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Strategy for the conservation and restoration of aquatic fauna diversity at the Ity mining site, west Cote d'ivoire

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Abstract

This study was carried out in order to participate in the conservation of the biodiversity of aquatic fauna and to develop a strategy for the conservation of fauna and flora in a mining environment. The study area is the Cavally River, precisely within the perimeter of the ITY gold mine in the ZOUAN-HOUNIEN department. Fish were sampled using a set of gillnets. Bathymetric surveys were carried out using an echo sounder. A Niskin bottle and a Van Veen bucket were used to sample the water and sediment respectively, prior to laboratory analysis. The inventory studies identified 76 species of fish, 19 species of amphibians and 10 species of shrimp. Some of these species are of conservation interest and merit special attention according to the IUCN (2023). Hydrological studies have shown the obstruction of the watercourse, the increase in suspended solids, the modification of the hydrological regime and the widening of the watercourse bed. Measurements of heavy metals such as arsenic, mercury and total cyanide showed traces of these metals in the sediments of the watercourse at values above the WHO guide value. In order to limit the loss of fish diversity, aquatic organism transfer activities were carried out. A fry production centre was built to produce species of conservation interest (*Coptodon walteri* and *Micralestes eburneensis*) and stock the Cavally river. Secondly, to supply the community with *Oreochromis niloticus* fry. At the end of each year, hydrobiological, hydrochemical and hydrological monitoring studies are carried out to guide the ITY mining company in its ecological monitoring of the Cavally river. This habitat, deeply disturbed by mining, is a danger for endemic species whose distribution is restricted. These species are of real conservation interest.

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Introduction

Freshwater habitats are among the most threatened ecosystems on the planet, with a projected extinction rate around five times higher than the average for terrestrial fauna.

Aquatic biodiversity is threatened by mining, which has intensified in recent years in our developing countries. In Ivory Coast, the authorities note an explosion in gold panning activity, with 1,098 sites in 2023, compared with 185 illegal gold panning sites on December 31, 2016, following the closure of 429 illegal sites in the country (CICG, 2024). Several rivers are impacted by this activity : the Cavally River (Zouan-hounien), the Bia River (Bianoua), the Bandama River (Bouaflé) and the Bagoé River (Tengrela).

Among aquatic resources, fish are highly vulnerable to pollution from the chemicals used in gold mining. Many development projects on rivers are launched without any real knowledge of the initial state of biodiversity, particularly aquatic fauna. This is the case of the Cavally river, with the planned construction of two hydroelectric dams, the Tiboto and Tahibli dams, and the expansion of gold panning activities.

The Cavally is one of the rivers whose aquatic fauna has been least studied in Ivory Coast. Furthermore, although a great deal of research has been carried out on the impact of agricultural and industrial activities on the diversity of aquatic fauna in Côte d'Ivoire, very little has been done on the impact of mining activities. The aim of this study was to determine the conservation status of the aquatic fauna and to monitor the hydrological and hydrochemical parameters of the river with a view to restoring its aquatic fauna.

Materials and methods

Study environment

The Cavally rises in Guinea, north of Mount Nimba, at an altitude of around 1,000 m, crosses western Côte d'Ivoire and flows into the Gulf of Guinea, south of Côte d'Ivoire at an altitude of 0 m. This cross-border river is 700 km long, with a catchment area covering 30,600 km² (Girard *et al.*, 1971; Brou *et al.*, 2017). Around 15,000 km² of its catchment area is in Côte d'Ivoire. In our study area, this river is located 400 m east of the Ity gold deposits and flows from north-east to south-west. In the Toulepleu-Ity sector, the river has a sinusoidal shape and crosses steep banks 5 to 10 m high.

In order to obtain a more comprehensive view of water quality in the study area, three sampling sectors were selected on the upper and middle reaches of the Cavally River, based on the intensity of anthropogenic pressures, habitat diversity, hydrological regime and canopy. The accessibility of the sectors to the sampling teams and equipment was also taken into account. Fourteen (14) stations were selected in our study area on the Cavally River (Fig. 1).

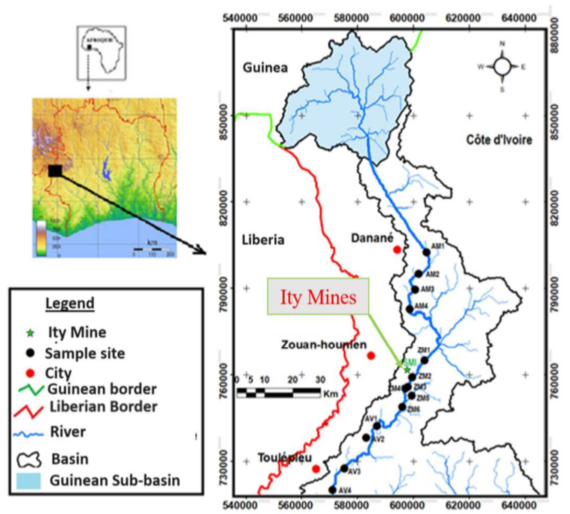

Fig. 1. Location of the study area and sampling stations on the Cavally River (Ivory Coast)

Aquatic fauna sampling

Fish

The fish caught came from both experimental and artisanal fisheries. A battery of 9 multi-filament nets with mesh sizes of 10, 15, 20, 25, 30, 35, 40, 45 and 50 mm was used for experimental fishing. For artisanal fishing, the gear used in this study consisted of monofilament gillnets, creels, dip nets and hawksbills.

