**Int. J. Aquat. Biol.** (2021) 9(5): 279-289
ISSN: 2322-5270; P-ISSN: 2383-0956
Journal homepage: www.ij-aquaticbiology.com


Original Article

# Ecological status of a West African lagoon complex under anthropogenic pressure, Toho-Todougba complex, Benin

**Mardochée Ephraïm Achoh[*1], Hyppolite Agadjihouèdé[1], Luc Gangbè[2], Arsène Houssou[1], Romaric Aïzonou[1], Simon Ahouanssou Montcho[1], Antoine Chikou[3]**

[1]Unit of Aquaculture Research and Fisheries Management, Laboratory of Fisheries and Animal Sciences, National University of Agriculture, PO Box 43 Ketou, Benin.
[2]National Institute of Agricultural Research of Benin, 01 Box 884 Cotonou, Benin.
[3]Laboratory of Hydrobiology and Aquaculture (LHA), Faculty of Agronomic Sciences, University of Abomey-Calavi, 01 PO Box: 526 Cotonou, Benin.

**Abstract:** Management and preservation of aquatic environments are essential for their productivity and the maintenance of aquatic life. This study aims to characterize the trophic state of Toho-Todougba lagoon complex which has been subject for several years, to an intense fish production in cages. For this purpose, physico-chemical parameters were measured from June 2019 to May 2020 as well as chlorophyll-α, phosphorus and nitrogen. The trophic characterization indices were calculated basedo n Carlson (1977), Burns and Bryers (2000), Neverova-Dziopak and Kowalewski (2018), Primpas et al. (2010) and CCME-WQI (2001). It appears that the temperature (29°C), dissolved oxygen (3.19 $mg.L^{-1}$ to 4.33 $mg.L^{-1}$) and pH (6.66 to 7.31) are those characteristic of tropical lake environments. The production parameters revealed that the chlorophyll-α concentration varies from 0.19 to 37 $mg.L^{-1}$ (stations and months combined). The concentration of phosphorus ranged from 0.02 to 0.42 $mg.L^{-1}$ while nitrogen varied from 1.91 to 4.03 $mg.L^{-1}$. Only nitrogen is not in critical proportion for the ecosystem. It should be noted that with the exception of the Carlson index, all other indices revealed that the ecosystem is in a state of advanced eutrophication with a tendency to hyper-trophication according to the eutrophication index of Primpas et al. (2010). Consequently, Toho-Todougba lagoon complex is eutrophic and requires adequate measures for its restoration despite its good health revealed by the physico-chemical parameters.

*Article history:*
Received 24 January 2021
Accepted 22 October 2021
Available online 25 October 2021

*Keywords:*
Eutrophication
Lagoon
Anthropogenic
Cage fish farming

## Introduction

The Food and Agriculture Organization of the United Nations has revealed that fish contributes 50% of the average per capita animal protein intake in developing countries (FAO, 2020). On the other hand, the projections made by Delgado et al. (2001) revealed that, to make animal protein available to all, it will be necessary to reach a fish production of 98.6 million tons in 2020 compared to 62.7 million tons in 1997. Consequently, the demand for fishery resources has reached a crucial level where the intensification of aquaculture in all its forms is required to meet the growing demand for food security especially in developing countries, including Benin (FAO, 2018).

In the perspective of intensification of aquaculture production, Republic of Benin has opted for cage fish farming since 2011 as an objective production strategy. Thus, the Toho-Todougba lagoon complex as other aquatic ecosystems in the country has experienced the installation of cages so that in 2019, 604 cages were counted (Aïzonou et al., 2019). The total number of cages in this aquatic ecosystem allows for production of about 600 tons of fish per year and about 700 tons of feed used. The proximity of the Toho-Todougba lagoon complex in Cotonou (a city that is a major market for fish farmers) has generated a strong interest among fish farming entrepreneurs to increase the number of production cages to meet demand. Also, the Territorial Agency for Agricultural Development Pole 7 has undertaken and signed agreements with the fish farmers' cooperatives that operate on the complex to develop fish farming infrastructure. Thus, a floating aquaculture village made up 100 cages with dimensions of 5 m on each

[*]Correspondence: Mardochée Ephraïm Achoh
E-mail: mardoachoh12345@gmail.com
DOI: https://doi.org/10.22034/ijab.v9i5.1033

side and 3 m of net fall is being installed on the lagoon complex.

Despite the will of fish farmers and the public authorities to boost the production of caged fish in Benin, concerns about ecological preservation arise because of the discharge of organic particles into the environment. Indeed, Schenone et al. (2011), Degefu et al. (2011), Gorlach-Lira et al. (2013) and Yoboue et al. (2018) have mentioned negative effects of the input of organic particles on aquatic ecological life. For organic particles discharged into the aquatic environment influence hydrobiological functioning both physically (change in water color, decrease in transparency, high water density, etc.) and chemically (high concentration of phosphorus, nitrogen, chlorophyll abundance etc.). They can constitute sources of ecological stress for living resources (Vodougnon et al., 2018) and lead to eutrophication (Mama et al., 2012) through a phytoplankton bloom.

In spite of these risks incurred by the Toho-Todougba lagoon complex and in the face of the evident willingness of fish farmers to intensify production, very little scientific information giving rise to an environmental impact study exists. This crucial lack of scientific information hinders all initiatives aimed at managing the installation and production in this ecosystem. The present study aims to assess the current level of organic pollution of the complex based on production parameters (phosphorus, nitrogen, and chlorophyll-α), trophic status characterization index and other physico-chemical water parameters to assist public institutions developers and aquaculture stakeholders in decision-making.

