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Ecologic stress in fish population of Lake Nokoué and Porto-Novo Lagoon in Benin

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Abstract
Ecologic stress resulting from human activities in the Lake Nokoué and Porto-Novo Lagoon complex was investigated from July 2015 to June 2016 at six stations of which three were located in each waterbody. The Lake Nokoué stations were Ganvié, Center of the lake and Dantokpa. According to the Porto-Novo Lagoon, the stations were Aguégués, Djassin and Agbokou. In that regard, water samples were analyzed for heavy metals as well as for Chemical Oxygen Demand **(**COD) and Biological Oxygen Demand (BOD-5). The ecological stress Indices (ABC, DAP and SEP) have allowed estimating, both spacially and temporally. The average BOD-5 and COD values of, respectively, 55 ± 47.7 and 407 ± 182.6 mg/L observed on Lake Nokoué are greater than the recommended thresholds in the continental waters of Benin. The average mercury content of the Porto-Novo Lagoon was found to be 1.7 ± 1 µg/L which is also greater than the WHO recommendation of 0.5 µg/L. The same applies to lead whose average concentration exceeds the norm in that waterbody. Overall, 62 species belonging to 49 genera and 35 families were identified in that lagoon complex. In the Porto-Novo Lagoon, the fish of the Agbokou area are dealing with a mild stress level. On the Lake Nokoué, fish of the Dantokpa area and those of the central part of the lake, closest to the ocean, are facing an elevated ecologic stress. In terms of temporal variations, the rainy season induces strong variations in the ecologic stress in Lake Nokoué, as opposed to the dry season which do not induce any ecologic stress in the complex. Generally speaking, fish shoals in the Nokoué Lake are faced with a higher stress level than their Porto-Novo Lagoon counterparts.

Keywords: Anthropic activities, BOD.5, COD, ecologic stress, heavy metals

Introduction
Lagoons are biodiversity-rich ecosystems [11, 24]. To many fish species, they serve as irreplaceable habitats, egg-laying areas, and nurseries [23]. At the same time, the importance of those waterbodies for humans continues to increase [17]. In Benin, the Lake Nokoué and Porto-Novo Lagoon complex is the most important lagoon system in the country due to its productivity, its areal extent, and the uses made of it [30, 13, 19]. However, for a few years now, a decline in its biodiversity has been observed as a result of a number of disruptions [2, 12, 27, 11, 24]. One of the major disruptions taking place in that environment has to do with pollution resulting from the illegal traffic in oil products [32], from biomedical refuse, and from industrial waste discharges [8, 16, 31]. All of this contributes to major heavy metal contaminations in the lagoon complex, namely lead, copper, and mercury [25, 32, 5, 4, 16, 31]. Such contaminations give rise to an ecologic stress which bears on the fish. This human-induced stress, in turn, generates various physiological responses in the individual fish and, when this state becomes chronic, ends up affecting the structure of the biological community [22]. The Lake Nokoué and Porto-Novo Lagoon complex, now a RAMSAR 1018 classified site, is an important fishing resource, and this implies a requirement for continued ecological monitoring [10]. Globally taken, this study aims at evaluating the spatial and temporal impacts of these multiple environmental and human-induced disruptions on the fish fauna within the Nokoué Lake and Porto-Novo Lagoon complex.

Materials and methods
Study Area
Lake Nokoué (Figure 1) is located between the 6°20’ and 6°30’ N parallels and between the 2°20’ and 2°35’E meridians.

Considered as the largest waterbody in Benin, Lake Nokoué covers an area of 150 km^2 [9, 18, 24, 19], with a 20-Km average length in the East-West direction and an 11 Km width in the North-South direction [32]. It is connected to the Porto-Novo Lagoon through the Totchè canal (Figure 1) and is freshwater-fed by both the Ouémé and Sô Rivers [9, 18, 19]. It is also affected by wastewater effluents coming from the surrounding cities, by the rainwater collectors of the city of Cotonou, as well as by the Cotonou tidal channel through which sea water reaches it [14].

The Porto-Novo Lagoon (Figure 1), on the other hand, is located between the 6°25'and 6°30' N parallels and between the 2°30'and 2°38 E meridians. Less stretched than the Nokoué Lake, the Porto-Novo Lagoon covers 35 km^2 [7], measures 7 Km in the East-West direction, while it measures 4 Km in the North-South direction [1]. It is the point through which the waters of the Ouémé River reach the ocean through the Lagos tidal channel. Moreover, the Porto-Novo Lagoon regularly receives domestic liquid wastes by means of the sewer system as it does rainwater overland flow drained by swamps and which channel various urban wastes to the lagoon [5].

Six stations have been established for the purposes of this study (Figure 1), three of which are located on each waterbody depending on the geography of the area, the intensity with which fishing is conducted, and the importance of human activities on there.

Based on its geographic characteristics, this lagoon system has a transitional subequatorial climate pattern, with two rainy seasons and two dry seasons which alternate continuously; namely a major dry season (mid-November through late March), a major rainy season (early April through mid-July), a minor dry season (mid-July through mid-September), and a minor rainy season (mid-September through mid-November) [3]. The average annual rainfall is 1200 mm [3]. Nonetheless, important variations are observed in the rainfall pattern throughout the years.