Taxonomic identification was carried out in the field using the identification keys proposed by Paugy *et al.* (2003) and Sonnenberg and Busch (2009).

Conservation status was assessed using Froese and Pauly (2019), following an increasing extinction risk scale from Not Evaluated (NE) to Extinct (EX).

Shrimp

Two types of fishing were used in this study: experimental fishing and commercial fishing. Experimental fishing was carried out using a dip net, creels and water scooping. The net was actively dipped into the water and the bottom and surrounding area were visited by scraping, then it was withdrawn after a period (5 min). A pause is taken to collect and sort the specimens caught. For creel fishing, capture creels baited with fresh or pre-cooked cassava residue were used.

The gutting method consisted of temporarily emptying the water in the dry season at the level of small tributaries in order to harvest the prawns.

Commercial fishing involved buying the prawns from local fishermen. As with the previous method, the aim is to complete the inventory of the shrimp population.

Taxonomic identification was carried out following an examination of metric, meristic and morphological characteristics, and using the determination keys of Powell (1982), Monod (1966, 1980), Gooré Bi (1998) and Konan (2009).

Batrachofauna

Specimens were captured using capture boxes and a dip net. Captured specimens were transported in plastic aquariums. A Dictaphone was used to record the songs of the amphibians.

Amphibians were sampled opportunistically, during visual and acoustic surveys in various habitats in the study area. Sampling was carried out day and night using the standard techniques of Heyer *et al.* (1994) and Rödel and Ernst (2004). These study techniques included capturing specimens encountered during habitat surveys and searching for refugia (i.e. rocks, dead wood or under leaf litter). Amphibians were also sampled by acoustic monitoring (listening and identification based on songs) in the various habitat types. Species identification was based on recent keys and descriptions (Rödel and Branch, 2002 ; Rödel and Ernst, 2004 ; Channing *et al.*, 2004). In addition, the phylogenetic classification of Frost *et al.* (2006) was used in this study. Reference specimens were collected, photographed and preserved in 70% ethanol.

Hydrological parameters

Bathymetric surveys were carried out using a Lowrance, Elite 9 HDI (Hybrid Dual Imaging™) echo sounder with a depth error of less than 10 cm. Movement on the water was carried out using a speedboat. These bathymetric surveys were made both longitudinally and transversely. Recordings were made in both automatic and manual mode using the echo sounder. The bathymetric maps were produced using ArcGis software on the basis of corrected satellite images. The interpolation method used was IDW (Inverse Distance Weighting).

Hydrochemical parameters

pH, dissolved oxygen (mg/L), electrical conductivity (µS/cm), dissolved solids (mg/L), water and air temperature (°C) were measured using a multi-parameter (HQ40d). Water samples for cyanide and nutrient analysis were taken using a 1-litre Niskin bottle. Sediments were collected from the river Cavally using a Van Veen grab sampler.

Physico-chemical parameters were measured seasonally in situ between April 2015 and May 2017. At each sampling station, water temperature, conductivity, TDS, dissolved oxygen and pH were measured twice daily. Water samples for the determination of nutrient salts and cyanide were stored in 1,000 ml and 500 ml polyethylene bottles and then packed in a cool box at 4°C before being transported to the laboratory. Nitrate was determined in accordance with standard ISO 7890-3, December

1988, and orthophosphate in accordance with standard NF ISO 6878, April 2005. Heavy metals (mercury, arsenic) and total cyanide were determined by atomic absorption spectrometry.

Statistical processing

In this work, the absence of normality in the distribution of the data to be analysed led to the use of the non-parametric Kruskal-Wallis test to compare fish catches and physico-chemical parameters in the different parts of the Cavally river (upstream, mining zone and downstream) at the 0.05 significance level. All these statistical analyses were carried out using PAST 3.15 software (Hammer *et al.*, 2001).

Results

Inventory and conservation status of aquatic fauna

Fish

Based on the classification of the International Union for Conservation of Nature (IUCN), the fish species sampled in the Cavally River can be divided into six (06) groups. These groups are as follows: Data Deficient (DD), Not Evaluated (NE), Least Concern (LC), Near Threatened (NT), Endangered (EN) and Vulnerable (VU) (Fig. 2).

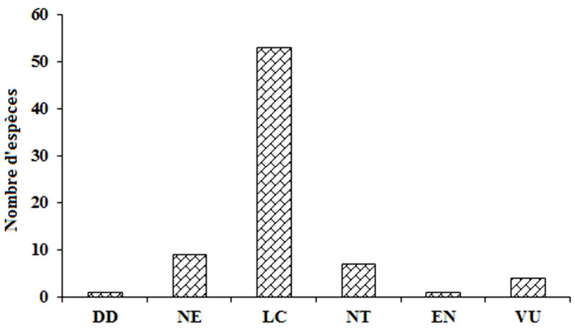

Fig. 2. Number of fish species by conservation status category throughout the surveyed area in the Cavally River.

