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Study of the Biological Quality of the Water in the Manantali Dam Reservoir: Analysis of the Fish Fauna and Plankton Communities

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Abstract

The aim of this study of the Manantali dam reservoir is to investigate the biological quality of the water through inventories and analysis of the ichthyofauna and planktonic communities (zooplankton and phytoplankton). Inventories of ichthyofauna and plankton communities were carried out quarterly from 2003 to 2022. The fish populations studied on the basis of bioindicators (species richness, diversity index, equitability index, diversification index) identified 29 species belonging to 10 families. The Cichlidae family is the most represented, while the Schilbeidae and Tetraodontioae families are less represented in terms of number of species. The species *Hydrocynus forskalii* and *Brycinus* nurse with relative abundances of 40.12% and 21.4% respectively, both from the family Alestidae, are the most abundant. The species *H. forskalii* has a frequency of occurrence of 100%. The specific diversity index of 2.9 and the equitability index of 0.6 show an average diversity of fish species. The diversification index of 2.9 indicates a theoretical number of habitats of 2 to 3. The planktonic community is made up of zooplankton and phytoplankton. The inventory of zooplankton shows the presence of 28 zooplankton species belonging to 9 families of the three zooplankton groups Rotifera, Cladocera and Copepoda. Analysis of the frequencies of occurrence of the various taxa showed that the characteristic species of Lake Manantali are the omnipresent rotifers *Keratella cochlearis*, *Keratella quadrata* and *Trichocerca chattoni*. For phytoplankton, the inventories carried out show the presence of 65 species belonging to 5 families (Chlorophycees, Diatomees, Dinophycees, Chrysophycees and Cyanophycees). An analysis of the frequency of occurrence of the various taxa shows that the characteristic species of Lake Manantali are Chlorophycees, with 7 species: *Desmidium baileyi*, *Micrasterias alata*, *Sphaerocystis schroeteri*, *Spondylosium* sp., *Staurastrum heimii*, *Staurastrum subancho-*

ra, *Staurodesmus wandae*; Diatoms, with one species: *Navicula* sp. and Cyanophycees, with one species: *Microcystis aeruginosa*.

Keywords

Inventory, Fish, Zooplankton, Phytoplankton, Diversity, Manantali

1. Introduction

At the heart of our lives, water is a natural resource with multiple facets, playing the role of habitat, food, means of production, transport and commodity. Its multifunctional and multidimensional nature makes it an essential pillar of our society. What's more, it is linked to other natural resources (soil, forest, biodiversity, etc.) and different interest groups use it to meet their needs. However, the combination of sustained demographic growth, increasing urbanization and advances in industrialization is leading to a growing demand for water. Ecosystems, which produce and regenerate this resource, are under threat from pollution and climate change, making water a source of competition and conflict [1].

Aquatic ecosystems are home to great biological diversity. Studying this biological diversity is important for understanding how these environments function, and more specifically intra- and interspecific interactions [2].

For the countries of West Africa, the drop in rainfall and the long, devastating drought of the 1970s represent one of the greatest extreme climate change events in the world [3].

As a result, in March 1972, Mali, Mauritania and Senegal set up the Organisation for the Development of the Senegal River (OMVS) to deal with the consequences of these years of drought and launched an ambitious program of investment in water control infrastructure on the Senegal River. This program has a threefold objective: to regulate the river's flow and produce energy; to make the river navigable from Kayes in Mali to its mouth at Saint Louis in Senegal; and to promote agricultural development in the three countries. The Manantali dam was built in 1988 to regulate the level of the river [4].

The aim of this study is to characterize changes in the fish fauna and plankton communities (phytoplankton, zooplankton) in the Manantali dam reservoir between 2003 and 2022.

2. Material and Methods

2.1. Site Presentation

The Senegal River basin extends over four countries. Its surface area is unevenly distributed between the different member countries: 22% in Senegal (northern and eastern regions), 30% in Mauritania (southern region), 38% in Mali (western part), 10% in Guinea (Fouta Djalon Highlands) [5]. It is made up of 7 sub-basins. The Manantali dam is located in sub-basin 1 (**Figure 1**).

