick D, Roux D (2009). Fish assemblage patterns as a tool to aid conservation in the Olifants River catchment (East), South Africa. Water SA 35(4):517-524.
Rice JC, Rochet M-J (2005). A framework for selecting a suite of indicators for fisheries management. ICES Journal of Marine Science 62:516e527.
Ruangrai TR (2006). Global fisheries and local problems: how ECOST might help ameliorate overfishing in Thailand? IIFET 2006 Portsmouth Proceedings 10 p.
Schmutz S, Cowx IG, Haidvogl G, Pont D (2007). Fish-based methods for assessing European running waters: a synthesis. Fisheries Management and Ecology 14:369-380.
Sheaves M, Johnston R, Connolly RM (2012). Fish assemblages as indicators of estuary ecosystem health. Wetland Ecology and Management 20:477-490.
Solomon-Wisdom GO, Olatunde AA (2014). An Assessment of Dry Season Fish Mortality and Water Quality of Selected Fish Ponds in Two Area Councils of the Federal Capital Territory, Nigeria. International Journal of Agriculture Innovations and Research 2(5):660-664.
Specziár A, Erős T (2020). Development of a fish-based index for the assessment of the ecological status of Lake Balaton in the absence of present day reference condition. Knowledge and Management of Aquatic Ecosystems 421:11.
van Zwieten PAM, Béné C, Kolding J, Brummett R, Valbo-Jørgensen J (2011). Review of tropical reservoirs and their fisheries – The cases of Lake Nasser, Lake Volta and Indo-Gangetic Basin reservoirs. FAO Fisheries and Aquaculture Technical Paper. No. 557. Rome, FAO. 148 p.
Vannote RL, Minshall GW, Cummins KW, Sedell JR, Cushing CE (1980). The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37:130-137.
Welcomme RL (2001). Inland fisheries; Ecology and Management. Published for the Food and Agriculture of the United Nations, by Blackwell Science 358 p.
Yelkouni M (2012). Gouvernance des ressources naturelles : un enjeu sociopolitique autant qu'écologique. Mémoire de maitrise de géographie Université de Ouagadougou 80 p.