Of a total of 74 species identified, 09 (12.16%) have not yet been assessed (NE) and one species (1.35%) is classified as Data Deficient (DD). Fifty-three (53) species are classified as species of minor concern. This category contains the majority of the species observed in this study, i.e. 71.62% of the species richness. Twelve species on the IUCN red list and of conservation interest were observed: 04 species (5.40%), including *Brycinus derhami*, *Epiplatys hildegardae*, *Scriptaphyosemion schmitti* and *Chromidotilapia cavalliensis*, were classified as vulnerable (VU); seven species (9.45%) were classified as Near Threatened (NT): *Marcusenius furcidens*, *Micralestes eburneensis*, *Raiamas nigeriensis*, *Labeobarbus parawaldroni*, *Enteromius bigornei*, *Malapterurus punctatus* and *Coptodon walteri* and 01 species namely *Chrysichthys teugelsi* is classified as Threatened (Endangered).

The near-threatened species inventoried are all almost present along the upstream-downstream gradient of the Cavally River sampled, with six (06) species upstream, five (05) species in the mining zone and seven (07) species in the downstream zone (Table 1).

Table 1. Number of fish species by conservation status category and sampling area in the Cavally River

	NE	DD	LC	NT	VU	EN
Upstream zone	8	1	52	6	3	1
Mining zone	7	0	39	5	1	0
Downstream zone	9	1	45	7	3	1

DD : Data Deficient ; EN : Threatened ; NE: Not Evaluated; LC: Least Concern; NT: Near Threatened; VU: Vulnerable.

Analysis of the data on the specific richness of fish inventoried in the Cavally River showed that there was significant variation (Kruskall-Wallis ; $p < 0.05$) in the specific richness according to the capture zones. The variation in species richness according to the sampling sectors did not show any significant difference between the upstream and downstream sectors (Mann-Whitney test ; $p > 0.05$). However, a significant difference was observed between these two sectors and the mining zone (Mann-Whitney test ; $p < 0.05$).

Shrimp

The species richness of the shrimp population in the Cavally River is shown in Table 2. The species richness is relatively higher upstream (7 species) and downstream (8 species). The mining area proved to be very poor in species (4 species).

Table 2. List of shrimp inventoried and their conservation status by sampling area in the River Cavally

Families	Types	Species	Sampling stations			Conservation
			Upstream	Mining zone	Aval	IUCN status
Atyidae	Caridina	*Caridina* sp.			+	DD
		Macrobrachium dux (Lenz, 1910)	+	+	+	LC
		Macrobrachium felicinum Holthuis, 1949	+			DD
		Macrobrachium macrobrachion (Herklots, 1851)	+	+	+	LC
		Macrobrachium thysi (Powell, 1980)		+		DD
Palaemonidae	Macrobrachium	*Macrobrachium vollenhovenii* (Herklots, 1857)	+	+	+	LC
		Macrobrachium sp1	+		+	DD
		Macrobrachium sp2	+		+	DD
		Macrobrachium sp3	+		+	DD
		Macrobrachium sp4			+	DD
		Total				
2	2	10	7	4	8	

Table 3. Composition of the amphibian population found in the River Cavally in the SMI extension zone

Taxon	Species distribution in Ivory Coast	Species distribution in Africa	Conservation status (IUCN)
Phrynobatrachidae			
Phrynobatrachus latifrons	North-South	Senegal-Cameroon	PM
Phrynobatrachus fraterculus *	West	Guinea - Ivory Coast	PM
Phrynobatrachus calcaratus	Centre-West-North	Senegal-R. Central African Republic	PM
Phrynobatrachus plicatus	Centre-West	Guinea-Nigeria	PM
Phrynobatrachus sp.	-	-	-
Arthroleptidae			
Arthroleptis sp.	-	-	-
Hyperoliidae			
Hyperolius concolor	North-South	Sierre Leone-Cameroon	PM
Hyperolius gutttulatus	North-South	Sierra Leone-Gabon	PM
Afrixalus dorsalis	North-South	Sierra Leone-Angola	PM
Leptopelis spiritusnoctis *	West-Centre-South	Sierra Leone-Nigeria	PM
Ptychadenidae			
Ptychadena mascareniensis	Centre-West-South	South Africa Sahara-Madagascar	PM
Ptychadena pumilio	North-South	Ethiopia-South Sahara Africa	PM
Ptychadena bibrioni	North-South	Mauritania-RD Congo	PM
Ptychadena tournieri *	Centre, North, West	Senegal-Benin	PM
Dicroglossidae			
Hoplobatrachus occipitalis	North-South	South Africa Sahara	PM
Pipidae			
Xenopus tropicalis	North-South	Senegal-Cameroon	PM
Pyxicephalidae			
Aubria subsigillata	West and South	Guinea-Gabon	PM
Bufonidae			
Amietophrynus regularis	North-South	All of Africa	PM
Amietophrynus maculatus	North-South	South Africa Sahara	PM

PM = of minor concern, * = endemic species

Of a total of 10 species identified, 07 (70%) are classified as Data Deficient (DD) and 03 species (30%) are classified as species of Least Concern. The Kruskal-Wallis test shows that the species richness of the mining zone differs significantly from that of the upstream and downstream zones ($p < 0.05$).