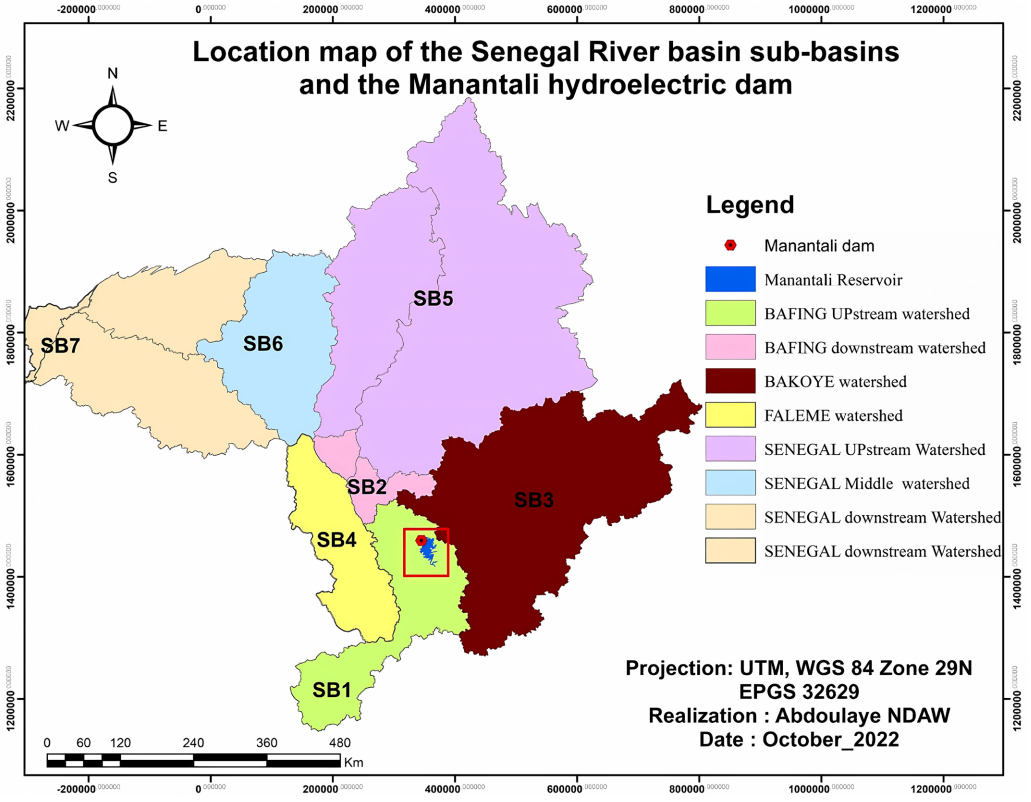

Figure 1. Map showing the location of the Senegal River sub-basins and the Manantali hydroelectric dam.

The multi-purpose Manantali dam, commissioned in 1988, is located on the Bafing River in Mali, and has a total storage capacity of 11.30 km^3. The dam has a hydroelectric power station, equipped with five units with a total capacity of 200 MW, and was commissioned between 2001 and 2002. As well as generating power, the dam is used to irrigate farmland and for navigation. The dam has a total crest length of around 1490 m and consists of a concrete structure housing the hydraulic works (spillway, bottom outlet, damping basin and water intakes) and two side dykes.

2.2. Sampling Strategy

Sampling was carried out in the Manantali reservoir at 3 limnological measurement stations marked by beacons. These are stations 1, 3 and 4. Scientific fishing was carried out at point 1 where the nets were set (**Figure 2**).

Sampling of ichthyofauna and plankton communities has been carried out since 2003, with samples taken every quarter [6]. For reasons of data availability, this study is based on data collected between 2003 and 2022.

Regarding to ichthyological fauna, scientific fishing was carried out over two nights using 10 gill, multifilament and monofilament nets. When the dam was impounded, scientific fishing was carried out at stations 1, 3 and 4, as well as at point 1 where the nets were set. It was found that the data in the samples collected in the different fishing zones were similar. It was therefore decided to take all the samples at point 1 where the net was set (**Figure 2**).