## Materials and Methods

**Study area and sampling sites:** The Toho-Todougba Lagoon Complex represents a significant portion of the ancient lagoons (known as the five-fingered lagoon) and is located between 6°23' and 6°27'N and 2°07' and 2°13'E in the heart of Ramsar site 1017. The complex has a surface area of 995 ha in recession according to Chippaux et al. (1990). For several decades, the communication of the Toho-Todougba

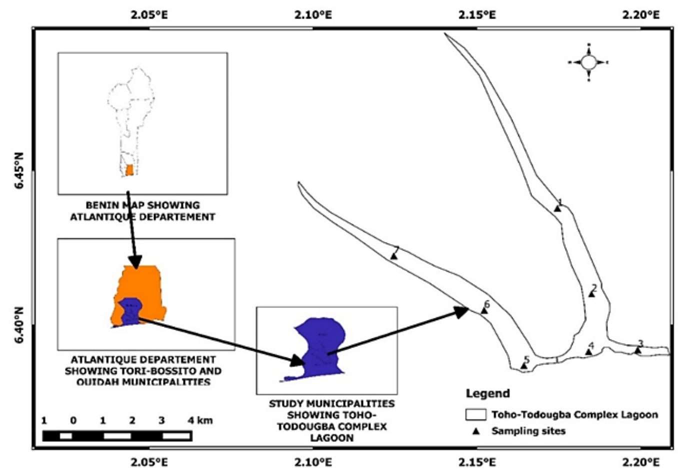


Figure 1. Map of the study area.

lagoon with the sea has broken due to various developments (Chippaux et al., 1990). The lagoon has become a closed ecosystem fed essentially by rainwater and runoff. The vegetation characteristic of this ecosystem is composed of grassy savannahs, meadows, swampy formations with *Raphia gigentea* (Capo-Chichi et al., 2018). The climate of the area is characterized by two rainy seasons (a large season from April to July and a small one from September to November) and two dry seasons (a small one covering the month of August and a large one from December to March). The average rainfall in the area varies between 936 and 1.200 mm.yr$^{-1}$. To conduct this study, the complex was subdivided into seven sites. The choice of stations throughout the complex was based on criteria, including the presence or absence of cages, the distribution of cages throughout the complex and accessibility. The geographic coordinates of the study sites are presented in Table 1 and the location of each is shown in Figure 1. At each study station, four points were selected for sampling.

**Measurement of physico-chemical parameters and water sampling:** From June 2019 to May 2020, the physico-chemical parameters (temperature in °C. dissolved oxygen in mg.L$^{-1}$, pH, salinity in ‰, transparency in cm and depth in m) were measured in situ at each station once a month between 6:30 and 8:30 AM. Parallel to the in situ measurement of the parameters, water from the lagoon was taken from the euphotic zone (40-50 cm) using the Van-Dorn bottle, poured into dark bottles of 0.5 liter capacity and kept

Table 1. Geographic coordinates and characteristics of study sites.

| | Sites | Latitude | Longitude | Site characteristics |
|---|---|---|---|---|
| 1 | Adjadji | 6.437893 | 2.174565 | Extreme zone of the right arm of the complex. in contact with the flood plain with low aquaculture production and receiving the water that has washed out the palm grove plantations |
| 2 | Lokohoué | 6.402386 | 2.184292 | Area of high aquaculture production |
| 3 | Pont | 6.392554 | 2.199051 | Exit area of the water circulation receiving all types of waste |
| 4 | Tonon | 6.391409 | 2.184055 | Zone housing the farm with more cages in operation on the ecosystem (300 cages in 2019). zone of high aquaculture production |
| 5 | Tchiakpè | 6.388619 | 2.170374 | Intersection zone between right and left arm. no aquaculture production |
| 6 | Savi II | 6.422442 | 2.124627 | Average aquaculture production area receiving water that has washed out the palm plantations |
| 7 | Savi I | 6.404449 | 2.150161 | Extreme zone of the left arm in contact with the flood plain, receiving the water that has washed out the palm groves plantations. no aquaculture production |

Table 2. Quality criteria for the protection of freshwater aquatic life.

| Environmental parameters | Quality criteria | Effect considered | Reference |
|---|---|---|---|
| pH | 6.5 - 9.0 | Chronic effect | (USEPA, 2006) |
| $O_2$ (mg.L$^{-1}$) | >4 | Chronic effect | (Squilbin and Yourassowsky. 2005) |
| PT (mg.L$^{-1}$) | <0.02 | Chronic effect | (MDDEFP, 2013) |
| NT (mg.L$^{-1}$) | <12 | Chronic effect | (AGRBC, 2011) |

PT=Total Phosphorus; NT=Total Nitrogen

under refrigeration temperature until it reached the laboratory for various analyses. Chlorophyll-α, total phosphorus and total nitrogen concentrations were measured in the laboratory by spectrophotometry within 48 hours of sampling.

**Measurement of ecological production parameters (chlorophyll-α, nitrogen, phosphorus):** The determination of chlorophyll-α was carried out according to the monochromatic method (Lorenzen, 1967) using 90% acetone as solvent. Total nitrogen was determined by the peroxodisulphate mineralization method (Rodier et al., 2009) and for total phosphorus, the persulphate digestion method in acidic medium was used (method no. 8190 of Hach Compagny, 2005).

**Data processing and analysis:** The averages the physico-chemical parameters were calculated per station for the entire period of the study and per month. The spatial variation of the data include means, standard deviations and minima-maxima. The temporal variation was presented as a figure by month. After verification of normality by the Shapiro-Wilk test and homogeneity by the Levene test, the means of the different stations were compared to each other by the analysis of variance test ($P$<0.05). The R software was used for the different analyses. The spatio-temporal variation in chlorophyll-α, the total phosphorus and the total nitrogen concentrations was calculated and presented. The averages were compared with each other using the analysis of variance test ($P$<0.05). A reference value for the concentration of chlorophyll-α was calculated according to De Bortoli and Argillier (2008) as follows:

$$\text{Reference}[\text{Ch}-\alpha] = 10^{0.745-0.489 \times \log(\text{medium depth})}$$