Batrachofauna

The inventory of batrachofauna carried out during the present study identified 19 species of Anuran amphibians divided into 10 genera and 8 families (Table 3). More than 66% of the species recorded during this period have a wide distribution in Côte d'Ivoire from the south to the north (Lamotte, 1967;

Rödel, 2000; Rödel, 2003; Rödel and Ernst, 2003; Rödel and Ernst, 2004; Rödel *et al.*, 2004), with the exception of three (03) species. *Phrynobatrachus calcaratus* was found in central, western and northern Côte d'Ivoire (Rödel and Ernst, 2004; Rödel *et al.*, 2004). *Aubria subsigillata* has been recorded in the west and south (Rödel and Ernst, 2004; Assemian *et al.*, 2006). The species *Phrynobatrachus fraterculus*, *Leptopelis spiritusnoctis* and *Ptychadena tournieri* are endemic to the Upper Guinea forest block (Rödel and Ernst, 2004).

Hydrological parameters

Morphology of the Cavally River within the SMI operating perimeter

The bathymetric map shows that the study area has a very uneven morphology. The maximum depth of the minor bed in the study area is 7.76 m (Fig. 3). The average depth is 3.6 m, with a standard deviation of 1 m.

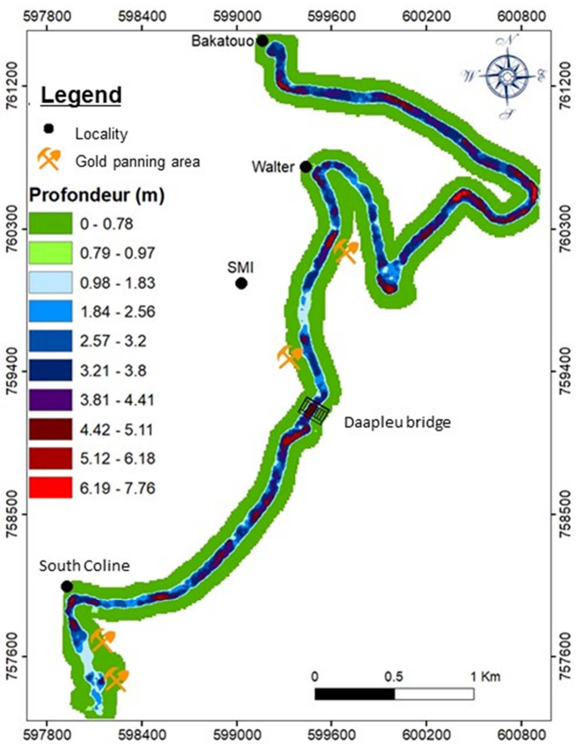

Fig. 3. Bathymetry of the portion of the Cavally River within the SMI exploitation perimeter (Kouassi *et al.*, 2019)

On the right bank of the canal, erosion and encroachment can be observed. Fine sediment is deposited on the right bank, while some of the material used to build the protective dyke is transported away.

Spatial variation in physico-chemical parameters

Physico-chemical parameters varied significantly from upstream to downstream in the upper reaches of the River Cavally in the Ity area.

The highest temperature was observed in the mining zone (28.7°C). The pH in the study area ranged from 6.31 (mining area) to 11.01 (upstream). The highest mean TDS was recorded in the mining zone (23.82 ± 1.5 mg/L). The mining zone (43.92 ± 6.6 µS/cm) had the highest mean conductivity value and the lowest value was measured upstream (41.23 ± 8.6 µS/cm). The highest average dissolved oxygen level was recorded upstream (8.59 ± 0.69 mg/L). The lowest average value for this parameter was recorded in the mining zone (7.31 ± 0.63 mg/L).

Water transparency values ranged from 20 to 112 cm, with an average value of 75.95 cm. The highest value was measured upstream (91.76 cm). It was lower in the mining zone (47.47 cm).

Spatial variation in heavy metals, total cyanide and nutrient salts The average mercury content was 0.00263 mg/Kg. The highest content (0.00575 mg/Kg) was obtained in the mining zone and the lowest (0.000793 mg/Kg) upstream.

The average arsenic content was 11.84 mg/Kg. The level of 30.9 mg/Kg obtained in the mining area is the highest and the level of 1.42 mg/kg obtained upstream is the lowest.

Cyanide measurements revealed that the water in the study area contained levels of less than 0.001 mg/L.

The average nitrate value for all the areas of the river Cavally visited was 1.12 mg/L. The highest value was measured upstream (1.35 mg/L) and the lowest value (0.98 mg/L) was measured in the mining area.

The average orthophosphate value for all the areas of the Cavally River visited was 0.10 mg/L. The highest orthophosphate value was measured in the mining zone and downstream (0.11 mg/L each). The lowest orthophosphate value (0.08 mg/L) was measured upstream.

