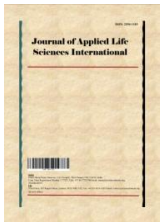

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Identification of Spawning Sites and Natural Nurseries of Fishes in Lake Buyo (Côte d'Ivoire)

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Authors' contributions

This work was carried out in collaboration among all authors. Author ORN designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors AIM, MB and YAK managed the analyses of the study. Author TK managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: Information on ichthyoplankton is an important tool in determining reproduction periods that if associated to environmental variables. The abundance and distribution of ichthyoplankton and their relationships to some environmental variables of the water in Lake Buyo were analyzed. Preferred microhabitats for spawning, dispersion and nursery were also verified.
Place and Duration of Study: The study was conducted monthly from April 2019 through September 2019 in lake Buyo.
Methodology: Acylindro-conical net (500 µm in mesh opening size, 50 cm in mouth diameter) and stream net (7 mm in mesh opening size) were used.
Results: During the study period, the very lowest densities of eggs (1-2 ind/10 m^3) and larvae were recorded in sites (S3 and S8) located relatively far from shoreline and the highest (186-724 ind/10 m^3) in sites located near shoreline. The sites closed to littoral were identified as spawning areas by fish species during study period and sites located in deep water are not spawning sites. No significant difference between seasons was observed for each sampling site.

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Conclusion: Eggs and larvae distribution in Lake Buyo was strongly influenced by water depth, water temperature, dissolved oxygen, percentage of gravel, percentage of coarse sand and proportion of very fine sand.

Keywords: Ichthyoplankton; abundance; environmental characteristics; spawning sites; Lake Buyo; Côte d'Ivoire.

1. INTRODUCTION

All organisms are constrained by a number of environmental factors, and these factors have been ranked different ecological studies. Also, many studies have indicated that aquatics organisms have been regarded as regulated by abiotic and biotic factors [1,2].

Thus, fish requires specific areas for reproduction, and recruitment success depends on favorable environmental conditions for the survival of the fish eggs and larvae (ichthyoplankton) [3]. To maintain fish stock equilibrium, it is important to maintain the integrity of the spawning sites and to allow the dispersion of fish eggs and larvae. Additionally, information regarding the location, dimension and characteristics of reproduction sites is the basis for the management and enhancement of fisheries resources and the preservation of fish species [4]. To do so, it is necessary to identify and map such areas and to determine their predominant environmental characteristics [5].

Lake Buyo, with an area of 600 km², born from the construction of a hydroelectric dam on the Sassandra River, is one of the four largest coastal basins of Côte d'Ivoire. This lake, which is one of the most important sources of production of fish consumed in Côte d'Ivoire, has a part that integrates the Taï National Park, an environment that benefits from ecological protection and monitoring measures, especially for terrestrial animal and plant species. Like in the other Lakes of Côte d'Ivoire (West Africa), Lake Buyo is vulnerable and undergo degradation under anthropogenic pressures, with numerous consequences on the riverine population [6]. It appears urgent that measures be taken to guarantee the renewal of exploited stocks, through the reproduction of different species, given that this resource represents the most easily accessible source of protein in West Africa.

Despite the evidence that ichthyoplankton studies are an important tool for providing information for ichthyology, environmental inventory, stock monitoring, and fisheries management, no works are available on the abundance of ichthyoplankton and environmental factors influencing their distribution in Lake Buyo.

Thus, this study aimed to assess the presence of fish eggs and larvae in a part of Lake Buyo that integrates the Taï National Park. Our hypothesis is that there is a spatiotemporal variation of eggs and larvae distribution in Lake Buyo. To test this hypothesis, the following are done: 1) assess the spatial and temporal abundance of the ichthyoplankton in different sites of the Lake and 2) correlate environmental variables of these sites with the density of eggs and larvae. By doing this, we determined the importance of the Lake Buyo for the conservation of fish species.