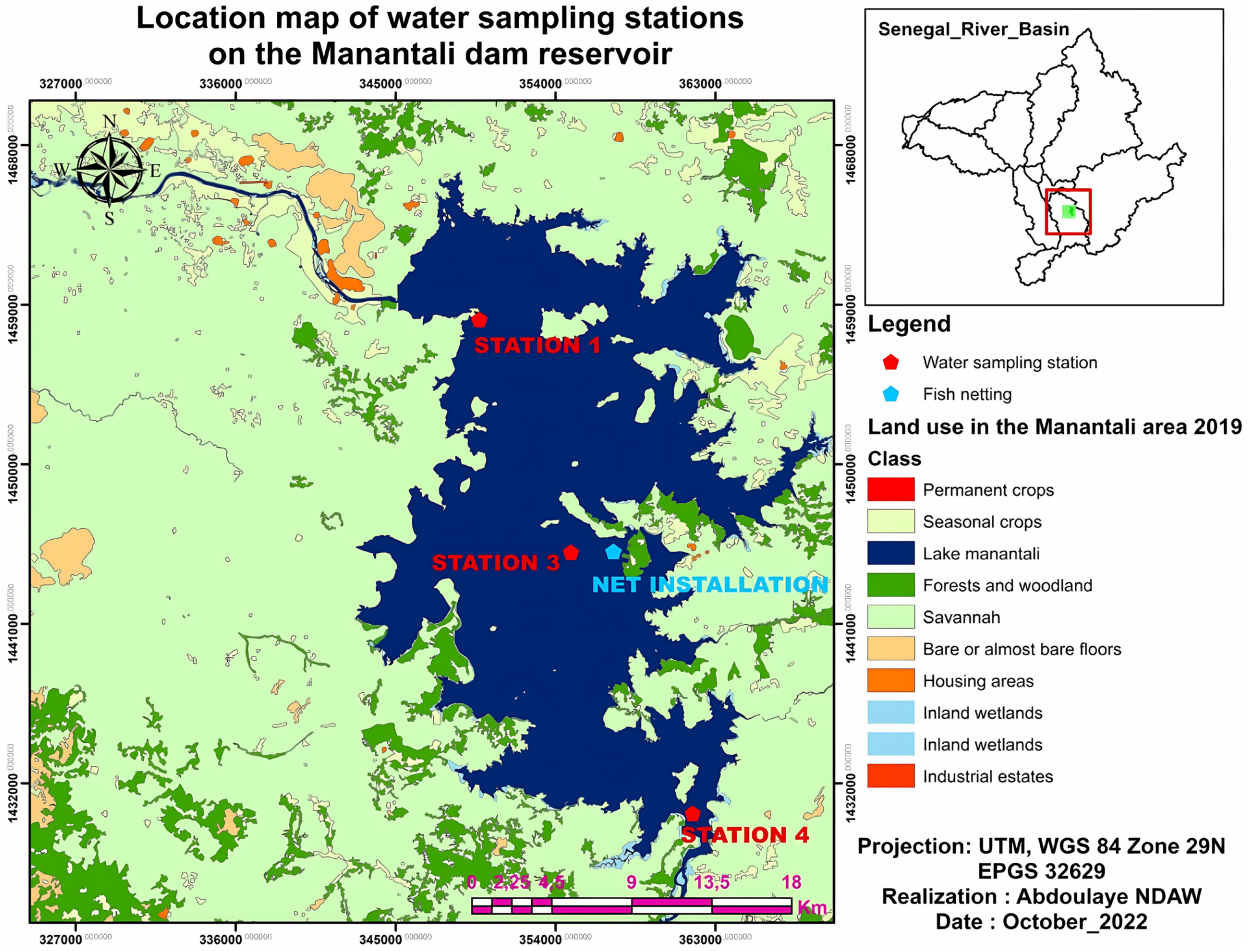

Figure 2. Map of stations and netting area.

Phytoplankton samples were taken using a 30 µm plankton net, while zooplankton samples were taken using 55 µm plankton nets. These samples were taken at the various stations (1, 3 and 4) based on water transparency. The sampling range varies from 2 to 20 m depth.

2.3. Fish Population Diversity Index

Indices are quantities of information about the structure of the stand from which the sample comes and about the way in which individuals are distributed between different species. Any variation in diversity indices relating to samples taken from the same stand over time therefore reflects changes in the structure of the stand and makes it possible to monitor its overall evolution over a certain period or during a cycle of specified duration [7].

The indices used to assess the fish population are species richness (S), specific and relative abundance, percentage of occurrence (F), as well as Shannon and Weaver's (1964) specific diversity index (H') [8] and Piélou's (1966) equitability index (E) [9].

1) Species richness (S) expresses the number of species found in the catches.

2) The specific abundance corresponds to the number of specimens of a spe-

cies in the catches.

3) Relative abundance expresses the percentage ratio of the number of a given species to the total number of fish caught.

4) Percentage of occurrence (F) is the ratio, expressed as a percentage, of the number of catches of a given species (F_i) to the total number of catches (F_t):

$$F = \left(\frac{F_i}{F_t}\right) \times 100$$

Depending on the value of F, the species is said to be constant if $F \geq 50\%$, accessory when $25\% \leq F \leq 50\%$ and accidental when $F < 25\%$ [10].