Discussion

The typology of fish species observed in the River Cavally during this study according to the classification of the International Union for Conservation of Nature (IUCN) made it possible to notify the presence of species with a special status. These include 16% of species of conservation interest (IUCN, 2019). These species, with their restricted geographical distribution and declining populations, are suffering from the degradation of the ecological quality of their environment (IUCN, 2018). This high percentage of threatened and endangered species can be explained mainly by the overexploitation of populations, water pollution, changes in hydrological regimes, the destruction, fragmentation and homogenisation of habitats and the increased introduction of invasive species (Dudgeon *et al.*, 2006). In addition, water pollution caused by intensive gold panning in and around the riverbed could be a source of species loss, or even the disappearance of certain species (Cheung *et al.*, 2005 ; Kantoussan, 2007 ; IUCN, 2018). In addition, it is recognised that the high pressure of human activities on watersheds and the aquatic environment are among the main threats to aquatic biodiversity (Gourène *et al.*, 1999; Koné, 2000; Ouattara, 2000; Kouamelan *et al.*, 2003; Lévêque and Paugy, 2006; Le Roux *et al.*, 2008). Ettien (2010) and Kouassi *et al.* (2017) have reported the presence of significant gold panning activities in the riverbed and in the vicinity of the River Cavally. Several studies have also shown that certain chemicals act in a similar way to female hormones and can have an influence on the fish population (Niamien-Ebrottié *et al.*, 2008).

In our study area, we identified ten shrimp species, including five valid species (*Macrobrachium vollenhovenii*, *M. macrobrachion*, *M. felicinum*, *M. thysi* and *M. dux*) and five invalid species (*Caridina* sp., *Macrobrachium* sp1, *M.* sp2, *M.* sp3 and *M.* sp4). These results are similar to those of Kouamé (2019) in the upper reaches of the Cavally River.

Specifically, the number of valid species in the present study is much lower than that reported by N'Zi (2007) and Djiriéoulou (2017) (13 species) and Konan (2009) (9 species). The difference between our results and those of previous work could be explained by the diversity of habitats visited.

The mining area has a relatively low diversity (4 species). This low species richness is certainly due to mining activity. A similar observation was made by Kouamélan *et al.* (2003), N'Zi *et al.* (2008), Yao *et al.* (2005) and Aboua (2012) during work carried out on the Boubo, Comoé and Bandama rivers respectively. For these authors, human activity is contributing to the increased loss of diversity in these rivers.

The presence of diversified habitats could explain the strong presence of different species of frog in the areas surveyed. In fact, the study area has extensive grassland formations and the presence of several ponds. These environments are favourable for the reproduction of the vast majority of amphibian species associated with wetlands (Barbault, 1972; Vallan, 2000). The relatively good conservation of the environment explains the high presence of species characteristic of primary and/or secondary forests (*Phrynobatrachus plicatus*, *P. calcaratus*, *P. fraterculus* and *Arthroleptis* sp.). Although these species are not threatened according to the IUCN, their endemic status means that measures must be taken to conserve their habitat in order to avoid threatening them.

The bathymetric map shows shoals caused by gold panning activities in several parts of the river. According to Doffou (2020), intensive and uncontrolled dredging in the riverbed leads to the establishment of shoals and depressions, which modify the depth and water conditions.

The reduction in draught in some places reduces the number of spawning grounds. The destruction of vegetation on the banks modifies the canopy. The obstruction of the watercourse by uprooted trees on the banks modifies the current. Illegal gold-panning increases suspended solids, making the water turbid and unfit for drinking. All these actions contribute to the loss of aquatic biodiversity.

The physico-chemical parameters varied significantly from one zone to another during our study, with very marked values in the mining zone. This variation could be explained by the profound changes undergone by the watercourse as a result of the action of dredgers and mudflows associated with gold panning. Acid mine drainage due to the leaching of rocks as a result of mining and gold panning would also justify the very high values of these parameters in the mining area. This activity results in a high concentration of solids and suspended matter, making the water in the mining area and downstream more turbid and unfit for consumption. According to Ouedraogo (2010), gold panning contributes to soil and water pollution through used oils from crusher engines and motor pumps, and chemical products, leading to a loss of biodiversity. For nitrate and orthophosphate, the results of this study are well below the threshold values (nitrate < 50 mg/L ; orthophosphate < 5 mg/L) defined by WHO (2008).

In the mining area, mercury values are above the WHO guide value (Hg < 0.001 mg/Kg). As for arsenic, all the values obtained (1.42 mg/Kg and 30.9 mg/Kg) are well above the WHO guide value for surface water (< 0.01 mg/Kg). These relatively high values in the river Cavally are justified by the fact that the analyses were carried out on sediments taken from the bed of the watercourse and not from the water column. Since the 1940s and 1950s, there has been intense gold panning activity in the study area (Papon, 1973). Since the mining industry moved into the area in the 1990s, clandestine gold panning has developed using chemical mining methods (Ettien, 2005). Total cyanide levels are well below WHO standards (0.7 mg/l). Nevertheless, there is a risk of cyanide pollution due to the use of this product in gold extraction by the mining industry in the study area.