2. MATERIALS AND METHODS

2.1 Study Area

Located in the southwest of the Ivory Coast, Lake Buyo is an artificial lac situated on the Sassandra River (1°14'-7°03'N, 6°54'- 7°31' W). It occupies an area of 920 km with a production capacity of 610 GWh [6]. The hydrological regime of the lake depends on that of the Sassandra River, tributaries of N'zo and rainfall of the region. The catchment area of this lake is agricultural and characterized by a tropical climate with:

- one rainy season (February-November); and one dry season (December-January)
- one period of high water (August-February) and one period of low water (March-July).

The data for this work comes from 11 sites of the Lake Buyo located in Taï National Park (Fig. 1); specifically, in the part which included the old bed of flooded N'zo River (OIPR, 2006).9 sites (S1, S2, S4, S5, S6, S7, S9, S10 and S11) were located in shoreline zone (depth varying between 27 and 927 cm) and 2 sites (S3 and S8) in deep water (sites located at distances > 600 m of

shoreline; and depth between 94 and 1253 cm). Sites were selected based on their easy accessibility. Specific richness was of 32 species of fish, belonging in 13 families and dominated by Cichlidae [2]. Based on advanced sexual maturity stages, 14 species in spawning period were captured at the 11 sampling sites [2].

2.2 Environmental Parameters

Water temperature (°C), dissolved oxygen (mg/l), pH, conductivity (µS/cm) were recorded monthly between 7: 00 and 9: 00 using Sper Scientific multiparameter while salinity (‰) and transparency (cm) were recorded with a Hydrobios refractometer and Secchi disk (30 cm diameter), respectively. The depth (cm) and one soil sample were collected at each sampling sites.

Sediment samples collected in different sites were dried and sieved in order to evaluate the grain size distribution [7,8].

Grain sizes were divided in 8 categories following [9]:

- Boulder (D ≥ 64 mm),
- Gravel (2≤ D < 64 mm),
- Sand (0.063 ≤ D < 2 mm) and,
- silt+clay (D < 0.063 mm).

2.3 Ichtyoplanklon Sampling

This study was carried out monthly from April 2019 through September 2019 between 15: 00 and 18: 00, using a cylindro-conical net (500 µm in mesh opening size, 50 cm in mouth diameter) and stream net (7 mm in mesh opening size). Samples were fixed in a buffered 4% formalin solution. In the laboratory samples were sorted and the eggs (pelagic and adhesives) and larvae fish were separated from the rest of the material. The abundance of eggs and larvae was standardized to a volume of 10 m of filtered water [5].

2.4 Statistical Analysis

Spatial and temporal variation in ichthyoplankton density and environmental variables were evaluated using Kruskal-Wallis test and Mann-Whitney *U* test. Spearman correlation rank test was used for the analysis of the relationship between ichthyoplankton abundance and environmental variables. The temporal variation concerns both seasonal variation and in water level.