The characterization of the trophic status of the Toho-Todougba lagoon complex was calculated based on four different indices namely the trophic status index of Carlson (1977), the trophic level index of Burns and Bryers (2000), the trophic status index of Neverova-Dziopak and Kowalewski (2018) and the eutrophication index of Primpas et al. (2010). These indeces are considered in the present study because they are specific to continental aquatic environments particularly lakes and lagoons and take into account most of the same parameters for their calculation. Then, the water quality index for the Protection of Aquatic Life proposed by the Canadian Council of Ministers of the Environment CCME-WQI (2001) was calculated and represented as a box-plot based on

Table 3. Trophic status characterization indices.

| Index | Classification scale |
|---|---|
| Trophic State Index (TSI) of (Carlson, 1977) | IET between [0 - 40[ : oligotrophic area; IET between [40 - 50[ : mesotropic area; EIT between [50 - 60[ : eutrophic area ; EIT > 60 : hyper-eutrophic area |
| The Trophic Level Index (TLI) of Burns and Bryers (2000) | TLI between 0 and 2, microtrophic area; TLI between 2 and 3, oligotrophic area; TLI between 3 and 4, mesotrophic area; TLI between 4 and 5, eutrophic area; TLI between 5 and 6, supertrophic area; TLI between 6 and 7. hypertrophic area |
| Trophic status index of Neverova-Dziopak and Kowalewski (2018) | EIT between 5.7 and 6, dystrophic area; EIT between 6 and 6.66, ultraoligotrophic area; EIT between 6.7-7.3, oligotrophic area; EIT between 7.4-8, mesotrophic area; EIT > 8; Eutrophic area |
| The Eutrophication Index (EI) of (Primpas et al., 2010) | EI between 0.04 and 0.38, oligotrophic area; EI between 0.37 and 0.87, mesotrophic area; EI between 0.83 and 1.51. eutrophic area |
| Water Quality Index for the Protection of Aquatic Life (CCME-WQI, 2001) | The index value between 0 and 100 is classified into five quality classes. Poor quality: 0-44; Poor quality: 45-64; Moderate pollution: 65-79; Good quality: 80 - 94; Excellent quality: 95 and 100 |

Table 4. Annual average of physico-chemical parameters for each study station.

| Sites | | T (°C) | DO (mg.L$^{-1}$) | pH | Transp (cm) | Sal (‰) | Dep (m) |
|---|---|---|---|---|---|---|---|
| Adjadji | M±Ecart type | 29.22±1.45$^{a}$ | 3.40±1.22$^{c}$ | 7.03±0.83$^{ab}$ | 44.74±0.32$^{a}$ | 2.19±0.52$^{ab}$ | 3.13±0.71$^{bc}$ |
| | Min-Max | 27-32.6 | 1.2-6.60 | 5.0-9.0 | 40-70 | 1.0-3.0 | 2.0-4.98 |
| Lokohoue | M±Ecart type | 29.3±1.34$^{a}$ | 4.72±0.99$^{ab}$ | 6.8±0.91$^{bc}$ | 46.28±0.33$^{a}$ | 2.19±0.57$^{ab}$ | 3.35±0.61$^{a}$ |
| | Min-Max | 26.8-32.6 | 1.60-6.90 | 5.10-9.14 | 41-80 | 1.0-3.0 | 2.20-4.79 |
| Pont | M±Ecart type | 29.5±1.19$^{a}$ | 4.17±1.11$^{a}$ | 7.21±0.95$^{a}$ | 47.06±0.35$^{a}$ | 2.17±0.56$^{b}$ | 3.18±0.56$^{abc}$ |
| | Min-Max | 28.00-32.1 | 2.44-7.4 | 5.6-9.4 | 40-78 | 1.0-3.0 | 2.20-4.5 |
| Savi1 | M±Ecart type | 29±3.34$^{a}$ | 3.5±1.38$^{bc}$ | 6.73±0.91$^{c}$ | 44.83±0.32$^{a}$ | 2±0.0$^{c}$ | 3±0.68$^{c}$ |
| | Min-Max | 29.10-32.2 | 1.20-7.7 | 5.0-8.7 | 24-85 | 2.0-2.0 | 1.80-4.8 |
| Savi2 | M± Ecart type | 29.36±1.20$^{a}$ | 3.99±1.34$^{a}$ | 6.78±0.89$^{bc}$ | 45.77±0.32$^{a}$ | 2.33±0.47$^{a}$ | 3.24±1$^{ab}$ |
| | Min-Max | 27.1-31.80 | 2.5-8.10 | 5.0-8.93 | 40-78 | 2.0-3.0 | 2.0-6.65 |
| Tchiakpe | M± Ecart type | 29.29±1.09$^{a}$ | 4.06±1.25$^{a}$ | 7.1±0.72$^{a}$ | 47.75±0.34$^{a}$ | 2.22±0.42$^{ab}$ | 3.37±0.49$^{a}$ |
| | Min-Max | 27.90-32.2 | 2.40-6.9 | 5.70-8.6 | 37-89 | 2.0-3.0 | 2.65-4.3 |
| Tonon | M± Ecart type | 29.29±1.05$^{a}$ | 4.16±1.22$^{a}$ | 7.12±0.80$^{a}$ | 46.7±0.34$^{a}$ | 2.14±0.54$^{bc}$ | 3.23±0.41$^{ab}$ |
| | Min-Max | 27.50-31.7 | 2.5-7.3 | 5.29-9.1 | 40-98 | 1.0-3.0 | 2.10-4.3 |
| *P*-value | | 0.741 | 0.00012 | 0.00157 | 0.998 | 0.00487 | 0.0133 |

Averages with different letters on the vertical differ from each other p-value =0.05; M=Mean; Min=Minimum; Max=Maximum; T=Temperature; Transp= Transparency; Sal= Salinity; Dep= Depth.

study stations. The quality criteria for the protection of aquatic life were selected in accordance with the literature (Table 2). The principle for determining these indices is summarized in Table 3.