Conclusion

The Cavally River in the Ity mine area contains several aquatic species of conservation interest. Anthropogenic pressures linked to gold panning and mining are considerably modifying the physico-chemical parameters of this watercourse.

According to the study, the waters of the River Cavally as a whole are of low alkaninity. However, the mining zone and the downstream zone were found to be slightly acidic. High conductivity was found in the mining area and downstream, where transparency and dissolved oxygen levels were low. With regard to nutrient salts, the nitrate and orthophosphate values recorded during the course of this work were low. Mercury (Hg) and arsenic values are relatively high in this study on the river Cavally. For total cyanides, the values recorded in the Cavally appeared to be below the detection threshold. The imbalance in physicochemical and hydromorphological parameters has a negative impact on the diversity of aquatic fauna. All these threats could lead to an irreversible loss of aquatic biodiversity if monitoring measures are not put in place. Thus, the transfer of aquatic organisms from impacted areas to more favourable areas and the production of fry of species of conservation interest would be an alternative to restoring aquatic fauna in the river Cavally.

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References

Aboua BRD. 2012. Développement d'un indice d'intégrité biotique piscicole pour la préservation de la biodiversité du fleuve Bandama. Thèse de Doctorat, UFR Biosciences, Université Félix Houphouët Boigny, Abidjan, Côte d'Ivoire, 227p.

Assemian NE, Kouamé NG, Tohé B, Gourène G, Rödel MO. 2006. The anurans of the Banco National Park, Côte d'Ivoire, a threatened West African rainforest. Salamandra **42**, 41–51.

Barbault R. 1992. Ecologie des populations et des peuplements. Des théories aux faits. Paris, Massons, 200p.

Brou LA, Kouassi KL, Konan KS, Kouadio ZA, Konan KF, Kamagaté B. 2017. Rain-flow modeling using a multi-layer artificial neural network on the watershed of the Cavally River (Côte d'Ivoire). Journal of Water Resource and Protection **9**(12), 1403–1413.

Channing A, Sinclair ARE, Mduma DAR, Moyer D, Kreulen DA. 2004. Serengeti amphibians: Distribution and monitoring baseline. Journal of Herpetology **53**(2), 163–181.

Cheung WWL, Pitcher TJ, Pauly D. 2005. A fuzzy logic expert system to estimate intrinsic extinction vulnerabilities of marine fishes to fishing. Biological Conservation **124**, 97–111.

CICG. 2024. Côte d'Ivoire : Lutte contre l'orpaillage illégal : les efforts significatifs du gouvernement pour éradiquer le fléau. Consulté le 04/07/2024. https://news.abidjan.net/articles/734049/lutte-contre-lorpaillage-illegal-les-efforts-significatifs-du-gouvernement-pour-eradiquer-le-fleau.

Djiriéoulou KC. 2017. Peuplements des crevettes des hydrosystèmes de marais et fluviolagunaires du Sud-Est de la Côte d'Ivoire : Diversité, structure et croissance des populations. Thèse de Doctorat, Université Félix Houphouët-Boigny, Abidjan, Côte d'Ivoire, 150p.

Doffou RJO. 2020. Influence de l'orpaillage sur la diversité du peuplement ichtyologique et l'écologie alimentaire d'une espèce endémique (*Micralestes eburneensis* Daget, 1964) dans le fleuve Cavally (Ouest de la Côte d'Ivoire). Thèse unique de Doctorat, Université Jean Lorougnon Guédé, Daloa, Côte d'Ivoire, 190p.

Dudgeon D, Arthington AH, Gessner MO, Kawabata ZI, Knowler DJ, Lévêque C, Naiman RJ, Prieur-Richard AH, Soto D, Stiassny MLJ. 2006. Freshwater biodiversity: Importance, threats, status, and conservation challenges. Biological Reviews **81**, 163–182.

Ettien DZ. 2005. Étude d'évaluation de l'impact des exploitations minières sur l'environnement et les populations en Afrique de l'Ouest : Cas de la mine d'or d'Ity dans la région semi-montagneuse de l'Ouest de la Côte d'Ivoire. Apport du système d'informations géographiques (SIG) et de la télédétection. Thèse de Doctorat, UFR STRM, Université Félix Houphouët Boigny, Abidjan, Côte d'Ivoire, 163p.

Ettien DZ. 2010. Exploitation industrielle des gisements d'or et dynamique spatiale du terroir d'Ity dans l'Ouest de la Côte d'Ivoire. Une étude à base de la télédétection. Revue de Géographie du laboratoire Leïdi **8**, 169–183.

Froese R, Pauly D. 2019. FishBase (Eds.). World Wide Web electronic publication. http://www.fishbase.org, version (02/2019). Consultée le 15 mars 2019.

Girard G, Sircoulon J, Touchebeuf P, Guillaumet LJ, Avenard MJ, Eldln M, Adjanohoun E, Perraud A. 1971. Le milieu naturel de la Côte d'Ivoire. Mémoires ORSTOM, Paris, France **50**, 401p.