5) Shannon and Weaver's (1963) diversity index (H') measures specific diversity and is expressed as follows:

$$H' = -\sum_{i=1}^{s}\left(\frac{n_i}{N}\right) \times \log_2\left(\frac{n_i}{N}\right)$$

with:

S: total number of species present; n_i: number of species i in the sample; N: total number of species.

H' varies between 0, in the case where the stand consists of a single species, and $\log_2 S$ in the case where all the species are present with equivalent abundance ($H' = 4.5$ or 5 for the most diverse stands).

Pielou's (1966) equitability index (E) is used to assess the quality of the distribution of individuals within the species in the environment. It is calculated using the following formula:

$$E = H'/\log_2(S)$$

The value of E is between 0 and 1. It tends towards 0 when almost all the individuals are concentrated in one species, and towards 1 when all the species have the same abundance (state of equilibrium). If E is less than or equal to 0.6, the environment is said to be degraded in relation to the species living there, and if E is close to 1, the environment is said to be in equilibrium in relation to the species living there [11].

The index of species diversification within families is calculated from Equation (3) below:

$$D = S/NF$$

where S is the species richness and NF is the number of families.

The assessment of species diversification within families gives an idea of the level of species diversification achieved within families and the existence of habitat variability in aquatic environments [11].

2.4. Frequency of Occurrence of Taxa

Occurrence (F), expressed as a percentage, provides information on the constancy of a species or taxon in each habitat without any indication of its quantitative importance [10]. A distinction is made between omnipresent species, which

appear in all the surveys (100%); regular species, present in 75 to less than 100% of the surveys; constant species, present in 50 to less than 75% of the surveys; accessory species present in 25 to less than 50% of the surveys and rare species present in less than 25% of the surveys [12]. This index, based on the presence/absence matrix, is calculated using the relationship:

$$F = \left(\frac{P_i}{P_t}\right) \times 100$$

where P_t = the total number of samples,

P_i = the number of samples where species is present.

3. Results and Discussion

3.1. Results

3.1.1. Plankton Communities

Zooplankton

During the surveys from 2003 to 2022, 28 zooplankton species belonging to 9 families of the three zooplankton groups Rotifera, Cladocera and Copepoda were recorded.

Rotifers

At the various sampling points, 12 species belonging to 4 families were recorded. The Brachionidae family with 6 species, the Trichocercidae with 4 species and the Conochilidae and Filiniidae with 1 species each (Table 1).

Cladocerans (Branchiopoda)

Cladocerans are present at the various sampling sites, with 8 species belonging to 3 families. The Daphniidae family has 6 species, the Bosminidae and Sididae families each have 1 species (Table 1).

Copepods

Copepods include 8 species divided into 2 families: Cyclopidae, 5 species and Diaptomidae, 3 species.

Phytoplankton

Phytoplankton is made up of 65 species belonging to 5 families.

Chlorophyceae or green algae comprise 42 species. Taxonomic analysis shows that rare species are more represented with a frequency of occurrence of 45.24%, followed by accessory species (19.05%), ubiquitous species (16.67%) and regular and constant species (9.52%) (Table 2).

Cyanophyceae or cyanobacteria comprise 12 species. Analysis of the phytoplankton taxonomic lists drawn up during the study period shows that rare species are more represented, with a frequency of occurrence of 50%, followed by accessory species (33.3%) and regular and ubiquitous species (8.33%) (Table 3).

The Chrysophyceae or golden algae consist of a single species classified as regular.

Diatoms (Bacillariophyceae) comprise 9 species. Taxonomic analysis shows that rare species are the most represented, with a frequency of occurrence of 88.89%, and one species is omnipresent (11.11%).

Table 1. Species richness of zooplankton groups and frequency of occurrence

Group	Family	Species	Frequency of occurrence
Rotifers	Brachionidae	*Kellicotia* sp.	**
		Kellicottia longispina	****
		Keratella cochlearis	*****
		Keratella Lenzi	**
		Keratella sp.	*
		Keratella quadrata	*****
	Conochilidae	*Conochilus natans*	*
	Filiniidae	*Filinia* sp.	*
	Trichocercidae	*Trichocerca chattoni*	*****
		Trichocerca longiseta	**
		Trichocerca quadrata	*
		Trichocerca sp.	**
Cladocerans (Branchiopods)	Bosminidae	*Bosmina longirostris*	*
	Daphniidae	*Ceriodaphinia* sp.	***
		Daphnia longispina	****
		Daphnia sp	*
		Daphnia magna	*
		Daphnia pulax pulex	*
		Sinocephalus sp.	*
	Sididae	*Diaphanosoma brachyurum*	**
Copepods	Cyclopidae	*Cyclops* sp.	**
		Cyclops strenuus	*
		Ectocyclops phaleratus	***
		Ectocyclops sp	**
		Macrocyclops sp.	***
	Diaptomidae	*Diaptomus sp*	**
		Eudiaptomus gracilis	****
		Eudiaptomus sp.	**

Ubiquitous = *****, Regular = ****, Constant = ***, Accessory = **, Rare = *.