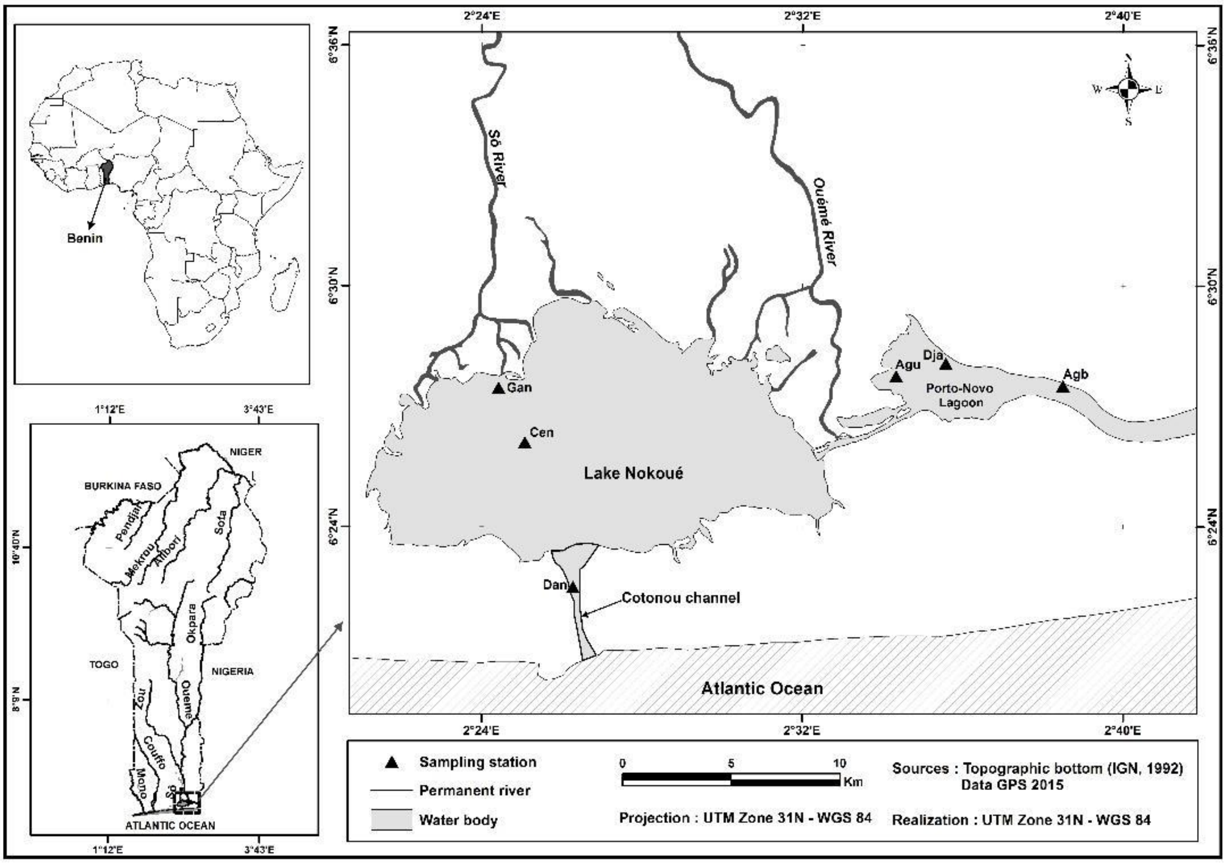

Fig 1: Lake Nokoué and Porto-Novo Lagoon complex and location of the sampling stations. Agb = Agbokou, Agu = Aguégués, Cen = Center of the Lake, Dan = Dantokpa, Dja = Djassin, Gan = Ganvié.

Data Collection

The data has been collected monthly, from July 2015 to June 2016. During this study, physical-chemical parameters (temperature, depth, transparency, pH, dissolved oxygen, and percentage of oxygen saturation) have been recorded and, at each station, the water has been sampled at the surface. Displaying an agreement with previous studies [9, 18, 30, 13], no significant difference was observed between water sampled at the surface and water sampled at a certain depth. Sampling was conducted between 0 and 10 cm into 33-cl plastic bottles which were kept at 4°C in a cooler and immediately brought to the laboratory for lead, copper, and mercury concentration analyses. Fish secured from traditional fishing methods were examined very early in the morning with the goal of characterizing their populations. As for the protocol for the fish sampling proper, the said fish were first identified using the guide by Paugy *et al* [20, 21], then sorted out and weighed. Information pertaining to overall quantity and the number of fish per species was recorded. A sub-sample of the most important takes was taken and the actual sample was extrapolated. At the time of each control of capture, a number of individuals representative of each species was selected for preservation in a 10% formalin solution with the goal of having our identification validated in the lab but also for the establishment of a reference collection.

Data analysis

Physical-chemical parameters

The average and standard deviations of the physical-chemical parameters have been computed with an Excel spreadsheet and are presented in the form of tables (Table 1).