Gooré Bi G. 1998. Contribution à l'étude des crevettes d'eau douce de Côte d'Ivoire : Systématique, biologie et analyse socioéconomique de la pêche de *Macrobrachium vollenhovenii* (Herklots, 1857) et de *M. macrobrachion* (Herklots, 1851) (Crustacea Decapoda, Palaemonidae) du bassin de la Bia. Thèse de Doctorat 3e cycle, Université de Cocody-Abidjan, Côte d'Ivoire, 145p.

Gourène G, Teugels GG, Hugueny B, Thys Van Den Audenaerde DFE. 1999. Évaluation de la diversité ichtyologique d'un bassin ouest africain après la construction d'un barrage. Cybium **23**(2), 147–160.

Hammer O, Harper DAT, Ryan PD. 2001. Paleontological Statistics Software Package for Education and Data Analysis. Paleontologica Electronica **4**(1), 1–9.

Heyer WR, Donnelly MA, McDiarmid RW, Hayek LAC, Froster MS. 1994. Measuring and monitoring biological diversity: Standard methods for amphibians. Smithsonian Institution Press, Washington and London, 364p.

Kantoussan J. 2007. Impacts de la pression de pêche sur l'organisation des peuplements de poissons : Application aux retenues artificielles de Sélingué et de Manantali, Mali, Afrique de l'Ouest. Thèse de doctorat, Université Agrocampus Rennes, Rennes, France, 170p.

Konan KM. 2009. Diversité morphologique et génétique des crevettes des genres *Atya* Leach, 1816 et *Macrobrachium* Bate, 1868 de Côte d'Ivoire. Thèse de Doctorat, Université d'Abobo-Adjamé, Abidjan, Côte d'Ivoire, 171p.

Konan KM. 2009. Diversité morphologique et génétique des crevettes des genres *Atya* Leach, 1816 et *Macrobrachium* Bate, 1868 de Côte d'Ivoire. Thèse de Doctorat, Université d'Abobo-Adjamé, Abidjan, Côte d'Ivoire, 171p.

Koné T. 2000. Régime alimentaire et reproduction d'un *Tilapia* lagunaire (*Sarotherodon melanotheron* Rüppell, 1852) dans la rivière Bia et le lac de barrage d'Ayamé (Côte d'Ivoire). Thèse de Doctorat, Katholieke Universiteit Leuven, Belgique, 253p.

Kouamé T. 2019. Peuplement des crevettes d'eau douce et régime alimentaire de trois espèces du genre *Macrobrachium* (*M. macrobrachion* (Herklots, 1851), *M. vollenhovenii* (Herklots, 1857) et *M. dux* (Lenz, 1910)) du cours supérieur du fleuve Cavally (Côte d'Ivoire) dans un environnement d'exploitation minière. Thèse de Doctorat, UFR Biosciences, Université Cocody-Abidjan, Abidjan, Côte d'Ivoire, 177p.

Kouamélan EP, Teugels GG, N'Douba V, Gooré Bi G, Koné T. 2003. Fish diversity and its relationship with environmental variables in West African basin. Hydrobiologia **505**, 139–146.

Kouassi KL, Konan KF, Konan KS. 2017. État des lieux du fleuve Cavally dans le département de Zouan-Hounien (Ouest Côte d'Ivoire): Aperçu de la géomorphologie, l'hydrologie, l'hydrochimie et l'hydrobiologie. Rapport d'étude – SMI-ENDEAVOR MINING / UJLOG, Daloa, Côte d'Ivoire, 58p.

Kouassi KL, Konan KF, Konan KS. 2019. État des lieux du fleuve Cavally dans le département de Zouan-Hounien (Ouest Côte d'Ivoire): Aperçu de la géomorphologie, l'hydrologie, l'hydrochimie et l'hydrobiologie. Rapport d'étude – SMI-ENDEAVOR MINING / UJLOG, Daloa, Côte d'Ivoire, 57p.

Lamotte M. 1967. Les batraciens de la région de Gpakobo (Côte d'Ivoire). Mémoires de l'Institut fondamental d'Afrique noire, Série A **29**, 218–294.

Le Roux X, Barbault R, Baudry J, Burel F, Doussan I, Garnier E, Herzog F, Lavorel S, Lifran R, Roger-Estrade J, Sarthou JP, Trommetter M. 2008. Agriculture et biodiversité: Valoriser les synergies. Expertise scientifique collective, synthèse du rapport. INRA, France, 117p.

Lévêque C, Paugy D. 2006. Impact des activités humaines. In: Les poissons des eaux continentales africaines: Diversité, écologie, utilisation par l'homme. Édition IRD, Paris, 365–383.

Monod T. 1966. Crevettes et crabes des côtes occidentales de l'Afrique. Réunion des spécialistes C. S. A sur les crustacés, Zanzibar, 1964. Mémoires de l'Institut fondamental d'Afrique noire, Dakar, Sénégal, 106–234.

Monod T. 1980. Décapodes. In: Durand JR, Lévêque C (éds.). Flore et faune aquatiques de l'Afrique sahélo-soudanienne. ORSTOM, Paris, France **44**(1), 369–389.