The Dinophyceae or dinoflagellates consist of only one species, classified as ubiquitous (Table 2 and Table 3).

3.1.2. Fish Fauna

A total of 9637 individual fish were sampled. They were divided into 29 species belonging to 10 families in the Manantali reservoir. The Cichlidae family is the most represented with 6 species (20.69%), followed by the Characidae with 5

Table 2. Chlorophyceae species richness and frequency of occurrence.

Family	Species	Frequency of occurrence	Species	Frequency of occurrence
CHLOROPHYCEAE	*Ankistrodesmus falcatus*	***	*Micrasterias mahabuleshwarensis*	*
	Ankistrodesmus sp.	*	*Micrasterias radians*	**
	Arthrodesmus borgei	*	*Micrasterias* sp.	*
	Chlorella vulgaris	**	*Micrasterias truncata*	*
	Closterium cornu	*	*Pediastrum clathratum*	*
	Closterium sp.	***	*Pediastrum* sp.	*
	Coelastrum reticulatum	***	*Phacotus lenticularis*	**
	Cosmarium binum	*	*Pleurotaenium ehrenbergii*	*
	Cosmarium depressum	*	*Sphaerocystis schroeteri*	*****
	Cosmarium galeritum	**	*Spondylosium* sp.	*****
	Cosmarium minutum	****	*Staurastrum brachiospromineus*	*
	Cosmarium moniliforme	****	*Staurastrum heimii*	*****
	Cosmarium sp.	***	*Staurastrum leptocladum*	****
	Cosmarium subauriculatum	**	*Staurastrum* sp.	**
	Desmidium baileyi	*****	*Staurastrum subanchora*	*****
	Endorina illinoisensis	****	*Staurastrum tohopekaligense*	*
	Euastrum divergens	*	*Staurastrum setigerum*	*
	Euastrum sp.	*	*Staurastrum ukerewense*	**
	Micrasterias alata	*****	*Staurodesmus subulatus*	*
	Micrasterias echinata	**	*Staurodesmus wandae*	*****
	Micrasterias foliacea	*	*Ulothrix* sp.	*

Table 3. Species richness of phytoplankton groups (Cyanophycees; Diatomees, Dinophycees, Chrysophycees) and frequency of occurrence.

Family	Species	Frequency of occurrence	Family	Species	Frequency of occurrence
CHRYSOPHYCEAE	*Aplanothece stagnina*	*	DIATOMS	*Cymbella* sp.	*
	Chroococcus turgidis	**		*Cymbella ventricosa*	*
	Isocystis planctonica	*		*Diatoma sp*	*
	Lyngbya limnetica	**		*Eunotia sp*	*
	Merismopedia punctata	*		*Navicula* sp.	*****
	Microcystis aeruginosa	*****		*Nitzschia* sp.	*
	Microcystis illinoisensis	*		*Surirella elegans*	*
	Microcystis marginata	****		*Surirella robusta*	*
	Microcystis punctata	*		*Surirella* sp.	*
	Microcystis sp.	*	DINOPHYCEAE	*Peridinium gatunense*	*****
	Oscillatoria sp.	**			
	Phormidium foveolarum	**	CHRYSOPHYCEAE	*Dinobryon sertularia*	****

species (17.24%), then the Cyprinidae (13.79%), Mochokidae (13.79%) and Mormyrioae (13.79%) families with 4 species each. Finally, the Bagrioae are represented by 2 species (6.90%). The other families are represented by 1 species, or 3.45% (Figure 3).

The species Hydrocynus forskalii and Brycinus nurse of the family Alestidae were the most abundant, with relative abundances of 40.12% and 21.4% respectively. The species Synodontis sp. and Synodontis violaceus with relative abundances of 0.03% and 0.04% of the family Mochokidae are the least represented (Table 4).

However, the relative abundance of families in total catches shows that the Alestidae (61.33%), followed by the Cichlidae (14.99%) and Bagrioae (9.43%) dominate the catches.