Ecologic stress index

The Abundance-Biomass Comparison index (ABC), the Difference in Area by Percent index (DAP), and the Shannon-Weiner Equitability Proportion index (SEP), Equitability were used in this study and are capable of revealing the existence of an ecologic stress at a particular station as well as at multiple stations.

The ABC index is defined as the average of the difference between cumulated proportions in biomass and abundance; we have: ABC = Bi – Ai/N

where ABC is the abundance-biomass comparison index, B*i* = biomass proportion of species *i* (ranked in decreasing order of proportions), A*i* = abundance proportion (number of individuals) of species *i* (ranked in decreasing order of proportions), N = total number of species. This index is positive in a stress-free environment. However, it is negative in a strongly-stressed environment, and close to zero in a moderately-stressed environment or one in a state of equilibrium.

The second ecologic index (DAP) was suggested by McManus and Pauly [15]. DAP is computed as follows:

DAP = (numbers area - biomass area)/ ln(s)

where biomass area = $\Sigma[C_i + (0{,}5\text{x}Y_i + 1)]$ x [ln (*i*+1) - ln(*i*)], *S* = total number of species, *Ci* = cumulated biomass up to the species with abundance rank *i*, Yi = biomass of species *i*. The numbers area is computed in the same manner. DAP values are located between -1 and +1, with higher values pointing to prevailing stress in the environment.

The third ecologic stress index, the Shannon-Weiner Equitability Proportion (SEP) was also suggested by McManus and Pauly [15] in order to estimate diversity proportions in terms of both abundance and biomass. It is written two ways because the number of species in a sample is the same whether one chooses to work with abundance or with biomass.

$SEP = E_{biomass} / E_{abundance}$ or $SEP = H'_{abundance}/H'_{biomass}$

with SEP = Shannon Equitability Proportion, $E_{biomass}$ and $E_{abundance}$ = Equitability index, H' biomass and H' abundance = Shannon diversity index, respectively computed with the biomass and the abundance.

The high values of the logarithm function to the base *e* [SEP(*ln* (SEP)] imply the existence of stress in the environment. According to McManus et Pauly [15], there is a very tight correlation between DAP and *ln*(SEP).

Results

Physical-chemical parameters

Water temperature within the Porto-Novo Lagoon varies between 23.7 and 33.3°C, with an average of 28.4 ± 2.5°C (Table 1). On the other hand, water temperature within Lake Nokoué varies between 24.1 and 31.4°C, with an average of 27.7 ± 2°C. Water depth varied from 0.5 to 2.35 m in the Porto-Novo Lagoon, with an average of 1.2 ± 0.5 m, and from 0.35 to 4.1 m in Lake Nokoué with an average of 1.8 ± 1.2 m. As far as water transparency is concerned, recorded values range from 0.15 to 1.3 m in the Porto-Novo Lagoon, with an average of 0.5 ± 0.3 m. In Lake Nokoué, an average of 0.8 ± 0.4 m was observed, the actual values ranging from 0.2 to 1.8 m. Recorded salinity values in the Porto-Novo Lagoon were located between 0 and 19 g/L, with an average of 4.2 ± 3.9 g/L. However, in Lake Nokoué, average salinity value was 15.3 ± 10.6 g/L, the actual values ranging from 0 to 40 g/L. pH values were located between 5.7 and 8.8 in the lagoon, with an average of 6.6 ± 0.4. pH on the lake, however, ranged from 6.2 to 7.9, with an average of 7.2 ± 0.4. Dissolved oxygen (DO) concentrations in the Porto-Novo Lagoon were found to be between 1.4 and 6.9 mg/L, with an average of 4.6 ± 1.1 mg/L. In Lake Nokoué, DO concentrations were located between 0.5 and 8.8 mg/L, with an average of 5.1 ± 1.9 mg/L. In the Porto-Novo Lagoon, oxygen saturation varied from 24.1 to 98%, with an average of 68.1 ± 18.2%. In Lake Nokoué, on the other hand, oxygen saturation ranged from 8.9 to 99.1%, with an average of 64.3 ± 23.6%.

Table 1: Summary of physical-chemical parameters recorded in the Lake Nokoué and Porto-Novo Lagoon complex.

		Temp (°C)	Depth (m)	Trans (m)	Sal (g/l)	pH	O_2 (mg/l)	Sat (%)
Porto-Novo Lagoon	Min	23.7	0.5	0.15	0	5.7	1.4	24.1
	Max	33.3	2.35	13	19	8.81	6.9	98
	Avg	28.4 ± 2.5	1.2 ± 0.5	0.5 ± 0.3	4.2 ±3.9	6.6 ± 0.4	4,6 ± 1.1	681 ± 18.2
Lake Nokoué	Min	24.1	0.35	0.2	0	6,15	0,52	8.9
	Max	31.4	4.1	1.8	40	7,96	8,8	99.1
	Avg	27.7 ± 2	1.8 ± 1.2	0.8 ± 0.4	15.3 ± 10.6	7.2 ± 0.4	5.1 ± 1.9	64.3 ± 23.6

Specific richness

We present the results pertaining to species richness in alphabetic order. Fifty-four (54) species belonging to 49 genera and 35 families were recorded in the Porto-Novo Lagoon (Table 2). The most diversified families were Cichlidae (6 species: 11.1%); Gobiidae (5 species: 9.3%); Eleotridae (4 species: 7.4%); Mochokidae and Carangidae (3 species: 5.6%). Next in line were Alestidae, Claroteidae, Clupeidae, Mormyridae, Mugilidae, Polypteridae, Schilbeidae and Sphyraenidae (2 species: 37%). Families which were represented by only 1 species made up 31.5% of the fauna.