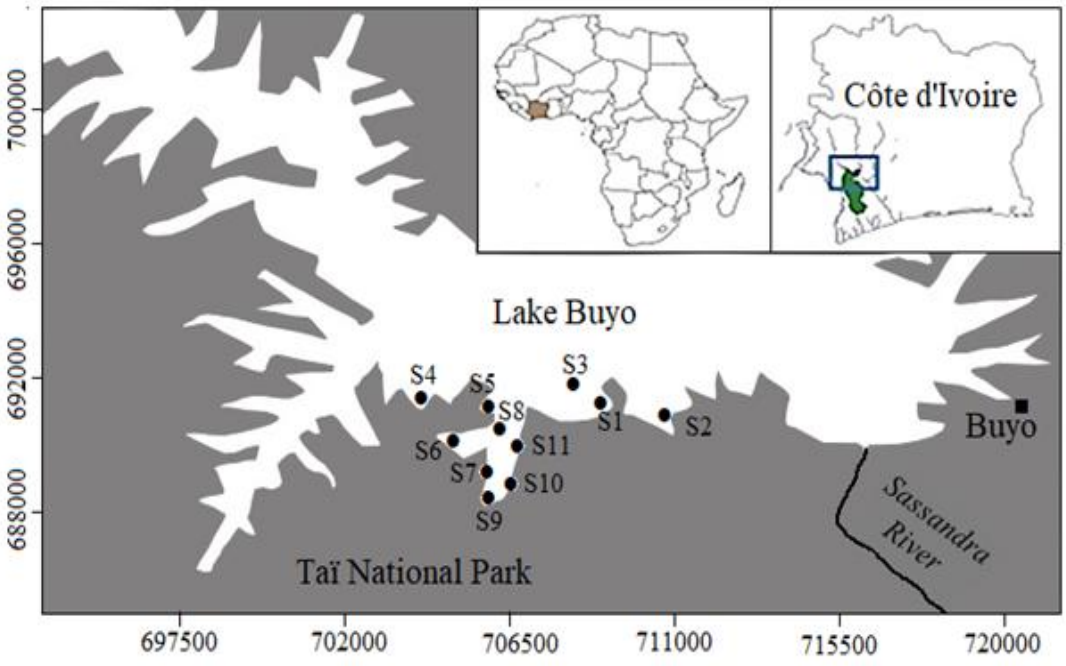

Fig. 1. Map showing the localization of sampling sites (•) in Lake Buyo (Côte d'Ivoire)

Environmental influences on ichthyoplankton composition, distribution and abundance were assessed with a ReDundancy Analysis (RDA). Environmental variables and ichthyoplankton data were log10 (x+1) transformed prior to analysis. RDA was performed using CANOCO 4.5 whereas STATISTICA 7.1 computer package was used the other tests. Differences were considered significant at $P < 0.05$.

3. RESULTS

The mean and ranges values of environmental variables are shown in Table 1. Water temperature varied from 28.9±1.10°C (S10) to 28.44±1.27°C (S5). The lowest dissolved oxygen values were recorded in station S7 (4.81±1.80 mg/l) and the highest values were observed in station S8 (5.94±0.70 mg/l). pH values varied between 6.38±0.69 (S9) and 6.84±0.80(S1). Conductivity ranged between 32.22±11.12µS/cm (S4) and 37.24±17.19 µS/cm (S8). The lowest values of transparency (80.33±51.294 cm) were recorded in station (S9), whereas the highest were registered at S3 (121.77±37.37 cm). For water depth, lowest value (316.22±182.11) was observed in S10 while the highest values (1052.09±512.67 cm) were obtained at station (S3). Significant differences were obtained between S3 and S6, S9, S10 and S11 (Kruskall-Wallis test, $P < 0.05$).

The results (Fig. 2) indicated that in sites S4, substrate is dominated by gravel (54.55%). In contrast, in sites S1, S5, S6, S7, S9, S10 and S11, substrate was mainly composed by sand (73.83-84.67%) with average proportions of gravel(8.41-24.25%). In sites located far from shoreline zone (S3 and S8), substrate is predominated by sand (93.34-97.85%) with very lowest gravel percentage (0.63-3.25%).

Hierarchical classification analysis (Fig. 3) based on the values of sediment particles help isolated three groups:

- The first group formed by S4 which was dominated by gravel;
- The second defined by the S3 and S8 with substrate is predominated by sand;
- The third group formed by S1, S2, S5, S6, S7, S9, S10 and S11 with substrate was composed of sand and gravel mixture.

3.1 Eggs Density

During the study period, the very lowest densities (1-2 eggs/10 m^3) of eggs were recorded in sites (S3 and S8) located relatively far from shoreline and the highest (186-666 eggs/10 m^3) in sites located near shoreline (S1, S2, S4, S5, S6, S7, S9, S10 and S11) (Fig. 4). But, significant difference (Kruskall-Wallis test, $P< 0.05$) was observed between S3 and other sites (S2, S5, S6 and S11) and between S8 and other sites (S2, S5, S6 and S11).

Except for S5 and S11, mean density of eggs was higher in dry season (394-969 eggs/10 m^3) and lower in rainy season (161-654 eggs/10 m^3) in sampling sites located near shoreline (Fig.5). At all seasons, the highest values of eggs density were observed in S6 (654-969 eggs/10 m^3). Mann-Whitney U-test performed showed no significant difference between seasons for each site ($P > 0.05$).