## Results

**Physico-chemical parameters of the Toho-Todougba Lagoon:** The averages of the environmental parameters measured during the study are presented in Table 4. The average depth varies from 3 to 3.37 m for all study stations. The transparency varies from 44.74 to 47.75 cm without being different between stations ($P>0.05$). The salinity varies between 2-2.33‰ with a significant difference between stations ($P<0.05$). The average temperature for all the stations is around 29°C for an average dissolved oxygen level that varies between 3.40-4.72 mg.L$^{-1}$ and an average pH ranging from 6.73 to 7.21. The results revealed that with the exception of temperature, pH and dissolved oxygen vary significantly between stations ($P<0.05$).

**Variation in production parameters (chlorophyll-α, total phosphorus, total nitrogen):** The spatial variation in production parameters, including chlorophyll-α, phosphorus and nitrogen are presented in Table 5. The values for chlorophyll-α loading vary by station. The stations of Adjadji, Lokohoué and Tchiakpè with respective means of 18.17±1.54, 14.38±0.72 and 19.80±1.6 µg.L$^{-1}$ with a significantly higher chlorophyll-α load than the others ($P<0.05$).

Table 5. Spatial variation in chlorophyll-α, total phosphorus and total nitrogen concentration.

| | Sites of study | | | | | | |
|---|---|---|---|---|---|---|---|
| | Adjadji | Lokohoue | Pont | Tonon | Tchiakpe | Savi I | Savi II |
| Ch-a (µg.L$^{-1}$) | 18.17±1.54$^{a}$ | 14.38±0.72$^{a}$ | 7.41±0.61$^{b}$ | 8.14±0.48$^{b}$ | 19.80±1.6$^{ac}$ | 6.92±0.92$^{b}$ | 5.68±0.49$^{c}$ |
| P (mg.L$^{-1}$) | 0.25±0.03$^{a}$ | 0.10 ±0.07$^{b}$ | 0.18±0.02$^{a}$ | 0.09±0.01$^{c}$ | 0.16±0.02$^{b}$ | 0.13±0.07$^{b}$ | 0.22±0.02$^{a}$ |
| N (mg.L$^{-1}$) | 3.01±0.96$^{a}$ | 2.10 ±0.02$^{b}$ | 3.70±0.16$^{a}$ | 2.47±0.04$^{b}$ | 2.80±0.04$^{b}$ | 1.91±0.05$^{b}$ | 3.79±0.35$^{a}$ |

Averages with different letters on the horizontal differ from each other p-value =0.05; Ch-a = Chlorophyll-a; P = Phosphorus, N=Nitrogen

Table 6. Spatial variation in chlorophyll-α, total phosphorus and total nitrogen concentration.

| Months | Organic pollution parameters | | |
|---|---|---|---|
| | Chlorophyll-α (µg.L$^{-1}$) | Phosphorus (mg.L$^{-1}$) | Nitrogen (mg.L$^{-1}$) |
| June | 0.33±0.10$^{a}$ | 0.11±0.04$^{a}$ | 2.58±0.89$^{a}$ |
| July | 0.19±0.09$^{b}$ | 0.42±0.09$^{b}$ | 2.56±0.88$^{a}$ |
| August | 0.28±0.12$^{a}$ | 0.42±0.09$^{b}$ | 2.57±0.89$^{a}$ |
| September | 0.26±0.14$^{a}$ | 0.29±0.07$^{c}$ | 2.58±0.89$^{a}$ |
| October | 0.73±0.16$^{c}$ | 0.02±0.00$^{d}$ | 3.24±0.99$^{b}$ |
| November | 0.73±0.2$^{c}$ | 0.02±0.01$^{d}$ | 3.24±0.99$^{b}$ |
| December | 23.53±5.42$^{d}$ | 0.16±0.02$^{ac}$ | 4.03±0.91$^{b}$ |
| January | 37.88±6.81$^{e}$ | 0.09±0.01$^{d}$ | 2.26±0.58$^{a}$ |
| February | 37.89±6.68$^{e}$ | 0.09±0.01$^{d}$ | 2.26±0.58$^{a}$ |
| March | 5.66±1.69$^{f}$ | 0.10±0.01$^{a}$ | 3.00±0.53$^{a}$ |
| April | 5.63±1.60$^{f}$ | 0.10±0.01$^{a}$ | 3.00±0.53$^{a}$ |
| May | 25.08±5.71$^{d}$ | 0.13±0.01$^{a}$ | 2.58±0.88$^{a}$ |
| *P*-value | <0.05 | <0.04 | <0.05 |

Averages with different letters on the vertical differ from each other *P*-value =0.05

The Savi II station had the lowest chlorophyll-α load (5.68±0.49 µg.L$^{-1}$) while the Pont, Tonon and Savi I stations with respective averages of 7.41±0.61, 8.14±0.48 and 6.92±0.92 µg.L$^{-1}$ recorded a moderate load. The reference value of chlorophyll-α for this ecosystem for the average depth of 3.20 m, is 13.781 µg.L$^{-1}$. By comparing the chlorophyll-α load of each station to the calculated reference value, it appears that the sites Adjadji and Tchiakpè have an average significantly higher than the reference value while all the other sites have a value below it, except the station of Lokohoué which has a value not different from the reference value.

As for phosphorus concentration, the Adjadji, Pont and Savi II sites have significantly higher concentrations with respective values of 0.25±0.032, 0.18±0.02 and 0.22±0.02 mg.L$^{-1}$, respectively ($P$<0.05). The Tonon site has the lowest concentration (0.09±0.01 mg.L$^{-1}$). The same trend was observed at the nitrogen level for the highest concentrations (Adjadji: 3.01±0.96; Pont: 3.7±0.16; Savi II: 3.7±0.35 mg.L$^{-1}$). These concentrations are significantly different from those at the other stations i.e. the lowest nitrogen concentration was at the Savi I station as 1.91±0.05 mg.L$^{-1}$.

