



# Bioindication of the Ecological Quality of the Ouémé Delta: An Approach Based on Abundance/Biomass Comparison Curves Using Benthic Macroinvertebrates

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**Abstract:** Benthic macroinvertebrates are widely recognized as effective biological tools that offer several advantages for monitoring water quality. Consequently, various index-based methods have been developed and applied in different aquatic environments. In this study, three indices were used for ecological assessment: the Abundance/Biomass Comparison (ABC), the Difference in Area Proportion (DAP), and the Shannon Evenness Proportion (Log<sub>e</sub>(SEP)). From April 2018 to May 2019, eight sampling stations distributed along a longitudinal pollution gradient were surveyed monthly. Collected taxa were identified to the genus level, and their abundance and biomass were used to calculate ecological stress indices. A total of 19,025 individuals, representing a biomass of 129.313 g, were analyzed, consisting of insects (59%), gastropods (26%), bivalves (10%), and crustaceans (4%). For insects, the mean DAP was 0.04, with the biomass curve dominating upstream (mean DAP=-0.07) and the abundance curve dominating downstream (0.10), although the difference was not significant (p=0.14). The mean Log<sub>e</sub>(SEP) was 0.28, with no spatial variation. Among mollusks, the mean DAP was -0.12, significantly lower upstream (-0.29) than downstream (-0.02) (p=0.04), while the mean Log<sub>e</sub>(SEP) of -1.61 indicated high ecological stress downstream. Crustaceans showed a mean DAP of 0.07 (±0.17) and a mean Log<sub>e</sub>(SEP) of -0.51, suggesting moderate pressure. Overall, ABC curves combined with DAP and SEP values indicated moderate ecological stress, providing a useful environmental diagnostic tool for ecosystem monitoring and management.

## 1. Introduction

Benthic macro-invertebrates are frequently used as biological indicators for monitoring of aquatic ecosystems (Kashian & Burton, 2000; Nichols & Norris, 2006; Grande *et al.*, 2008). This advantage of macro-invertebrates is due to the fact that they integrate environmental conditions as they importance being the main element of food web (Borja *et al.*, 2000). Various studies have shown that this group is a favorable material in ecological studies, particularly in estimating the biological quality

of water (Bebba *et al.*, 2015). Indeed, when subjected to disturbance, community structure and composition change due to the disappearance of sensitive taxa and/or the appearance of more tolerant ones. Invertebrate communities can be characterized according to biomass, abundance, specific richness and their variation in the time and space as a function of nature and stress type (De Sousa *et al.*, 2008). Considering this importance, benthic fauna in Benin draws particular attention through deeper studies in aquatic ecosystems. Indeed, works of Gnohossou (2006) enabled to know diversity, abundance, spacio-temporal variations and the place of food chain of benthic fauna of Lake Nokoué. By the same way, works of Adandédjan (2012) on Porto-Novo and Coastal lagoons enabled to determine stress level of these water bodies thanks to the use of benthic macro-invertebrates communities.

Benin has a complex water system though the most important is Ouémé River. It plays an important ecological role in the conservation of aquatic fauna and economic for surrounding population (Lalèyè *et al.*, 2004 ; Chikou, 2006). as declared RAMSAR site in 2000, its delta part though subject to degradation risk (Toko, 2007; Yehouenou-Pazou, 2005) was not assessed regarding benthic macro-invertebrates.

To analyze ecological integrity of benthic macro-invertebrates communities, several tools comprising Abundance and Biomass Comparison (ABC) curves, DAP (Difference Area Proportion) and the Shannon-Wiener Equitability Proportion (SEP) constitute an effective alternative for biotic indexes to assess impact of ecological stress (Warwick, 1986). These approaches are interesting due to they enable understand community response to human pressure through development of diverse strategies (McManus & Pauly, 1990).

In this context, the current work aims to evaluate stress level of macro-invertebrate community in the Ouémé Delta by ABC, DAP and SEP indexes to appreciate ecological quality of ecosystem. It will consist to study spatial variation of these indicators by mentioning degradation areas affecting communities in order to make up tools for integrate delta management.