In Lake Nokoué, however, 44 belonging to 33 genera and 23 families have been recorded (Table 2). The most diversified families were Cichlidae (6 species: 13.6%) Carangidae (5 species: 11.4%), Eleotridae, and Gobiidae (4 species: 91%). Next in line were Claroteidae, Clupeidae, Elopidae, Lutjanidae, Mochokidae, and Mugilidae (2 species: 4.6%). Families which were represented by only 1 species made up 29.5% of the fauna.

Overall, in the Lake Nokoué and Porto-Novo Lagoon complex, 62 species, involving 49 genera and 35 families, were recorded (Table 2). Cichlidae (6 species: 9.7%) were the most represented family, followed by the following: Carangidae (5 species: 8.1%); Gobiidae and Eleotridae (4 species: 6.5%); Mochokidae (3 species: 4.8%); Claroteidae, Clupeidae, Elopidae, Lutjanidae, Mugilidae, Polypteridae, Schilbeidae and Sphyraenidae (2 species: 3.2%). 38.7% of the fauna is made up of families represented by only 1 species.

Table 2 : List of fish species for Lake Nokoué and Porto-Novo Lagoon

	Agbokou	Djassin	Aguégués	Ganvié	Centre du Lac	Dantokpa
Acanthuridae						
Acanthurus moronviae (Steindachner, 1876)						+
Alestidae						
Brycinus longipinnis (Günther, 1864)	+	+				
Hydrocynus forskali (Cuvier, 1819)	+		+			
Anabantidae						
«Ctenopoma» kingsleyae Günther, 1896	+					
Belonidae						
Strongylura senegalensis (Valenciennes, 1846)	+				+	+
Carangidae						
Caranx crysos (Mitchill, 1815)			+		+	+
Caranx hippos (Linnaeus, 1766)	+	+			+	+
Hypacanthus amia (Linnaeus 1758)					+	
Trachinotus maxillosus Cuvier, 1832		+				
Trachinotus teraia Cuvier, 1832						+
Centropomidae						
Lates niloticus (Linnaeus, 1762)		+				
Channidae						
Parachanna obscura (Günther, 1861)	+	+	+			
Cichlidae						
Chromidotilapia guntheri guntheri (Sauvage, 1882)	+	+	+		+	
Hemichromis bimaculatus Gill, 1862	+	+	+	+		
Hemichromis fasciatus Peters, 1852	+	+		+	+	
Sarotherodon melanotheron Rüppell, 1852	+	+	+	+	+	+
Coptodon guineensis (Bleeker in Günther, 1862)	+	+	+	+	+	+
Coptodon mariae Boulenger, 1899	+	+	+	+		
Clariidae						
Clarias (Anguilloclarias) ebriensis Pellegrin, 1920	+		+			
Claroteidae						
Chrysichthys (Melanodactylus) nigrodigitatus (Lacépède, 1803)	+	+	+	+	+	+
Chrysichthys (Chrysichthys) auratus (Geoffroy Saint-Hilaire, 1808)	+	+	+	+	+	+
Clupeidae						
Ethmalosa fimbriata (Bowdich, 1825)	+	+	+	+	+	+
Pellonula leonensis Boulenger, 1916	+	+	+	+	+	+
Cynoglossidae						
Cynoglossus senegalensis (Kaup, 1858)	+	+	+		+	+
Eleotridae						
Bostrychus africanus (Steindachner, 1880)	+	+		+		+
Dormitator lebretonis (Steindachner, 1870)	+					+
Eleotris senegalensis Steindachner, 1870	+	+				+
Eleotris vittata Duméril, 1858	+	+	+	+		+
Elopidae						
Elops lacerta Valenciennes, 1846	+	+	+	+	+	+
Elops senegalensis Regan, 1909	+	+	+	+	+	+
Gerreidae						
Eucinostomus melanopterus (Bleeker, 1863)	+	+	+	+	+	+
Gobiidae						
Awaous lateristriga Valenciennes, 1837	+					
Gobioides africanus (Giltay, 1935)		+				+
Gobioides sagitta (Günther, 1862)		+				+
Gobionellus occidentalis (Boulenger, 1909)	+	+	+	+	+	+
Porogobius schlegelii (Günther, 1861)	+	+	+	+	+	+
Gymnarchidae						
Gymnarchus niloticus Cuvier, 1829		+				
Haemulidae						
Pomadasys jubelini (Cuvier, 1830)	+	+	+		+	+
Hemiramphidae						
Hyporamphus picarti (Valenciennes, 1847)		+			+	+
Hepsetidae						
Hepsetus odoe (Bloch, 1794)	+		+	+		
Lutjanidae						
Lutjanus agennes Bleeker, 1863						+
Lutjanus goreensis (Valenciennes, 1830)				+	+	+
Mochokidae						