Except in site S3 and S8, the highest mean density of eggs was noted during the low water period (224-920 eggs/10 m^3) and the lowest during the high water period (120-446 eggs/10 m^3) at all sites sampling (Fig. 6). A significant difference (Mann-Whitney U test,$P< 0.05$) was observed between the periods for sites S2 and S4.

Table 1. Environmental variables (mean and standard deviation) measured at different sites in Lake Buyo Côte d'Ivoire from March 2018through February 2019

SITES	T (°C)	DO (mg/l)	Cond µs/cm	Transp (cm)	Depth (cm)	pH
S1	28.49±1.07	5.39±0,92	34.76±10.25	102.82±30,82	478.09±347.46	6.84±0.80
S2	28.83±1.25	5.61±1.11	34.01±9.56	105.09±27.93	436.91±263.03	6.56±0.59
S3	28.58±1.09	5.79±0.87	33.67±8.70	121.77±37.37	1052.09±512.67	6.64±0.61
S4	28.67±1.36	5.62±1.24	32.22±11.12	101±18.49	514.18±311.62	6.73±0.78
S5	28.44±1.27	5.2±0.99	32.65±9.73	92.27±33.27	613.27±367.87	6.74±0.63
S6	28.59±1.38	5.76±0.82	32.3±10.49	91,36±44.09	410.36±245.12	6.73±0.73
S7	28.9±1.21	4.81±1.80	32.74±9.65	96,55±31.53	417.22±293.79	6.43±0,53
S8	28.52±1.38	5.94±0.70	37.24±17.19	96,63±37.08	599.18±335.32	6.65±0.54
S9	28.59±1.79	4.9±0.62	33.72±12.63	80,33±51.23	358.67±195.56	6.38±0.69
S10	28.92±1.10	4.86±1.28	35.97±13.78	96,78±47.14	316.22±182.11	6.62±0.53
S11	28.59±1.32	5.69±1.19	37.05±10.83	106,82±41.49	358.55±171.86	6.83±1.12

Temp:Temperature ;DO : Dissolved oxygen ; Cond : Conductivity ; Transp : Transparency

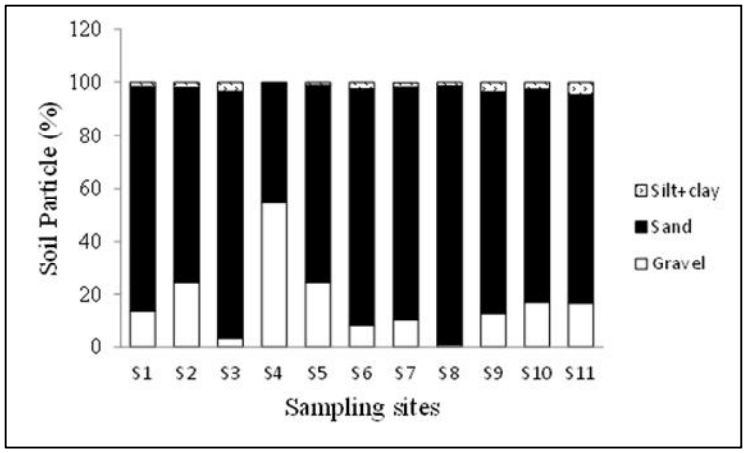

Fig 2. Mean percentages of different soil particles in the sediments of sampling sites (S1 to S11) of Lake Buyo (Côte d'Ivoire)

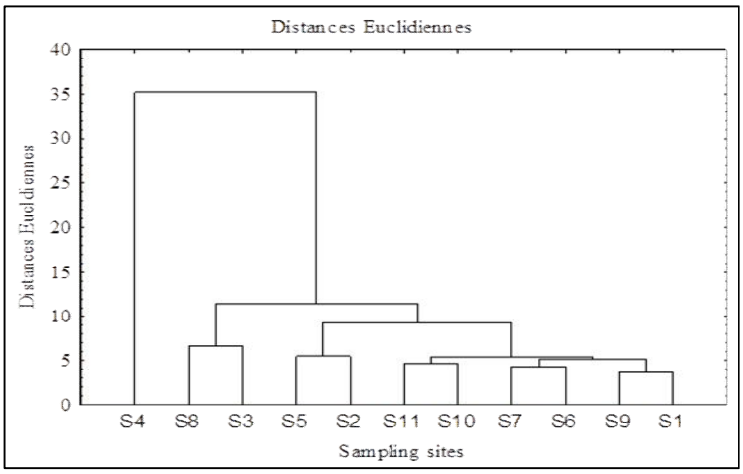

Fig.3. Hierarchical classification of sampling sites (S1 to S11) in Lake Buyo (Côte d'Ivoire) based on the values of different soil particles in the sediments