N'Zi KG, Gooré BG, Kouamélan EP, Koné T, N'Douba V, Ollivier F. 2008. Influence des facteurs environnementaux sur la répartition spatiale des crevettes dans un petit bassin ouest africain: rivière Boubo (Côte d'Ivoire). Tropicultura **26**(1), 17–23.

N'Zi KG. 2007. Diversité biologique des peuplements de crevettes d'eaux douces de Côte d'Ivoire en relations avec les variables environnementales du milieu. Thèse de Doctorat, Université de Cocody, Abidjan, Côte d'Ivoire, 178p.

Niamien-Ebrottié EJ, Konan KF, Gnagne T, Ouattara A, Ouattara M, Gourène G. 2008. Étude diagnostique de l'état de pollution du système fluvio-lagunaire Aby-Bia-Tanoé (Sud-Est, Côte d'Ivoire). Sud Sciences and Technologies **16**, 5–13.

OMS. 2008. Guidelines for Drinking-water Quality. Third edition, incorporating the first and second Addenda, Recommendations, Geneva, Volume **1**, 515p.

Ouattara M. 2000. Stratégies de reproduction et réactions aux pressions de l'environnement chez le poisson africain *Mormyrops anguilloides* et *Marcusenius ussheri* (Mormyridae), *Schilbe mandibularis* et *Schilbe intermedius* (Schilbeidae). Thèse de Doctorat, UFR des Sciences et Gestion de l'Environnement, Université d'Abobo-Adjamé, Abidjan, Côte d'Ivoire, 256p.

Ouédraogo AH. 2010. L'impact de l'exploitation artisanale de l'or (orpaillage) sur la santé et l'environnement : Cas de l'utilisation du mercure dans l'exploitation artisanale de l'or et l'évaluation des impacts sur la santé et l'environnement au Burkina Faso. Mediaterre. Consulté le 05-08-2019. Available at: https://www.mediaterre.org/membres/Aboubakar.

Papon A. 1973. Géologie et minéralisation du Sud-Ouest de la Côte d'Ivoire : Synthèse des travaux de l'opération SASCA 1962-1968. Mémoire du BRGM **80**, 285p.

Paugy D, Lévêque C, Teugels GG. 2003. Faune des poissons d'eaux douces et saumâtres de l'Afrique de l'Ouest. Tome 1. IRD (Paris), MNHN (Paris), MRAC (Tervuren), 457p.

Powell CB. 1982. Fresh and brackish water shrimps of economic importance in the Niger Delta. University of Port Harcourt. Presented at the second conference of the Fisheries Society of Nigeria held at Calabar, 24–27 January 1992, 1–45.

Rödel MO, Bangoura MA, Böhme W. 2004. The amphibians of southeastern Republic of Guinea (Amphibia: Gymnophiona, Anura). Herpetozoa **17**, 99–118.

Rödel MO, Branch WR. 2002. Herpetological survey of the Haute Dodo and Cavally forests, western Ivory Coast, Part I: Amphibians. Salamandra **38**, 245–268.

Rödel MO, Ernst R. 2003. The amphibians of Marahoué and Mont Péko National Parks, Ivory Coast. Herpetozoa **16**, 23–39.

Rödel MO, Ernst R. 2004. Measuring and monitoring amphibian diversity in tropical forests. I. An evaluation of methods with recommendations for standardization. Ecotropica **10**, 1–14.

Rödel MO. 2000a. Herpetofauna of West Africa, Vol. I: Amphibians of the West African savanna. Edition Chimaira, Frankfurt/M., 335p.

Rödel MO. 2000b. Les communautés d'amphibiens dans le Parc National de Taï, Côte d'Ivoire. Les anoures comme bio-indicateurs de l'état des habitats. In: Girardin O, Koné I, Tano Y (eds.), État des recherches en cours dans le Parc National de Taï (PNT). Sempervira, Rapport du Centre Suisse de la Recherche Scientifique, Abidjan **9**, 108–113.

Rödel MO. 2003. The amphibians of Mont Sangbé National Park, Ivory Coast. Salamandra **39**, 91–110.

Sonnenberg R, Busch E. 2009. Description of a new genus and two new species of killifish (Cyprinodontiformes: Nothobranchiidae) from West Africa, with a discussion of the taxonomic status of *Aphyosemion maeseni* Poll, 1941. Zootaxa **2294**, 1–22.

UICN. 2018. IUCN Red List of Threatened Species. Union Internationale de la Conservation de la Nature (IUCN). Version 2018-2. Available at: http://www.iucnredlist.org. Consulted on 16 March 2018.

UICN. 2019. IUCN Red List of Threatened Species. Union Internationale de la Conservation de la Nature (IUCN). Version 2019.1. Available at: http://www.iucnredlist.org. Consulted on 12 May 2019.

Vallan D. 2000. Influence of forest fragmentation on amphibian diversity in the nature of Ambohitantely highland Madagascar. Biological Conservation **96**, 31–43.

Yao SS, Kouamélan EP, Koné T, N'Douba V, Gooré Bi G, Ollevier F, Thys Van Den Audenaerde DFE. 2005. Fish communities along environmental gradients within the Comoé River basin, Côte d'Ivoire. African Journal of Aquatic Science **30**(2), 185–194.