Synodontis nigrita Valenciennes, 1840	+	+			+	
Synodontis Ouéménsis	+	+	+	+		
Synodontis schall (Bloch et Schneider, 1801)		+				
Monodactylus sebae (Cuvier, 1829)	+	+		+	+	
Mormyridae						
Brevimyrus niger (Günther, 1866)	+	+				
Hyperopisus bebe (Lacépède, 1803)	+	+				
Mugilidae						
Liza falcipinnis (Valenciennes, 1836)	+	+	+	+	+	+
Mugil cephalus Linnaeus, 1758	+	+	+	+	+	+
Ophichthyidae						
Dalophis boulengeri Blache et Bauchot, 1972	+					**X**
Paralichthyidae						
Citharichthys stampflii (Steindachner, 1895)	+	+	+	+	+	+
Polynemidae						
Polydactylus quadrifilis (Cuvier, 1829)	+	+	+			
Polypteridae						
Polypterus bichir Geoffroy Saint-Hilaire, 1802		+				
Polypterus senegalus senegalus Cuvier, 1829	+					
Schilbeidae						
Parailia pellucida (Boulenger, 1901)	+	+	+			
Schilbe intermedius Rüppell, 1832	+	+				
Sciaenidae						
Pseudotolithus (Pseudotolithus) senegalensis (Valenciennes, 1833)		+				
Scombridae						
Scomberomorus tritor (Cuvier, 1831)						+
Serranidae						
Epinephelus aeneus (Geoffroy Saint-Hilaire, 1817)						+
Soleidae						
Solea solea solea (Linnaeus, 1758)						+
Sphyraenidae						
Sphyraena afra Peters, 1844	+					
Sphyraena guachancho Cuvier, 1829	+	+				

Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD)

Values recorded over the Porto-Novo Lagoon ranged from 23.2 mg/L (Agbokou) to 148.4 mg/L (Aguégués), with an average of 95.5 ± 64.9 mg/L (Figure 2a). In Lake Nokoué, chemical oxygen demand varied from 212 mg/L (Ganvié) to 574 mg/L (Dantokpa), with an average of.407 ± 182.6 mg/L (Figure 2b). Generally speaking, Lake Nokoué COD is greater than Porto-Novo Lagoon COD. Regarding the Porto-Novo Lagoon, recorded BOD values ranged from 12 mg/L (Agbokou) to 35 mg/L (Aguégués), with an average of 22.7 ± 11.6 mg/L (Figure 2a). The average biological oxygen demand over Lake Nokoué was 55 ± 47.7 mg/L. The smallest value in that ecosystem was recorded at the Lake Center station (25 mg/L), while the Dantokpa station displayed the highest value (110 mg/L) (Figure 2b).

As a result of the foregoing, it can be seen that values of pollution indicators are greater in Lake Nokoué than in the Porto-Novo Lagoon.

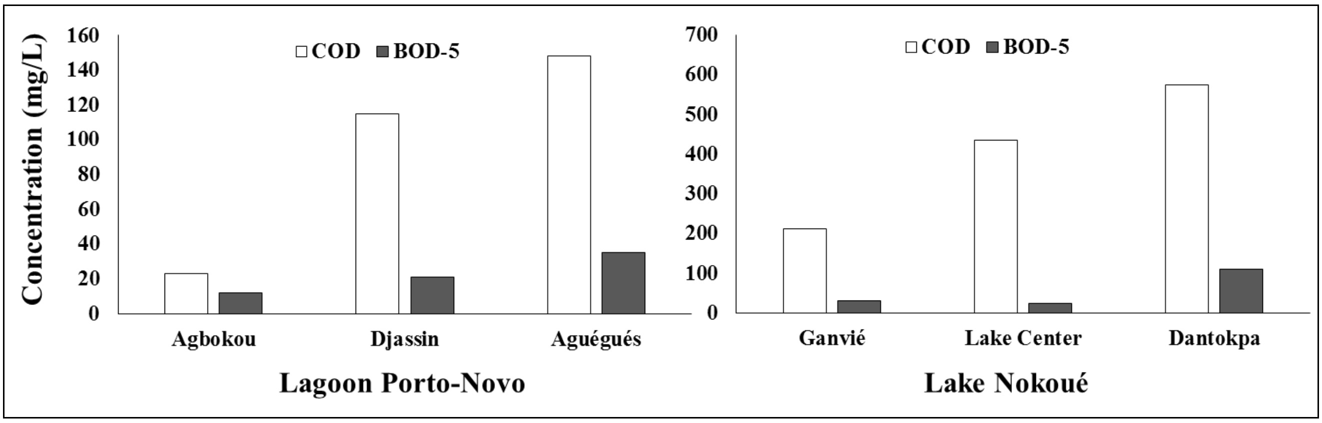

Fig 2: COD and BOD-5 in (a) Porto-Novo Lagoon and in the (b) Lake Nokoué.