## 2. Methodology

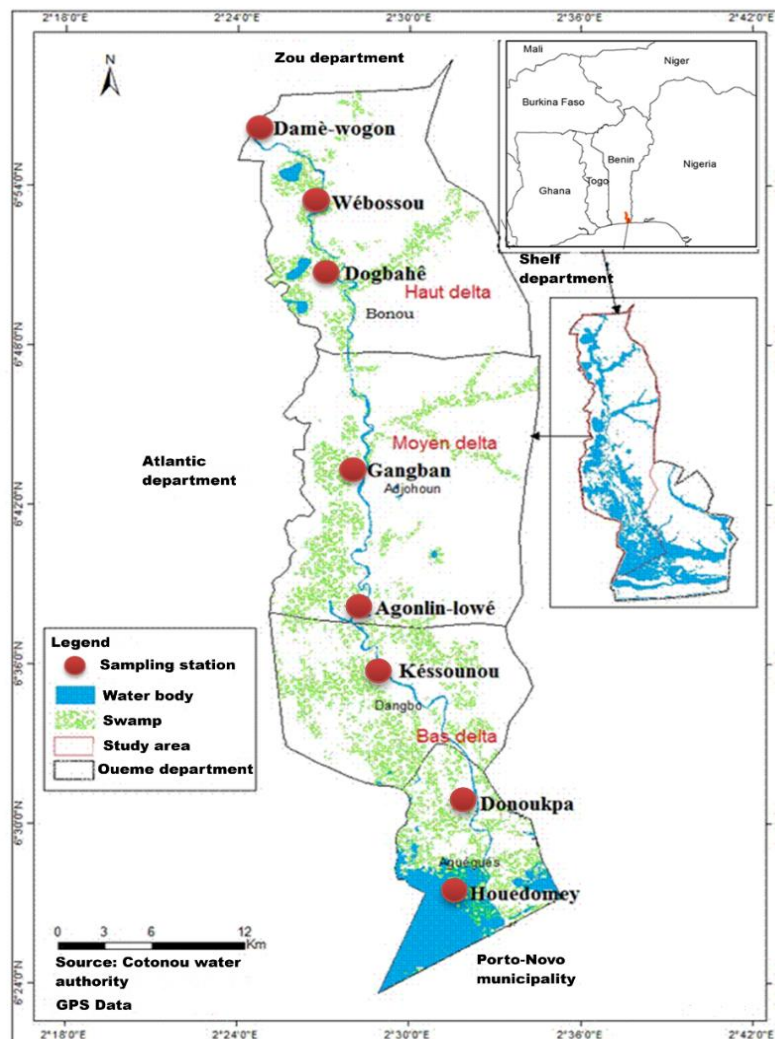
### 2.1 Study area

The study was led in the Ouémé Delta River. This river is 510 km long with more than 50000 km<sup>2</sup> (variable according to water periods) is the greatest basin in Benin (Lalèyè *et al.*, 2004). Eight stations (**Figure 1**) were chosen to represent spacio-longitudinal gradient and pollution (weeds, domestic flows, piloti habitations, human density) considering stations accessibility across periods and the presence of variable habitats in each station.

### 2.2 Sampling of benthic macro-invertebrates

Linear systematic sampling method was used in the current study (Lazorchak *et al.*, 1998). Data were collected monthly between April 2018 and may 2019 corresponding to 12 sampling campaign. In each station, macro-invertebrates were sampled using Surber sampler (mesh 500 µm, 0.25 m<sup>2</sup>). The sample operation was replicated three times in each station. Campaigns were separated regarding densities and biomass in order to assess different stations individually. Macro-invertebrates were washed before being preserved with formaldehyde 5%. Samples were brought to laboratory for sorting and identification. Complete sorting of organisms was carried out in laboratory using binocular lens *Olympus SZ40*. Different taxons sorted were identified at genus level using standard key of Durand & Lévêque (1981), Merrit & Cummins (1996), Moisan (2010), Diomandé *et al.*, (2000), Tachet *et al.*, (2010), Grassé & Doumenc (1993). The abundance was obtained by the number of individuals per m<sup>2</sup>

and corresponding biomass to fresh organic weight was determined after weighing using electronic scale 200 g and 0.001 precision. In mollusks, shell weight was removed. It represents the 2/3 of fresh weight (Lévêque *et al.*, 1983).



**Figure 1.** Map showing the sampling Sites of the Study

### 2.3 Data treatment

To determine stress presence in the different stations, we used simultaneously abundance and biomass matrices comprising macro-invertebrate taxons. Data were treated with ecological indexes ABC (Comparaison Abondance/Biomasse), DAP (Difference Area Proportion) and SEP (Shannon Equitability Proportion).

- ABC index: it is based on ecological theory that stress free community are near natural balance. Developed by Warwick (1986), the index can be defined as mean of difference between cumulated proportions of biomass and abundance according to the following formula:

$$ABC = \frac{Bi - Ai}{N}$$

With ABC = Abundance – Biomass Comparison; Bi = biomass proportion of the species i (classified in decreasing proportion order); N = total number of observed species.

The index is negative in highly stressed area, nearby zero if the medium is balanced or moderately stressed and positive in a non-stressed area. The concept model proposed by Warwick (1986) uses "dominance-k" curves. However, this graphic method lacks statistical test for quantifying divergence level between the two curves leading us to adopt the DAP index.