The temporal variation in chlorophyll-α, phosphorus and nitrogen loading in Toho-Todougba Lagoon is summarized in Table 6. The chlorophyll-α load varied significantly between months. December, January, February and May are the months in which high chlorophyll-a concentrations are obtained (respectively 23.53±5.42, 37.88±6.81, 37.89±6.68, and 25.08±5.71 mg.L$^{-1}$). March to April have a moderate load of 5.63±1.69 mg.L$^{-1}$. The month of July recorded lower averages (0.19±0.09 mg.L$^{-1}$). The concentration recorded for phosphorus has a tendency more or less opposite to that of chlorophyll-α so that the months of June, December, January, February, March, April and May had the lowest concentrations ranging from 0.09±0.01 to 0.16±0.02 mg.L$^{-1}$. July (0.42±0.09 mg.L$^{-1}$), August (0.42±0.09 mg.L$^{-1}$) and September (0.29±0.07 mg.L$^{-1}$) measured concentrations that are significantly higher than the other months ($P$<0.05). With regard to nitrogen, only

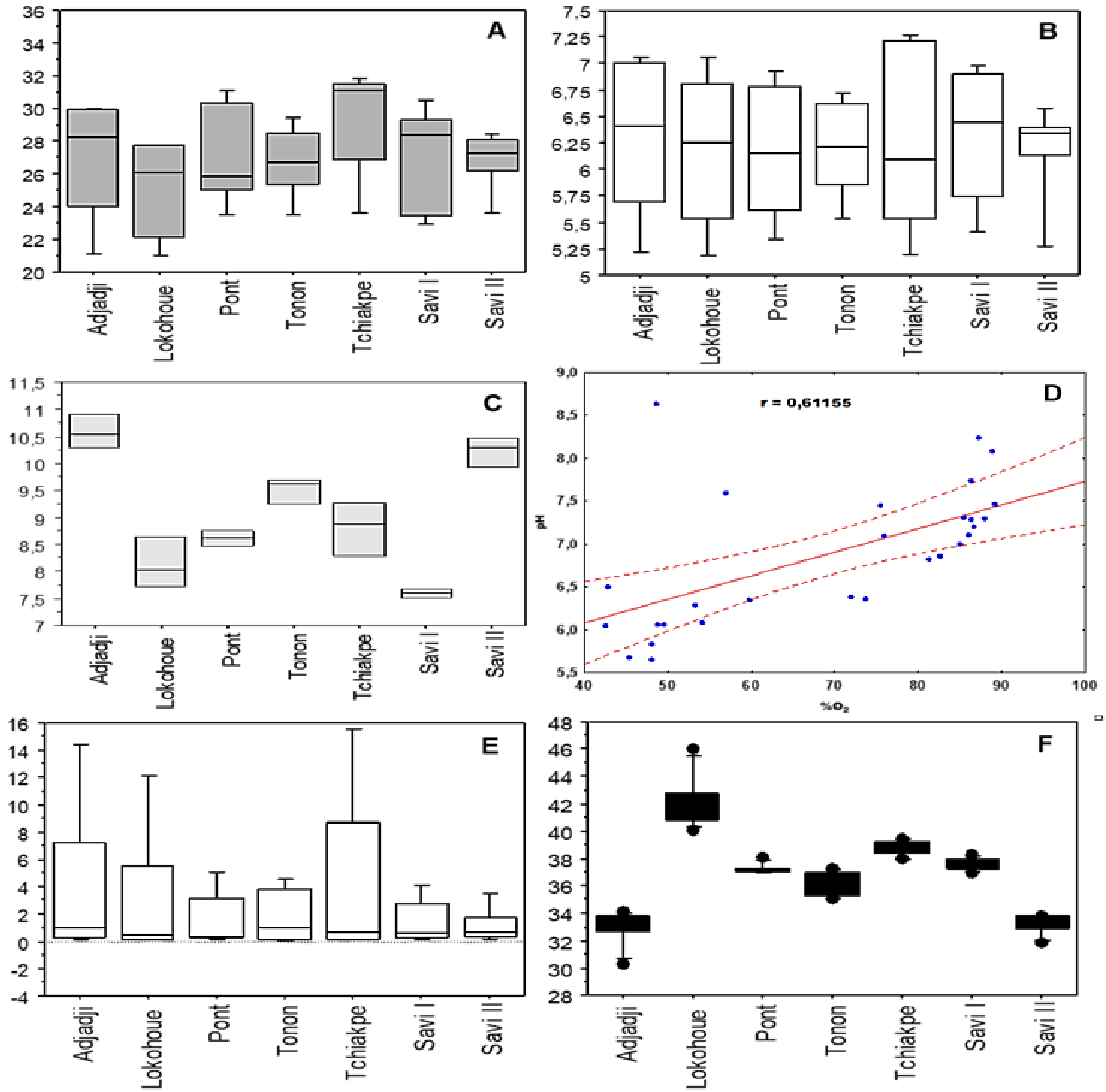


Figure 2. (A) Trophic Status Index of Carlson (1977), (B) Trophic Level Index Burns and Bryers (2000); (C) Trophic Status Index of Neverova-Dziopak and Kowalewski (2018), (D) Linear regression between pH and %O2; (E) Eutrophication Index of Primpas et al. (2010); (F) Water Quality Index for the Protection of Aquatic Life.

the concentrations in October, November and December recorded significantly higher averages than the others, ranging from 3.24±0.99 to 4.03±0.91 mg.L$^{-1}$. Concentrations in the other months ranged from 2.58±0.88 to 3.00±0.53 mg.L$^{-1}$.