Metal indicators of water quality

Mercury concentrations recorded in the Porto-Novo Lagoon ranged from 0.0008 (Agbokou) to 0.0028 mg/L (Djassin), with an average of 0.0017 ± 0,001 mg/L (2). In Lake Nokoué, those concentrations were located between 0.0007 mg/L (Lake Center) and 0.0016 mg/L (Ganvié), with an average of 0.0011 ± 0.0005 mg/l. Lead concentrations ranged from 0.101 (Agbokou) to 0.121 mg/L (Djassin and Aguégués) on the Porto-Novo Lagoon, with an average of 0.114 ± 0.011 mg/L (Table 3). On Lake Nokoué, lead concentrations were between 0.094 (Ganvié) and 0.128 mg/L (Lake Center), with an average of 0.107 ± 0.018 mg/L. Copper concentrations in the Porto-Novo Lagoon ranged from 0.039 mg/L (Agbokou) to 0.061 mg/L (Djassin), with an average of 0.054 ± 0.009 mg/L. Values over Lake Nokoué ranged from 0.04 (Ganvié) to 0.232 mg/L (Dantokpa), with an average of 0.110 ± 0.106 mg/L.

Table 3: Heavy metal concentrations in the Lake Nokoué and Porto-Novo Lagoon complex

	Station	Mercury (mg/L)	Lead (mg/L)	Copper (mg/L)
Porto-Novo Lagoon	Agbokou	0.0008	0.101	0.039
	Djassin	0.0028	0.121	0.061
	Aguégués	0.0014	0.121	0.043
	Average	0.0017	0.114	0.047
Lake Nokoué	Ganvié	0.0016	0.094	0.04
	Lake Center	0.0007	0.128	0.057
	Dantokpa	0.0011	0.101	0.232
	Average	0.0011	0.107	0.109

Ecologic stress index

A total of 15,444 fish specimens weighing 563.63 Kg and belonging to 42 species, 33 genera, and 23 families were recorded over Lake Nokoué. Over the Port-Novo Lagoon, 5,765 fish specimens weighing 272.76 Kg were analyzed. Based on the trend displayed by the curves characteristic of the ecologic stress index for Ganvié (Lake Nokoué), Djassin and Aguégués (Porto-Novo Lagoon) stations, the biomass curve is located above the abundance curve, which is in agreement with the first hypothetical scenario advanced by Warwick [26]. Furthermore, the ABC index for those three stations are positive, while the Log_eSEP and DAP values are all negative. That result is reflective of an absence of stress in the fish communities at the Ganvié, Djassin, and Aguégués stations.

At the Agbokou station, biomass and abundance curves are almost identical with each other, which is in agreement with the second hypothetical scenario advanced by Warwick [26]. The Log_e SEP and DAP values (-0.08 and -0.06, respectively) are all negative while the ABC value (0.05) is positive (Figure 3). We observe that all of those values are close to zero, meaning that fish populations at the Agbokou station are undergoing limited stress.

At the Dantokpa and Lake Center stations, the abundance curves are above the biomass curves. This, also, is in agreement with the third hypothetical scenario advanced by Warwick [26]. For those two stations, the ABC values are negative while the Log_eSEP and DAP values are positive. These pieces of information allow us to conclude that the fish fauna at the Dantokpa station as well as the one at the Lake Center station are dealing with a high stress level. In terms of temporal variations, all of those biomass curves for the Porto-Novo Lagoon are located above the abundance ones. Moreover, the ABC values are all positive while the DAP and Log_eSEP values are positive. Consequently, it can be stated that temporal variations do not disrupt the fish communities of the Porto-Novo Lagoon in any way (Figure 4). On Lake Nokoué, on the other hand, ecologic index values obtained over the dry seasons (both the major and minor ones) are similar to those of the Porto-Novo Lagoon. It can be seen that the ABC index are positive while the DAP and Log_eSEP index are negative. Furthermore, the biomass curves are above the abundance curves. Such results reflect an absence of ecologic stress during the dry season over Lake Nokoué. On the other hand, the abundance curves for the rainy seasons (both the major and minor ones) over Lake Nokoué are located above the biomass curves, additionally, DAP and Log_eSEP stress index are positive while the ABC index is negative (Figure 4). All of this is an indication of the existence of an ecologic stress on the fish populations in Lake Nokoué during the rainy seasons.