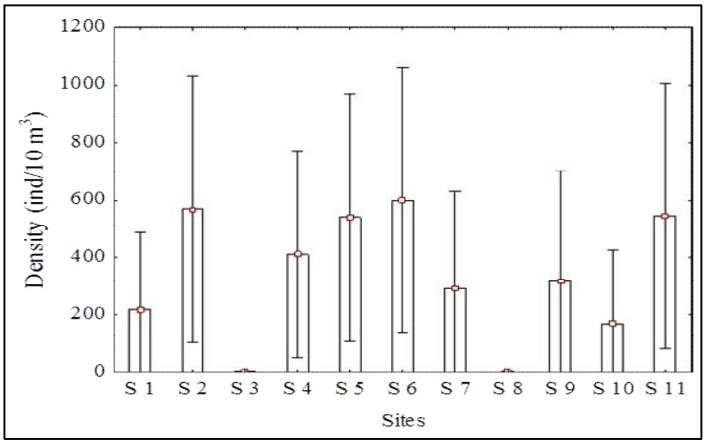

Fig. 4. Spatial variation of eggs density (mean ± SD) in sampling sites of Lake Buyo (Côte d'Ivoire)

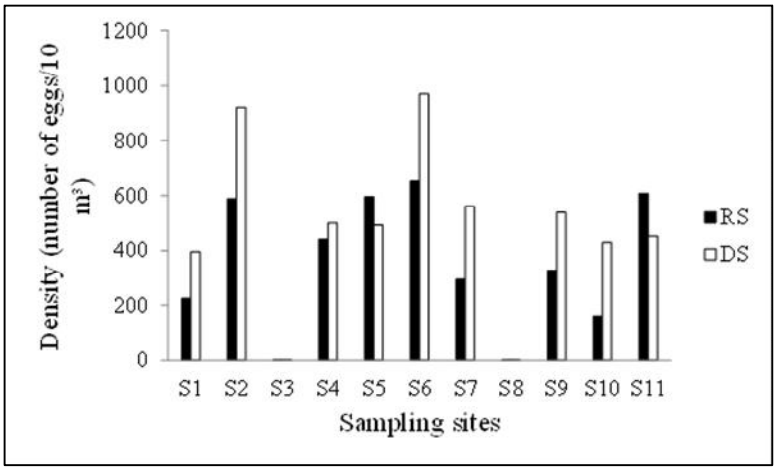

Fig. 5. Seasonal variation of eggs density in sampling sites of Lake Buyo (Côte d'Ivoire) (RS: Rainy season; DS: Dry season)

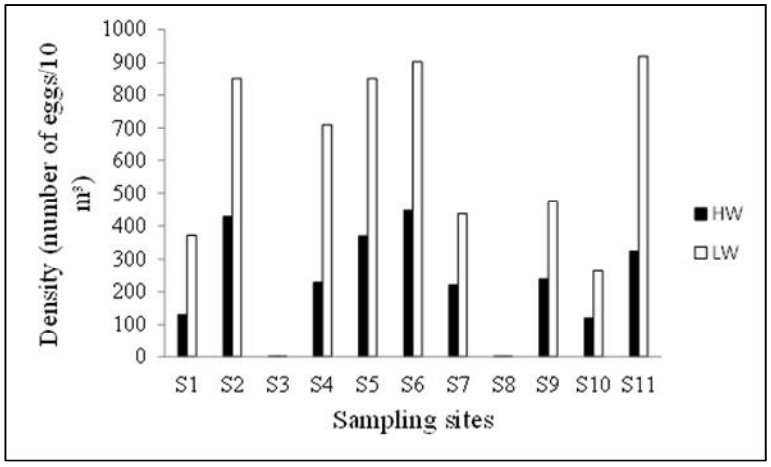

Fig. 6.Variation of eggs density depending on water levelvariation in sampling sites of Lake Buyo (Côte d'Ivoire) (HW: high water; LW: Low water)