The frequencies of occurrence identified 17 accidental species, 3 by-catch species and 9 constant species.

The Shannon diversity index calculated during the period of this study is 2.90, the equitability index is 0.60 and the diversification index is 2.90.

The Shannon index calculated annually shows a higher value of 3.28 in 2004 and a lower value of 1.61 in 2009.

The equitability index calculated annually shows a higher value of 0.45 in 2003 and 0.18 in 2016.

The diversification index varies from 2.57 in 2009 to 1.75 in 2020 (Figure 4).

3.2. Discussions

The zooplanktonic taxonomic analysis carried out during the study period shows

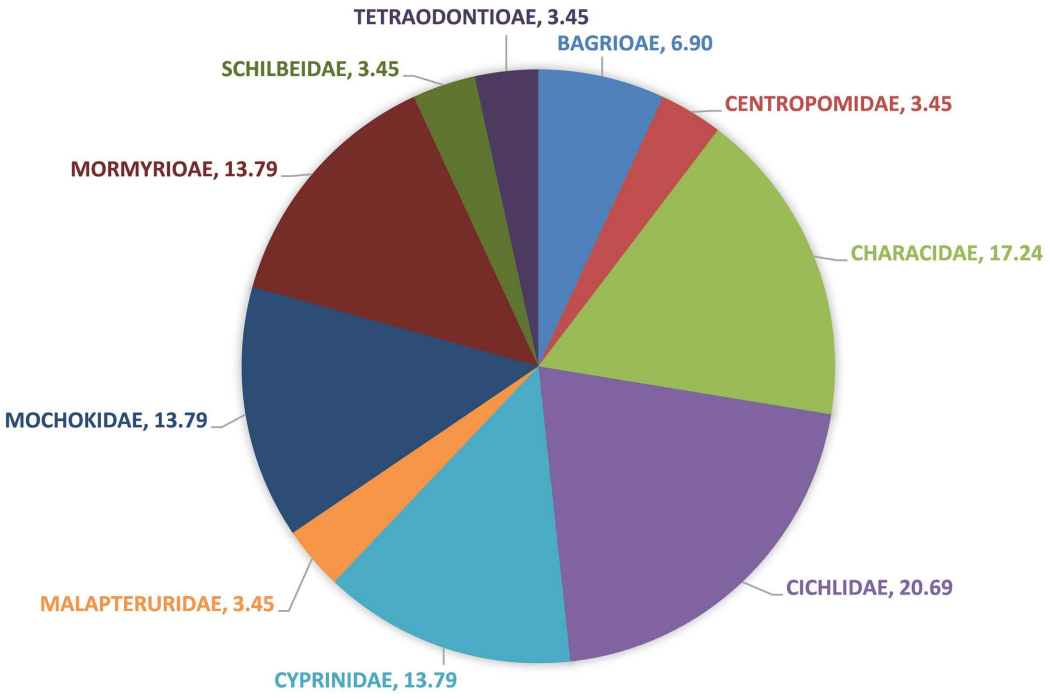

Figure 3. Distribution of fish species according to the main families in the Manantali reservoir.

Table 4. Diversity and abundance of fish species in the Manantali reservoir.

Family	Species	Specific abundance	Relative abundance (%)	% occurrence	
BAGRIOAE	*Bagrus docmac*	16	0.17	14.08	*
	Chrysichthys auratus	893	9.27	84.51	***
CENTROPOMIDAE	*Lates niloticus*	533	5.53	88.73	***
ALESTIDAE	*Brycinus macrolepidotus*	8	0.08	11.27	*
	Brycinus nurse	2028	21.04	61.97	***
	Hydrocynus brevis	8	0.08	8.45	*
	Hydrocynus forskalii	3866	40.12	100.00	***
CICHLIDAE	*Hemichromis fasciatus*	376	3.90	67.61	***
	Sarotherodon galilaeus	202	2.10	61.97	***
	Tilapia dageti	270	2.80	80.28	***
	Tilapia zillii	475	4.93	88.73	***
CYPRINIDAE	*Clarias anguillaris*	12	0.12	14.08	*
	Hemichromis bimaculatus	110	1.14	42.25	**
	Barbus macrops	35	0.36	11.27	*
	Labeo coubie	31	0.32	23.94	*
	Labeo senegalensis	64	0.66	21.13	*
	Raiamas senegalensis	29	0.30	8.45	*
MALAPTERURIDAE	*Malapterurus electricus*	18	0.19	19.72	*
MOCHOKIDAE	*Synodontis ocellifer*	100	1.04	46.48	**
	Synodontis schall	64	0.66	46.48	**
	Synodontis sp.	3	0.03	4.23	*
	Synodontis violaceus	4	0.04	4.23	*
MORMYRIOAE	*Hyperopisus bebe*	5	0.05	7.04	*
	Marcusenius senegalensis	22	0.23	19.72	*
	Mormyrops anguilloïdes	7	0.07	8.45	*
	Mormyrus rume	17	0.18	16.90	*
	Petrocephalus bovei	246	2.55	60.56	***
SCHILBEIDAE	*Schilbe intermedius*	188	1.95	22.54	*
TETRAODONTIOAE	*Tetraodon lineatus*	7	0.07	9.86	*
Numbers			9637		
Specific richness S			29		
Shannon and Weaver diversity index (*H'*)			2.90		
Pielou equitability index (E)			0.60		