**Trophic status characterization index:** The trophic status of the Toho-Todougba lagoon complex has been characterized on the basis of four index. Following the Carlson (1977) scale, it appears from Figure 2A that none of the stations recorded a Carlson index that exceeds the limit of 40 representing the maximum limit for characterizing an oligotrophic environment i.e. the Toho-Todougba lagoon complex is in an oligotrophic state. The Burns and Bryers (2000) index showed in Figure 2B indicating the opposite by revealing that all study stations recorded a value greater than 5 which is the critical threshold for a eutrophic environment. The values reached the threshold of 6 or even 7 indicating that the Toho-Todougba lagoon complex is in an enlarged state. The index of Neverova-Dziopak and Kowalewski (2018) based on the relationship between pH and %$O_2$

revealed that all the stations are eutrophied with the exception of Savi I which recorded for this index a value lower than 8 and to some extent the station of Lokohoue (Fig. 2C). The sites of Adjadji and Savi II recorded for this index a value higher than 10, which testifies to the level of pollution of these sites. The correlation coefficient r of the regression in pH and %O2 is higher than 0.6 (Fig. 2D; r = 0.61155) and testifies that the criteria of use of this index is respected. This eutrophication trend of the Toho-Todougba lagoon complex is also confirmed by the eutrophication index of Primpas et al. (2010) which recorded for all sites, a value above the critical threshold of eutrophication which is 1.51 (Fig. 2E). In contrast to the index of Neverova-Dziopak and Kowalewski (2018), the index of Primpas et al. (2010) revealed that the Savi II site recorded the lowest eutrophication level compared to the other stations, but without guaranteeing an ecologically pleasing health of aquatic resources.

**Water quality index for the protection of aquatic life (CCME-WQI):** The water quality index for the protection of aquatic life was calculated for each station (Fig. 2F). When considering the decision scale for this index, all sites recorded a value of less than 50. This bodes poor quality of life for the aquatic resources of the Toho-Todougba lagoon complex. Considering each site, the site of Adjadji and Savi II recorded the lowest values (35).

## Discussions

**Physico-chemical parameters and production parameters:** Physico-chemical parameters influence water quality and the health of aquatic ecosystems. In most developing countries, aquatic environments are subject to a variety of problems related to anthropogenic activities and the misuse of their resources (El-Serehy et al., 2018). These activities are likely to influence the physical and chemical parameters of aquatic environments. Thus, a state of permanent stress is increasingly observed in most aquatic ecosystems. In the present study, the parameters temperature and pH did not record average values likely to disturb aquatic life. The values obtained (29°C; 6.73 to 7.21) for temperature and pH are characteristic of tropical environments (Houssou et al., 2017) and could not particularly affect the biotope of the ecosystem. However, transient decreases in pH below 6 in some locations are observed for some measurement sites indicating a slightly acidic pH. This transient and unevenly distributed acidity within the same study station may result from the decomposition of organic matter or the dissolution of atmospheric $CO_2$ at these sites (Beaune et al., 2018). For dissolved oxygen, the average varies between 3.19 and 4.33 $mg.L^{-1}$ exposes the quality of life at the water level. This concentration is vital for aquaculture species and in this case Cichlids, the most dominant in Benin's aquatic ecosystems (Achoh et al., 2018). However, disparities are observed depending on the time of year for some stations, notably Adjadji and Savi II, so that very low values of the order of 1.77 $mg.L^{-1}$ are recorded for the months of June, January, February and March. This low concentration is characteristic of polluted environments with a reversible character (Squilbin and Yourassowsky, 2005). Although having a reversible character, this low concentration of dissolved oxygen can indirectly contribute to global warming by promoting the oxidation of ammonia into nitrous oxide ($N_2O$), which is a greenhouse gas (Peng et al., 2015).

Regarding the production parameters (chlorophyll-α, phosphorus and nitrogen), this study revealed that the sites of Adjadji (18.17±7.54 $\mu g.L^{-1}$) and Tchiakpè (19.80±5.3 $\mu g.L^{-1}$) and to a lesser extent that of Lokohoue (14.38±2.52 $\mu g.L^{-1}$) recorded values higher than the reference value of chlorophyll-α (13.781 $\mu g.L^{-1}$) for this ecosystem. This indicates that there is increased phytoplankton production at these stations. For the Adjadji site, agricultural activities and large livestock breeding in the large palm grove of Gakpe are developing and runoff drains organic waste in this portion of the lagoon (Koné et al., 2009). The Tchiakpè site is a transit strait for the population of Tchiakpecodji (a village in the district of the commune) on their way to the commercial city and market of Pahou. This site receives waste of all kinds inciting phytoplankton production, hence its value as a polluted station. Mama et al. (2012) and Djihouessi et al. (2019) reported similar pollution on behalf of Lake Nokoué where fluvio-lagunar transport and human waste from the Dantokpa market caused eutrophication of the lake. Along with nitrogen, phosphorus is a limiting factor in the eutrophication of aquatic ecosystems (Issola et al., 2008; Dodds and Smith, 2016; Schindler et al., 2016). Total phosphorus concentrations recorded in this study ranged from 0.02 to 0.42 $mg.L^{-1}$ for all sites and months. These values exceed the phosphorus concentrations (0.005 to 0.1 $mg.L^{-1}$) for continental aquatic ecosystems with hydrobiological functioning without exogenous influence (Issola et al., 2008). Consequently, the concentrations of phosphorus in the present study refer to anthropogenic input into the ecosystem (Powers et al., 2016). Dietary intake in the highly developed floating cage fish farming in the lagoon is also an important source of phosphorus for the ecosystem coupled with the organic load of runoff water. Worse, a floating infrastructure dedicated to festive events is erected in the heart of this lagoon complex with all these corollaries of organic pollution. As phosphorus is a limiting factor in eutrophication, the risk will be increasingly high that fish farming will be further developed on the water body and that the discharge of organic matter by man will be increasingly significant. As for nitrogen, the averages range from 1.91 to 4.02 $mg.L^{-1}$ considering the spatial and temporal variation. This concentration is below 12 $mg.L^{-1}$ which is the threshold value for good water quality according to AGRBC (2011). It appears from the values recorded that the nitrogen load in the Toho-Todougba lagoon ecosystem could not negatively influence the ecological balance of the environment.