3.2 Larvae Density

Larvae abundance showed similar spatial variation as eggs density, with very lowest density (0-1 larvae/10 m^3) recorded in sites located relatively far from shoreline and the highest (289-724 larvae/10 m^3)in sites located near shoreline (S1, S2, S4, S5, S6, S7, S9, S10 and S11) (Fig. 7). But, significant difference (Kruskall-Wallis test, $P < 0.05$) was observed between S3 and other sites (S2, S6 and S11) and between S8 and other sites (S2, S5, S6 and S11).

Except in site S4,S6 and S9, mean density of larvae was higher in dry season (431- 690 larvae/10 m^3) and lower in rainy season (256-663 larvae/10 m^3) in sampling sites located near shoreline (Fig. 8). During the dry season, the highest values of larvae density (690 larvae/10 m^3) were observed in S2 while during the rainy season the highest (724 larvae/10 m^3) were recorded in S6. Mann-Whitney U-test performed showed no significant difference between seasons for each site ($P > 0.05$).

Except for S3 and S8, the mean density of larvae is higher during the low water (329-1134 larvae/ 10 m^3) and lower during the high water period (171-386 larvae/10 m^3) at all sampling sites (Fig. 9). Comparisons of fish larva density data showed significant differences (Kruskall-Wallis test, $P < 0.05$) between the periods for sites S2, S5, S6 and S11.

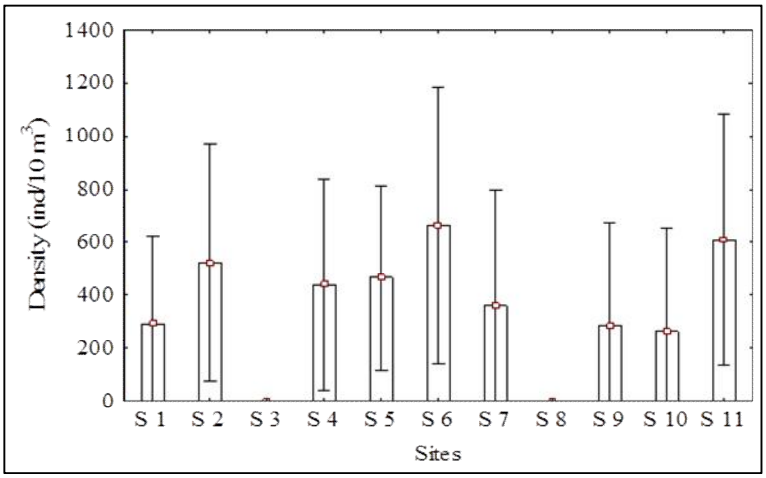

Fig. 7. Spatial variation of larvae density (mean ± SD) in sampling sites of Lake Buyo (Côte d'Ivoire)

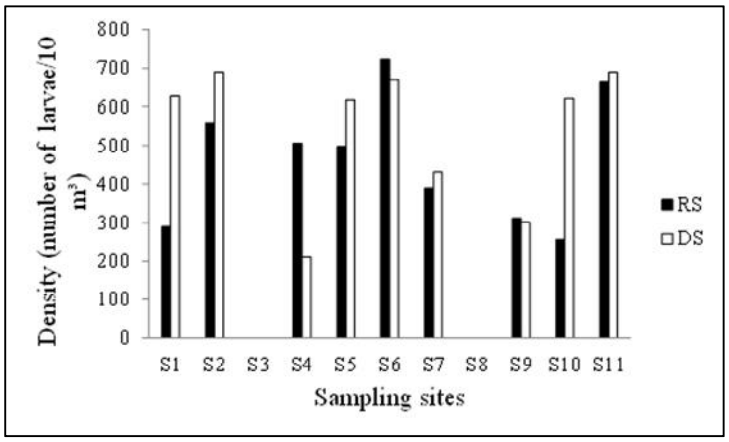

Fig. 8. Seasonal variation of larvae density in sampling sites of Lake Buyo (Côte d'Ivoire) (RS: Rainy season; DS: Dry season)