***Constant, **Accessory, *Accidental.

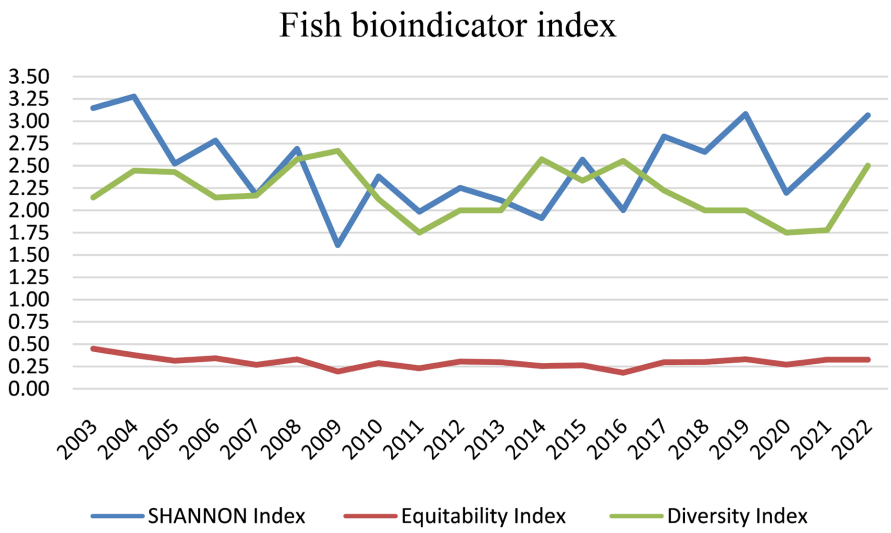

Figure 4. Variation in fish bioindicator index values in the Manantali reservoir.

that rare species with an occurrence of 35.71% are the most abundant, followed by accessory species (32.14%) and constant, regular and omnipresent species with an occurrence frequency of 10.71 (**Table 1**).

The frequencies of occurrence of the various taxa show that the characteristic species of Lake Manantali rotifers are *Keratella cochlearis*, *Keratella quadrata* and *Trichocerca chattoni*, which are omnipresent. *Kellicottia longispina* (rotifers), *Daphnia longispina* (cladocerans) and *Eudiaptomus gracilis* (copepods) are also regular; *Ceriodaphinia* sp. (*cladocerans*), *Ectocyclops phaleratus* and *Macrocyclops* sp. (copepods) are constant (**Table 1**).

These results are similar to those found in the Sassandra river basin in Côte d'Ivoire, which is marked by the qualitative dominance of Rotifera. This dominance of Rotifera in the Sassandra stream is also linked to the genus *Trichocerca*, *Keratella* and *Lecane* [13]. It should be noted that no species of the genus *Lecane* was recorded in our study. All 9 families of species identified in the Manantali reservoir were recorded in the Sassandra River.

The Brachionidae is the most diverse family in tropical and low-lying rivers, lakes, ponds, etc., in the Jesumira River (State of Acre, Brazil) [14] and in the Orogodo River (Nigeria) [15].

In addition, it is widely accepted that Brachionidae taxa are in the majority and regularly found in eutrophic tropical waters due to their high tolerance of eutrophication, and that they are associated with hyper-eutrophic waters and considered to be good bioindicators of eutrophication. [16] [17].

In this context, copepods from the Cyclopidae and Diaptomidae families are well represented, in addition to their major role in the food chain [18], and are intermediate hosts or vectors of water-borne diseases [19]. Moreover, the prevalence of water-borne diseases has increased since the Manantali and Diama dams were commissioned [20].