**Trophic status of the ecosystem:** To characterize the trophic status of the Toho-Todougba lagoon complex, several indices were calculated and the recodef values were compared to the classification scale for each index. Thus, Carlson's (1977) trophic status index, based on transparency, phosphorus and chlorophyll-α, obtained values that are below the threshold value of an oligotrophic environment and shows that all the stations are in good ecological health and are not, at least for the moment, vulnerable to the pressure of organic pollution. In contrast, the trophic level index of Burns and Bryers (2000), the eutrophication index of Primpas et al. (2010) and the eutrophication index of Neverova-Dziopak and Kowalewski (2018) showed a pollution trend contrary to the Carlson index. Indeed, the Toho-Todougba lagoon complex is in a state of advanced eutrophication according to these indices. This level of pollution is all the more critical as the index of Primpas et al. (2010) characterized the ecosystem in a hypertrophic state. The combination of chemical parameters to determine overall water quality in the ecosystem has shown that water quality is poor for the chronic protection of aquatic life based on the CCME-WQI water quality index. The values for this index at all stations is below 50 (minimum threshold for good quality of life). It therefore reflects that all stations are unfit for aquatic life. By grading the sites, Adjadji and Savi II are the most polluted stations. This is in line with the results of the Neverova-Dziopak and Kowalewski (2018) index. The level of pollution of these two stations exposed by these indices is related to the geographical position of the Adjadji station which is presented as the receptacle of field leaching water on the one hand, and the receptacle of wastewater from the numerous hotels and rest homes that are installed all around and the fish farm on the other hand. It is the same for the Savi II site.

It results from the pooling of the measurements of production parameters (Chlorophyll-α, phosphorus and nitrogen) and calculated indices that the Toho-Todougba lagoon complex is in a eutrophic state. Even if according to Bourdin (2004), the eutrophication of a water body exists outside of any human action, activities such as fish farming and agriculture would have an important part in the eutrophic state of the Toho-Todougba lagoon. Thus, the eutrophication of the lagoon will worsen over time as long as fish farming in cages is developed and significant input of organic matter from agriculture and dwellings is observed. In addition, another factor favoring the eutrophic evolution of this lagoon complex is the closure of the contact of the Toho-

Todougba lagoon with the sea through the coastal lagoon of Ouidah. As a result, there is no possibility of evacuation and renewal of water from the Toho-Todougba lagoon and all organic matter is concentrated there. As a result of this eutrophication, organisms in the Toho-Todougba lagoon complex live permanently under the stress of organic pollution. The long-term consequences are the decline of stocks, the rarefaction of certain species in the catches and the decrease in the size of adults. The consequence on fishing practice is the use of fine mesh nets for catches as a measure of resilience by fishermen and a progressive destruction of the ecosystem. Continuous monitoring of the trophic level is necessary to mitigate or prevent serious negative impacts on aquatic resources and anthropogenic activities (Napiórkowska -Krzebietke and Hutorowicz, 2014).

## Conclusion

The Toho Todougba lagoon complex is in a state of eutrophication considering the calculated trophic status indices. The paradox of this study is that the recorded physico-chemical parameters indicate that the environment is still conducive to an intensification of fish farming. What is the share of fish farming in this evolution of the trophic level of the Toho-Todougba lagoon? Will we continue to intensify fish farming with regard to the physico-chemical parameters despite the organic pollution revealed by the trophic status indices? Studies on the dynamics of chlorophyll production and carrying capacity are essential to further elucidate the decision-makers on management and environmental preservation measures to safeguard this ecosystem.

## Acknowledgements

The authors thank the Laboratory of Applied Hydrology (LHA) of the Faculty of Science and Technology of the University of Abomey-Calavi for its contribution through laboratory analysis of production parameters.

## References

Achoh M.E., Agadjihouèdé H., Gangbé L., Dougnon T.V., Hounmanou Y.M.G., Baba-Moussa L. (2018). Diversité et abondance des poissons tilapias exploités au Bénin et le virus TiLV (Tilapia Lake virus): Revue de synthèse et prospection des risques d'explosion de l'épidémie. Afrique Science, 14(2): 90-99.

Aïzonou R., Achoh M.E., Agadjihouèdé H. (2019). Analysis of Practice of Cage Aquaculture System in TohoTodougba Lagoon, Southern Benin (West Africa). Aquaculture Studies, 19(2): 113-123.

Arrêté Gouvernementale de la Région de Bruxelles-Capitale (AGRBC). (2011). Normes de qualité environnementale, des normes de qualité de base et des normes chimiques pour les eaux de surface contre la pollution causée par certaines substances dangereuses et autres polluants. 22887 p.

Beaune D., Sellier Y., Luquet G., Grandjean F. (2018). Freshwater acidification: An example of an endangered crayfish species sensitive to pH. Hydrobiologia, 813(1): 41-50.

Bourdin L. (2004). Caractérisation et suivi de de l'eutrophisation des lacs et cours d'eau lentiques en France, Une ouverture Europenne. Synthèse technique, Office International de l'Eau-SNIDE. 30 p.

Burns N., Bryers G. (2000). Protocol for Monitoring Trophic Levels of New Zealand Lakes and Reservoirs. Ministry for the Environment. 130 p.

Canadian Council of Ministers of the Environment (CCME-WQI). (2001). Canadian Water Quality Guidelines for the Protection of Aquatic Life. Canadian Council of Ministers of the Environment, Winnipeg. 5 p.

Capo-Chichi H.B.P., Adandédjan D., Adandédjan H.A., Houélomè M.A. (2018). Diversité des macro-invertébrés benthiques du complexe lagunaire TohoTodougba au Sud-Ouest du Bénin. Bulletin de la Recherche Agronomique du Bénin (BRAB, Numéro Spécial Développement Agricole Durable (2018).

Carlson R.E. (1977). A trophic state index for lakes1: Trophic state index. Limnology and Oceanography, 22(2); 361-369.

Chippaux J.P., Massougbodji A., Zomadi A., Kindafodji B.M. (1990). Etude épidémiologique des schistosomes dans un complexe lacustre côtier de formation récente. Bulletin de la Société de Pathologie Exotique, 83: 498-509.

De Bortoli J., Argillier C. (2008). Définition des conditions de référence et des limites des classes d'état sur la base d'une approche pressions/impacts, Plans d'eau, Paramètre chlorophylle-a. irstea. 49 p.