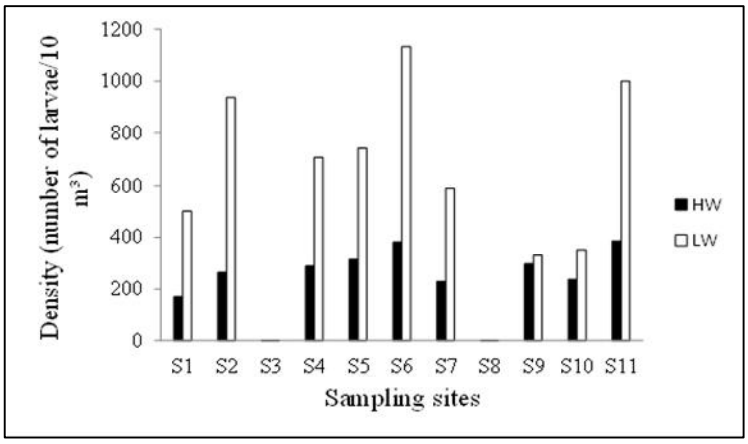

Fig. 9. Variation of larvae density depending on water levelin sampling sites of Lake Buyo (Côte d'Ivoire) (HW: High water; LW: Low water

3.3 Correlation between Nest Density and Environmental Factors

Results of the Redundancy Analysis (RDA) showed that the correlation between environmental factors and ichthyoplankton was mainly explained by the first two axes (100% of total variance). The first represents more than 99%. Water depth, dissolved oxygen, water temperature, percentage of gravel, percentage of coarse sand and proportion of very fine sand were the best at explaining ichthyoplankton distribution in the explored Lake Buyo (Fig. 10). Eggs were more abundant in sites where water temperature was higher. High abundances of larvae were mainly influenced by higher proportion of gravel.

Overall, axis 1 successfully separated sites located relatively far from shoreline from those located near shoreline: sites located relatively far from shoreline were mainly located in the positive part of axis 1 and were characterized by highest values of Water depth, dissolved oxygen, percentage of coarse sand and proportion of very fine sand, and an absence of shrimps; sites located near shoreline were located in the negative part of axis 1 and had lowest Water depth, dissolved oxygen, percentage of coarse sand and proportion of very fine sand, and included ichthyoplankton presence.

4. DISCUSSION

Ichthyoplankton surveys have underpinned understanding of the life history cycles of fishesin water bodies. These surveys also played an important role in the management of the fish through, for example, application of the DEPM to estimate spawning stock size and in identifying key mechanisms thought to impact on fish recruitment success. The latter is an important management consideration since most of the catch consists of juvenile of the year.

Fish requires specific areas for reproduction, and recruitment success depends on favorable environmental conditions for the survival of the larvae and juveniles [3].

In Lake Buyo, the specific richness is 32 species of fish, belonging to 13 families and dominated by Cichlidae [2]. Based on advanced stages of sexual maturity, 14 spawning species were caught at the 11 sampling stations. Eggs and larvae were recorded year-round and at all stations, but were most abundant at stations near shore and the lowest catch was recorded relatively far from shore. The increased abundance of ichthyoplankton at nearshore sites indicates that these sites are an important spawning and nursery area for fish species in Lake Buyo. These sites sampled in Taï National Park offer environmental characteristics suitable for fish reproduction, such as a good level of water temperature, dissolved oxygen, and water depth. In these sites, light penetrates to the bottom of the water due to their shallow depth. Light is used as an energy source for the growth of algae and aquatic plants, providing more abundant and more diverse food resources at these sites. In addition, according to Gophen [10], the food resources of adults and juvenile of *Coptodonzillii* (specie very abundant in Lake Buyo) are found at the bottom of shallow waters. Also, the tendency towards a greater abundance of eggs and larvae in the littoral results from the interaction of the spawning and nursery areas, the swimming behavior of the fish species and the interaction with the hydraulic conditions of the system.