Analysis of the phytoplankton taxonomic lists drawn up during the study pe-

riod shows that rare species are the most represented with a frequency of occurrence of 50.77%, followed by accessory species (18.46%), omnipresent species (15.38%), regular species (9.23%) and constant species (6.15%) (**Table 2**, **Table 3**).

The frequencies of occurrence of the various taxa allow us to state that the characteristic species of the Manantali reservoir are among the Chlorophycees: *Desmidium baileyi*, *Micrasterias alata*, *Sphaerocystis schroeteri*, *Spondylosium* sp., *Staurastrum heimii*, *Staurastrum subanchora*, *Staurodesmus wandae*; the diatoms with one species (*Navicula* sp.) and the cyanophycees with one species (*Microcystis aeruginosa*).

The taxonomic composition of the algal flora in the Manantali reservoir is characterized by the dominance of chlorophycees and cyanophycees in terms of number of species, representing 54% of the total. These results confirm several studies carried out in the Lake Guiers on the Senegal River, where chlorophycees and cyanophycees predominate in terms of number of species (representing more than 50% of the total) [21] [22] [23] [24] [25].

High taxonomic richness, as in the case of the Manantali reservoir, would indicate greater stability in the functioning of the ecosystem in the face of environmental disturbances [26].

The first ichthyological inventories carried out when the Manantali dam was impounded in 1989 showed 43 species divided into 16 families [27]. However, during the period of this study, the loss of 12 species and 5 fish families was noted, as well as the appearance of 5 new species, namely *Synodontis* sp., *Tilapia zillii*, *Clarias anguillaris* and *Hemichromis bimaculatus*. The reasons for the change in the specific composition of a reservoir vary. After this initial phase, the fish population underwent profound changes in line with the evolution of the environment. These changes resulted in a loss of species richness and diversity and the development of adaptive tendencies. The species least adapted to the new environmental conditions have declined sharply or disappeared altogether, while those that are best adapted have developed strongly [28].

Of the 29 fish species identified, the 9 that are*Brycinus nurse*, *Sarotherodon galilaeus*, *Tilapia dageti*, *Clarias anguillaris*, *Labeo coubie*, *Synodontis schall*, *Synodontis* sp., *Marcusenius senegalensis* and *Schilbe internedius*, are common to the various watercourses of the Bafing, Bakoye, Baoulé, Lake Magui and Falémé of the upper Senegal River basin in Mali [11].

The occurrences show a similarity with the studies carried out by Kantoussan (2007) in the Manantali and Selingué reservoirs through the regular presence in the catches of the families Cichlidae, Mormyridae, Alestiidae and the family Mochokidae, which is incidental in the context of this study [29].

The ichthyological fauna encountered has affinities with that of the upper Niger River basin in Mali and with the freshwater ichthyofauna of the lower Senegal River delta [30]. The most represented families are common to the major river basins of West Africa [31] [32].

The diversity index value of 2.9 at the Manantali reservoir is close to that of the fish community in the Sô River in Benin [33], where the specific diversity index values ranged from 2.26 to 2.99. The same is true for the diversity indices of the Manantali reservoir and the Sô River in Benin [33]. The same applies to equitability indices, which ranged from 0.5 to 0.72. The low values obtained for the equitability indices in our study highlight the dominance of one species or a small number of species in Lake Manantali.

The low equitability index of 0.6 seems to indicate a disturbed ecological state of the habitat in the Manantali reservoir. It is close to that found in the Bafing river [11].

The average annual diversification index, with monthly values of between 2.57 and 1.75, is similar to the values obtained in the Baoulé, Bakoye, Bafing, Faleme and Lake Magui rivers. The indices in these rivers vary from 1.64 to 2.86 in 2019 and from 1.57 to 2.70 in 2020, indicating a theoretical number of habitats of 2 to 3 [30].

4. Conclusion

The fish fauna of the Manantali dam reservoir comprises 29 species belonging to 10 families. Biological diversity remains average in terms of the various indices calculated. The fish species encountered are common to the major river basins of West Africa. The plankton community is made up of 65 species belonging to 5 phytoplankton families and 28 species belonging to 9 zooplankton families. It is necessary to carry out a combined study of physical and biological parameters (the subject of this study) and also to correlate seasonal variations with planktonic and ichthyological populations in order to determine the factors likely to influence the health and stability of the ecosystem in order to better characterise the state of the Manantali reservoir. The results of the study could provide new basic data for the conservation of the ichthyofauna and the plankton community.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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