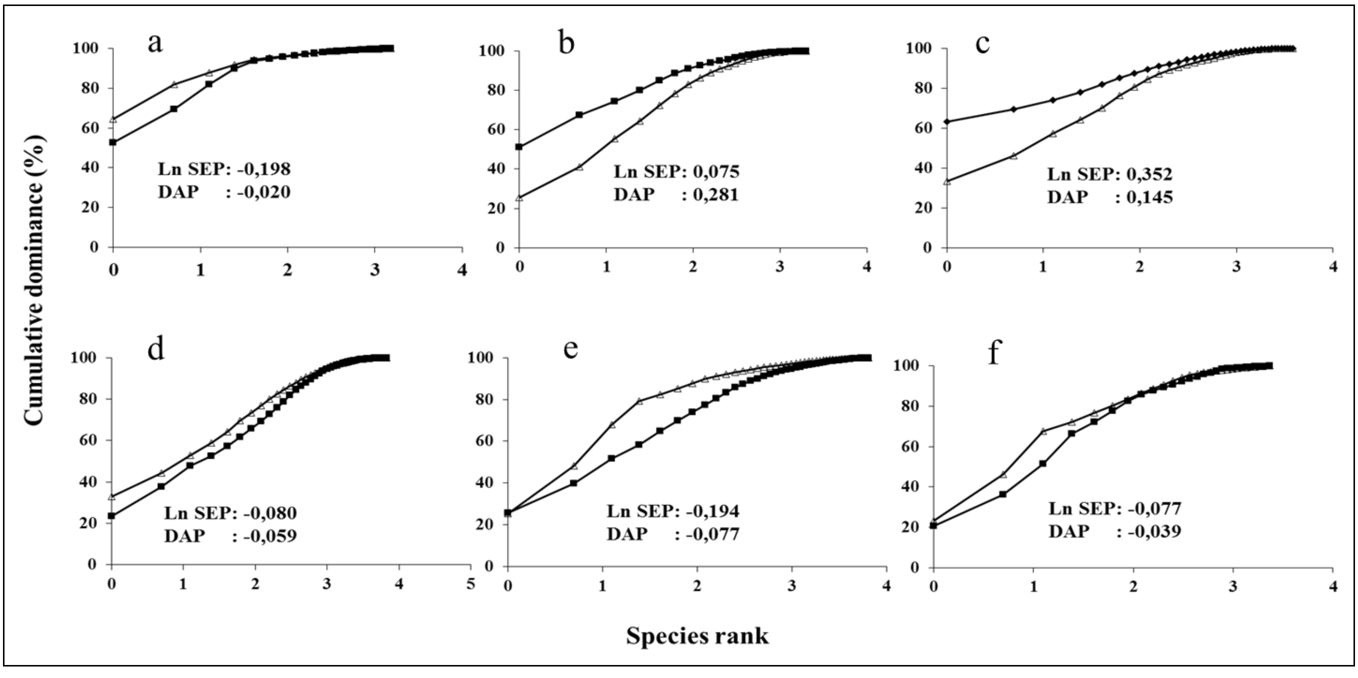

Fig 3: Spatial variations in the ecologic stress within the Lake Nokoué and Porto-Novo Lagoon complex a: Ganvié, b: Lake Center, c: Dantokpa, d: Agbokou, e: Djassin and f: Aguégués.

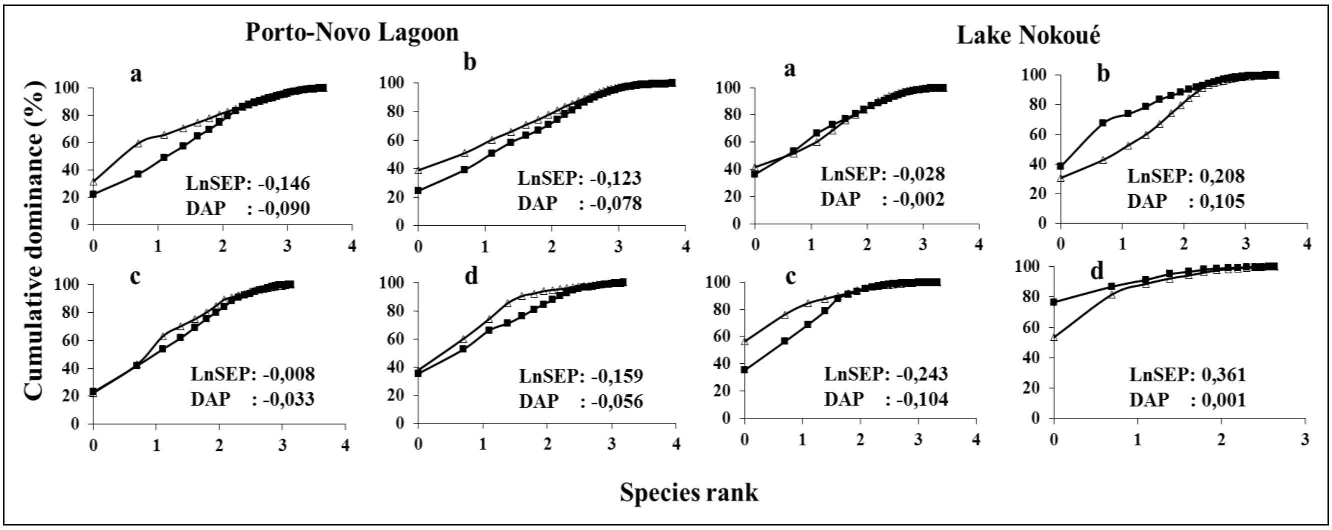

Fig 4: Temporal variations in the ecologic stress within the Lake Nokoué and Porto-Novo Lagoon complex a: major dry season, b: major rainy season, c: minor dry season and d: minor rainy season.