The abundance of eggs and larvae in deep water was extremely low (0 to 1 ind/10 m^3), suggesting that fish do not spawn in this part of the lake.There is no significant difference in the density of eggs and larvae between the dry and rainy seasons. On the other hand, a significant difference in these parameters was noted during the periods of low water and high water. This would explain why the distribution of ichthyoplankton is strongly influenced by the hydrological conditions of lake. In this lake, fluctuations in the water level are mainly governed by the irrigation authorities and, as such, the authorities Irrigation responsible for fluctuations in the water level of the lake have a potential role in improving recruitment to fish fisheries in the lake.

The environmental factors associated with higher egg and larvae densities were high temperatures and the percentage of gravel. This was reinforced by the redundancy analysis and the Spearman rank correlation analysis. These results are consistent with those of previous work. Indeed, [11] indicated that, as a general rule, the spawning of migratory fish coincides with the highest water temperature while [12] has shown that the influence of temperature on the development of eggs and larvae consists of a temperature variation that changes the speed of chemical and biochemical reactions. The density of ichthyoplankton observed in Lake Buyo is

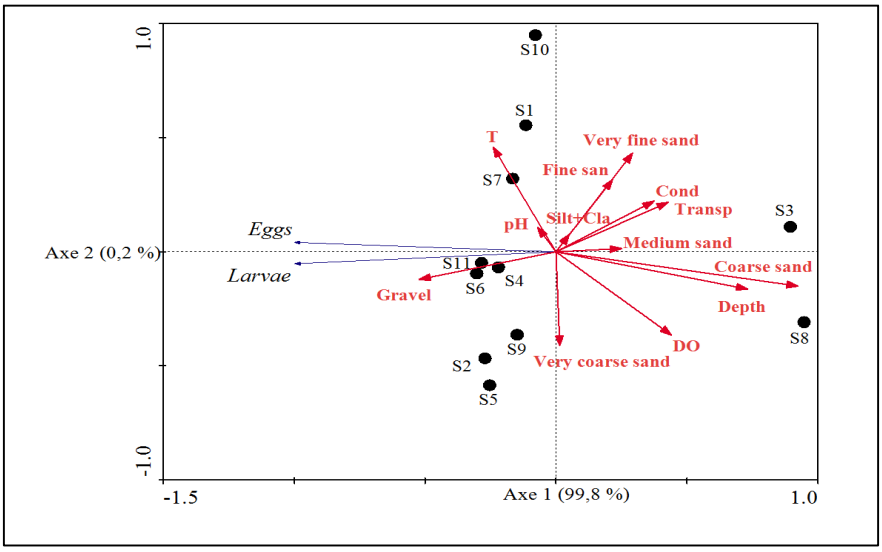

Fig.10. Redundancy analysis showing correlation between environmental variables and principal taxa collected in the study site Sample (DO: Dissolved oxygen, Transp: Transparency, Cond: Conductivity)

abundant (greater than 188 ind/10 m^3) compared to that (18.9 ind/10 m^3) in noted in the estuary Channel of Patos lagoon (Brazil) [13]. Despite the fact that mortality is extremely high during the early life stages of a fish, the ichthyoplankton observed in Buyo Lake is abundant. The coastal area of Lake Buyo serves as a spawning and nursery area for many species of fish. This is consistent with the idea that coastal modification is a major threat to aquatic ecosystems and that the protection of unmodified habitats, such as the aquatic habitats of Taï National Park, appears as an important objective of research on ecosystems. .

Lake Buyo, in particular the sites located in the Taï National Park, offer environmental characteristics favorable to the reproduction of fish species. The present study has shown that fish use the littoral zone as a spawning ground.

5. CONCLUSION

Lake Buyo, specifically sites located in the Taï National offer favourable environmental characteristics for reproduction of many fish species. The present study has shown that fish used littoral zone as spawning area during the study period. Eggs and larvae distribution in Lake Buyo was strongly influenced by water depth, water temperature, dissolved oxygen, percentage of gravel, percentage of coarse sand and proportion of very fine sand.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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