Degefu F., Mengistu S., Schagerl M. (2011). Influence of fish cage farming on water quality and plankton in fish ponds: A case study in the Rift Valley and North Shoa reservoirs, Ethiopia. Aquaculture, 316(1): 129-135.

Delgado C., Rosegrant M., Steinfeld H., Ehui S., Courbois C. (2001). Livestock to 2020: The next food revolution. Outlook on Agriculture, 30(1): 27-29.

Djihouessi M.B., Djihouessi M.B., Aina M.P. (2019). A review of habitat and biodiversity research in Lake Nokoué, Benin Republic: Current state of knowledge and prospects for further research. Ecohydrology and Hydrobiology, 19(1): 131–145.

Dodds W.K., Smith V.H. (2016). Nitrogen, phosphorus, and eutrophication in streams. Inland Waters, 6(2): 155-164.

El-Serehy H.A., Abdallah H.S., Al-Misned F.A., Irshad R., Al-Farraj S.A., Almalki E.S. (2018). Aquatic ecosystem health and trophic status classification of the Bitter Lakes along the main connecting link between the Red Sea and the Mediterranean. Saudi journal of biological sciences, 25(2): 204–212.

FAO. (2018). La situation mondiale des pêches et de l’aquaculture 2018. Atteindre les objectifs de développement durable. Rome. 254 p.

Gorlach-Lira K., Pacheco C., Carvalho L.C.T., Melo Júnior H.N., Crispim M.C. (2013). The influence of fish culture in floating net cages on microbial indicators of water quality. Brazilian Journal of Biology, 73: 457-463.

Houssou A., Ahouansou Montcho S., Montchowui E., Bonou C. (2017). Spatial and seasonal characterization of water quality in the Ouémé River Basin (Republic of Benin, West Africa). Egyptian Journal of Chemistry, 60(6): 1077-1090.

Issola Y., Kouassi A.M., Dongui B., Biemi J. (2008). Caractéristiques physico-chimiques d’une lagune côtière tropicale: Lagune de Fresco (Côte d’Ivoire). Afrique Science: Revue Internationale des Sciences et Technologie, 4(3).

Koné M., Bonou L., Bouvet Y., Joly P., Koulidiaty J. (2009). Etude de la pollution des eaux par les intrants agricoles: Cas de cinq zones d’agriculture intensive du Burkina Faso. Sud Sciences et Technologies, 17.

Lorenzen C.J. (1967). Determination of chlorophyll and pheo-pigments: Spectrophotometric equations 1. Limnology and oceanography, 12(2): 343-346.

Mama D., Aina M., Alassane A., Boukari O., Chouti W., Deluchat V., Bowen J., Afouda A., Baudu M. (2012). Caractérisation physico-chimique et évaluation du risque d’eutrophisation du lac Nokoué (Bénin). International Journal of Biological and Chemical Sciences, 5(5): 2076.

Ministère du Développement durable, de l’Environnement de la Faune et des Parcs (MDDEFP). (2013). Critères de qualité de l’eau de surface. Rapport d’étude, Direction du suivi de l’état de l’environnement. 526 p.

Napiórkowska-Krzebietke A., Hutorowicz A. (2014). Phytoplankton in an ecological status assessment of the vendace-type Lake Dejguny (northeastern Poland). Fisheries and Aquatic Life, 22(1): 29-40.

Neverova-Dziopak E., Kowalewski Z. (2018). Foundation and application of new method of trophic state assessment. Geomatics and Environmental Engineering, 12(2): 63.

Peng L., Ni B.-J., Ye L., Yuan Z. (2015). The combined effect of dissolved oxygen and nitrite on N2O production by ammonia oxidizing bacteria in an enriched nitrifying sludge. Water Research, 73: 29-36.

Powers S.M., Bruulsema T.W., Burt T.P., Chan N.I., Elser J.J., Haygarth P.M., Howden N.J., Jarvie H.P., Lyu Y., Peterson H.M. (2016). Long-term accumulation and transport of anthropogenic phosphorus in three river basins. Nature Geoscience, 9(5): 353-356.

Primpas I., Tsirtsis G., Karydis M., Kokkoris G.D. (2010). Principal component analysis: Development of a multivariate index for assessing eutrophication according to the European water framework directive. Ecological Indicators, 10(2): 178-183.

Rodier J., Legube B., Merlet N., Brunet R. (2009). L’analyse de l’eau—9e éd.: Eaux naturelles, eaux résiduaires, eau de mer. Dunod.

Schenone N.F., Vackova L., Cirelli A.F. (2011). Fish-farming water quality and environmental concerns in Argentina: A regional approach. Aquaculture International, 19(5): 855-863.

Schindler D.W., Carpenter S.R., Chapra S.C., Hecky R.E., Orihel D.M. (2016). Reducing phosphorus to curb Lake Eutrophication is a success. Environmental Science and Technology, 50: 8923-8929.

Squilbin M., Yourassowsky C. (2005). Qualité physico-chimique et chimique des eaux de surface: Cadre général. Institut Bruxellois pour la Gestion de l’Environnement / Observatoire des Données de l’Environnement.16 p.

United State Environmental Protection Agency (USEPA).

2006. National recommended water quality criteria, Office of water, Office of science and Technology. 4 p.

Vodougnon H., Lederoun D., Amoussou G., Adjibogoun D., Lalèyè P. (2018). Ecologic stress in fish population of Lake Nokoué and Porto-Novo Lagoon in Benin. International Journal of Fisheries and Aquatic Studies, 6(3): 292-300.

Yoboue K.P., Aboua B.R.D., Berte S., Coulibaly J.K., Ouattara N.I., Kouamelan E.P. (2018). Impacts des exploitations piscicoles en cages flottantes sur la structure des macroinvertébrés benthiques de la lagune Ebrié (Côte d'Ivoire). International Journal of Biological and Chemical Sciences, 12(2): 769-780.