Discussion

Because of their extreme sensitivity to increases in the impact of fishing and to all kinds of environmental degradations, including those resulting from non-point source pollutions as well as changes related to competition and predation, fishes are very good indicators of the quality of a given environmental [28]. The ABC index analysis that we've conducted in this study allows the identification of stress borne by fish populations at a number of stations in the Lake Nokoué and Porto-Novo Lagoon complex, on the one hand, and potential seasonal disruptions, on the other hand. Comparison of the DAP or SEP index of the various stations has made it possible to quantitatively state that stress level is not the same from one station to another and neither is it the same across all seasons. Nonetheless, the challenge is that the DAP and SEP index allow diagnosing all kinds of stress [29] without any indication of the source of that stress whether this is due to pollution, to the environmental conditions, or to fishing by humans. But in any case, our understanding of this particular environment allows us to hypothesize on what the causes are. In fact, the computed ABC, DAP and SEP index values at each station make it possible to say that the fish communities at the Dantokpa and Lake Center stations are facing a high level of stress. This stress seems to be greater in stations closest to the ocean. This result agrees with findings by Villanueva [24] in the estruary of Gambia and which show that stress level is higher in stations closer to the sea as opposed to those farther away. So, the salt content of the water is a stress inducer in the fish. Furthermore, human fishing is more intense in those two stations, whereas Ganvié is a place of residence. Beyond salt content, the recorded physical-chemical parameters values have no negative impact on the fish and agree with the findings of past studies on that fishing environment [2, 24, 7, 11, 5, 6, 14, 1, 19, 31]. However, analsyis of chemical pollutions in Lake Nokoué reveals a high lead and mercury content. It appears that these heavy metals are of human origin, essentially resulting from the illegal traffic in oil products and from industrial and biomedical wastes discharged into the waterbody [25, 8, 32, 6].

Very high COD and BOD values come on top of all that and reflect serious organic pollution in this environment. That set of disruptive factors create an instability in the environment. We have also observed that, in the Porto-Novo Lagoon, fish communities at the Agbokou station are facing a limited stress level. This is explained by discharges of industrial effluents by the Sonicog plant (a soap-making company). These effluents are understood to lead to an acidification of the water and, as a result, stress the fish populations therein. Taking a look at the various index, it can be seen that Ganvié, Djassin and Aguégués stations are not under stress. This is potentially due to the large number of acadjas encountered at those stations. As a matter of fact, acadjas are a good source of organic matter resulting from the breakdown of the tree branches they are made of and offer a reliable environment for the wellness of the fish. According to Villanueva [24], the impact of pollution can be mitigated by the use of acadjas which also curb predation. However, some climatic variations, particularly heavy rainfall, can lead to a significant decrease in salinity in the water. Sea- and estuary-originated species encountered in the lake are consequently oppressed by that new, birthing environment. In addition, lots of municipal solid wastes and polluted water from public sewers get discharged into this same waterbody at the favor of rising water in rainy seasons. All of this could explain the high ecologic stress observed during the rainy season over Lake Nokoué. In spite of those multiple disruptions, the Lake Nokoué and Porto-Novo Lagoon complex is still the home of a wide diversity of species. In fact, 62 species, belonging to 49 genera and 35 families, have been recorded in the course of this study. It is, however, to be noted that diversity richness recorded over Lake Nokoué, 44 species, belonging to 33 genera and 23 families, is less than that observed by Lalèyè *et al* [11]. This state of affairs is probably due to the recent increase in the sources of stress in that waterbody. Nonetheless, in the Porto-Novo Lagoon, the fifty-four recorded species, involving 49 genera and 35 families, outnumber those recorded by Yacoubou [30]. The most represented families in those two waterbodies are Cichlidae, Carangidae, Gobiidae, Eleotridae, Claroteidae, and Clupeidae.

Conclusion

The results of this investigation advance our knowledge of how much stress is borne by fish populations in the Lake Nokoué and Porto-Novo Lagoon complex through a select number of data collection stations. Analysis of the chemical pollution status of that waterbody reveals high concentrations in heavy metals, namely lead and mercury, with concentrations exceeding WHO limits. The computed ABC, DAP, and SEP index inform that fish populations at the Dantokpa and Lake Center stations in Lake Nokoué are dealing with a high ecologic stress, while those at the Agbokou station face limited stress. On the other hand, our results show that Ganvié, Djassin, and Aguégués stations in Porto-Novo Lagoon are stress-free. This study indicates that high-stress stations are either those closest to the ocean or those subject to pollutants discharge. The relatively high salinity at stations near the ocean, the intense fishing pressure exerted on the species, and the widespread water pollution are all factors that are responsible for the stressed condition prevailing in those aquatic environments. In any case, we take note of the observed high diversity in fish species, with 62 species belonging to 49 genera and 35 families, among which Cichlidae, Carangidae, Gobiidae, Eleotridae, Claroteidae; and Clupeidae are represented in the greatest number. It is therefore critical that necessary clean-up measures be taken and that watch be kept on that ecosystem in order to preserve this precious fauna for posterity.

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