- DAP index: As proposed by McManus and Pauly (1990), this index quantifies the difference between abundance and biomass curves. This DAP difference is expressed as a proportion of the total surface of the graphic when it is divided by the logarithm of the total number of species. So, biomass surface is calculated as follow:

$$Biomass\ area = \sum_1^{s-1} [Ci + (0,5 \times Yi + 1)] \times [\ln(i+1) - \ln(i)]$$

With S = total number of species; Ci = cumulated biomass till abundance i species; Yi = biomass of species i. The abundance surface is calculated by the same way. DAP can be obtained as follow:

$$DAP = \frac{Abundance\ area - Biomass\ area}{\ln(s)}$$

So, DAP index is comprised between -1 and +1, where high values indicate stress conditions.

- Log<sub>e</sub>(SEP) index: developed by McManus & Pauly (1990), it measures the Shannon-Wiener Equitability Proportion (SEP) and enables estimation of diversity proportion of abundance and biomass making more efficient ABC curves interpretation. This index that increases in line with pollution can be calculated as follow:

$$SEP = \frac{H'_{Biomass}}{H'_{Abundance}}$$

With SEP = Shannon Equitability Proportion, H' <sub>biomass</sub> and H' <sub>abundance</sub> = Shannon diversity index respectively determined from biomass and abundance.

There is high correlation between DAP and Log<sub>e</sub>(SEP), and high values of SEP logarithm reveal stress conditions (McManus & Pauly, 1990).

Statistically, the Shapiro-Wilk test was used to verify the normality of data. Descriptive statistics (means, standard deviation, minimum-maximum) were calculated. A one-way ANOVA was carried out in order to appreciate spatial differences among upstream, downstream and center, followed by Tukey post-hoc test in case of significance (p < 0.05). The Pearson correlation was used to evaluate relationships between DAP and Log<sub>e</sub>(SEP). These tests were carried out thanks to the R software.

### 3. Results and Discussion

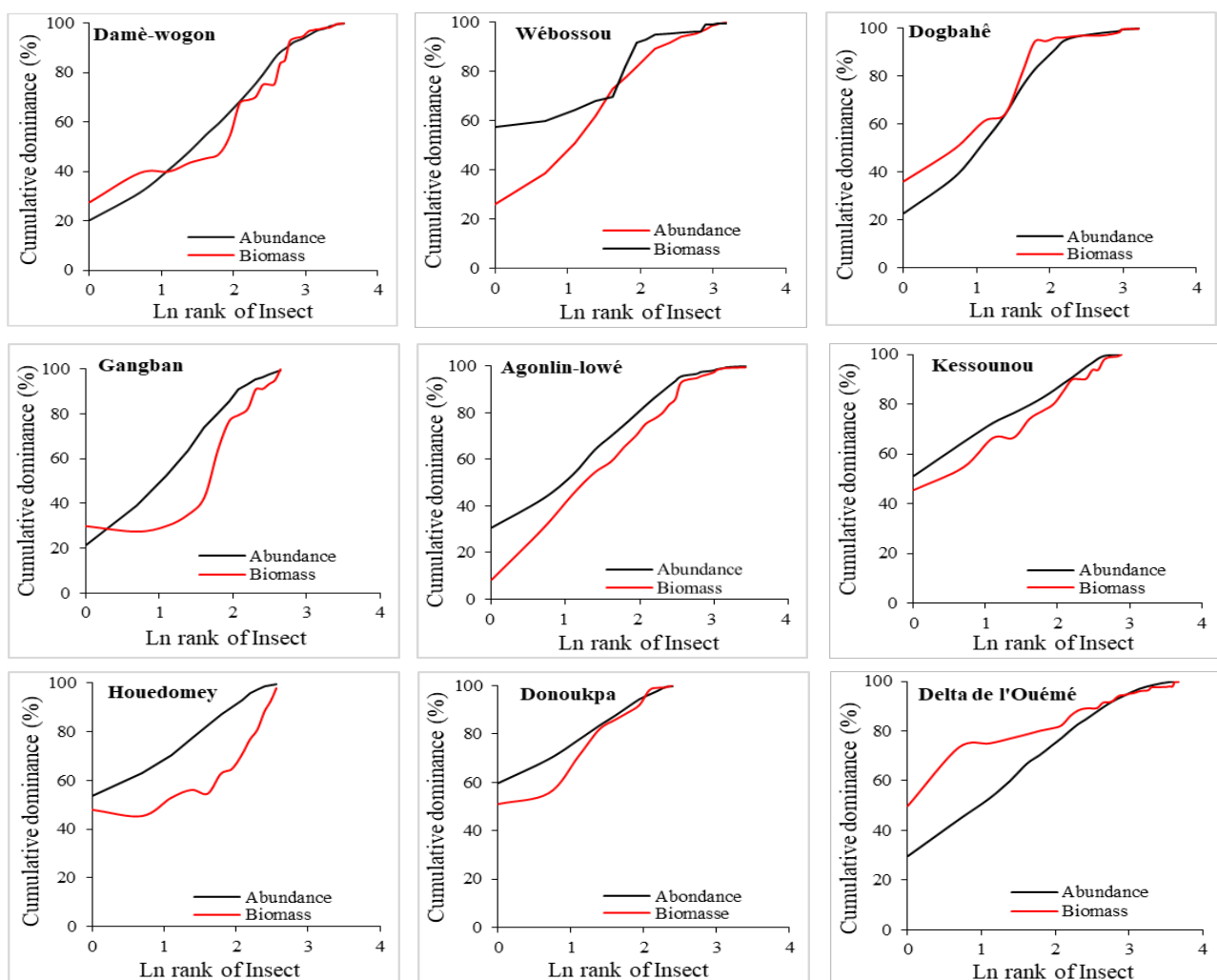
#### 3.1 Abundances and densities of different macro-invertebrate groups

A total of 19025 invertebrate individuals representing 129.313 g of biomass were harvested during the study period. Main groups of invertebrates represented were: insects, gastropods, bivalves and crustaceans. Insects were the major invertebrates sampled with 59% of total fauna and 9351 ind/m<sup>2</sup>. They are followed by gastropods (26.35% ; density 4178 ind/m<sup>2</sup>), Bivalves (10.35% ; density 1642 ind/m<sup>2</sup>), Crustaceans (4.31% ; density 683 ind/m<sup>2</sup>). Annelids representing 1% of the total number were not considered in the current analysis. Similar studies conducted on the Oued Khoumane in Morocco revealed that 64.2% of macroinvertebrate populations were dominated by insects (Ben Moussa *et al.*,

2014) and 12.5% by mollusks. This confirms the importance of insect larvae, which are very often present in various biotopes (torrents, streams, and rivers).

### 3.2 Variation trends of ecological stress indexes in insects

A total of 42 insect taxa distributed into 11222 individuals for 12.6 g of biomass were used for building biomass and abundance, DAP and Log<sub>e</sub>(SEP) k dominance curves. Thus, curves in **Figure 2** illustrated spatial variation trends of ABC ecological stress index. Specifically, we can notice that stations located upstream of delta (Damè-wogon, Wébossou and Dogbahê), biomass curve is above that of abundance with considerable difference of biomass that is lower in first rank of Damè-wogon. In the contrary, at the mid and down side of delta, reverse trends were observed with abundance curves set above those of biomass in the different stations (Agonlin-lowé, Gangban, Kessounou, Houedomey and Donoukpa). Besides, in the whole delta, figure shows that biomass curve is above that of abundance.



**Figure 2.** Abundance and biomass dominance-K curves in insect taxa of delta of Ouémé

The results of the descriptive analysis of the ecological indices DAP and Log<sub>e</sub>(SEP) for insects are presented in **Table 1**. Thus, mean DAP obtained was  $0.04 \pm 0.16$ . This surface difference varied between -0.17 and 0.26. Besides, the mean of diversity proportion of abundance and biomass (SEP) was  $-0.21 \pm 0.27$  with variation between -0.59 and 0.30. Otherwise, spatial variations showed that means relating to each zone were  $-0.07 (\pm 0.08)$  upstream,  $0.17 (\pm 0.03)$  in the central part and then

0.06 ( $\pm$  0.22) downstream for DAP showing progression in stress response. In the contrary, for Log<sub>e</sub>(SEP), mean recorded upstream was -0.11 ( $\pm$  0.37), -0.23 ( $\pm$  0.21) in the central and -0.29 ( $\pm$  0.26) downstream. For the whole delta of Ouémé, DAP was -0.17 and Log<sub>e</sub>(SEP) -0.35. The analysis of variance (ANOVA) focused on both of indexes showed no significant difference among stations and considered zones (F-statistic 1.68;  $p$  = 0.277). For Log<sub>e</sub>(SEP), F value was 0.27 with  $p$ -value 0.775 > 0.05. Pearson correlation between DAP and Log<sub>e</sub>(SEP) indexes in insects was 0.25.

**Table 1.** Mean and extreme values of ecological stress indexes in insects

Station	DAP Insects	Log <sub>e</sub> (SEP) Insects
Dame-wogon	0.006	-0.2
Wébosou	-0.14	-0.43
Dogbahê	-0.08	0.3
Gangban	0.19	-0.38
Agonlin-lowé	0.15	-0.08
Kessounou	0.08	-0.2
Houedomey	0.26	-0.08
Donoukpa	-0.17	-0.59
Mean $\pm$ standard dev	0.04 $\pm$ 0.16	-0.28 $\pm$ 0.12
Minimum	-0.17	-0.43
Maximum	0.26	-0.08

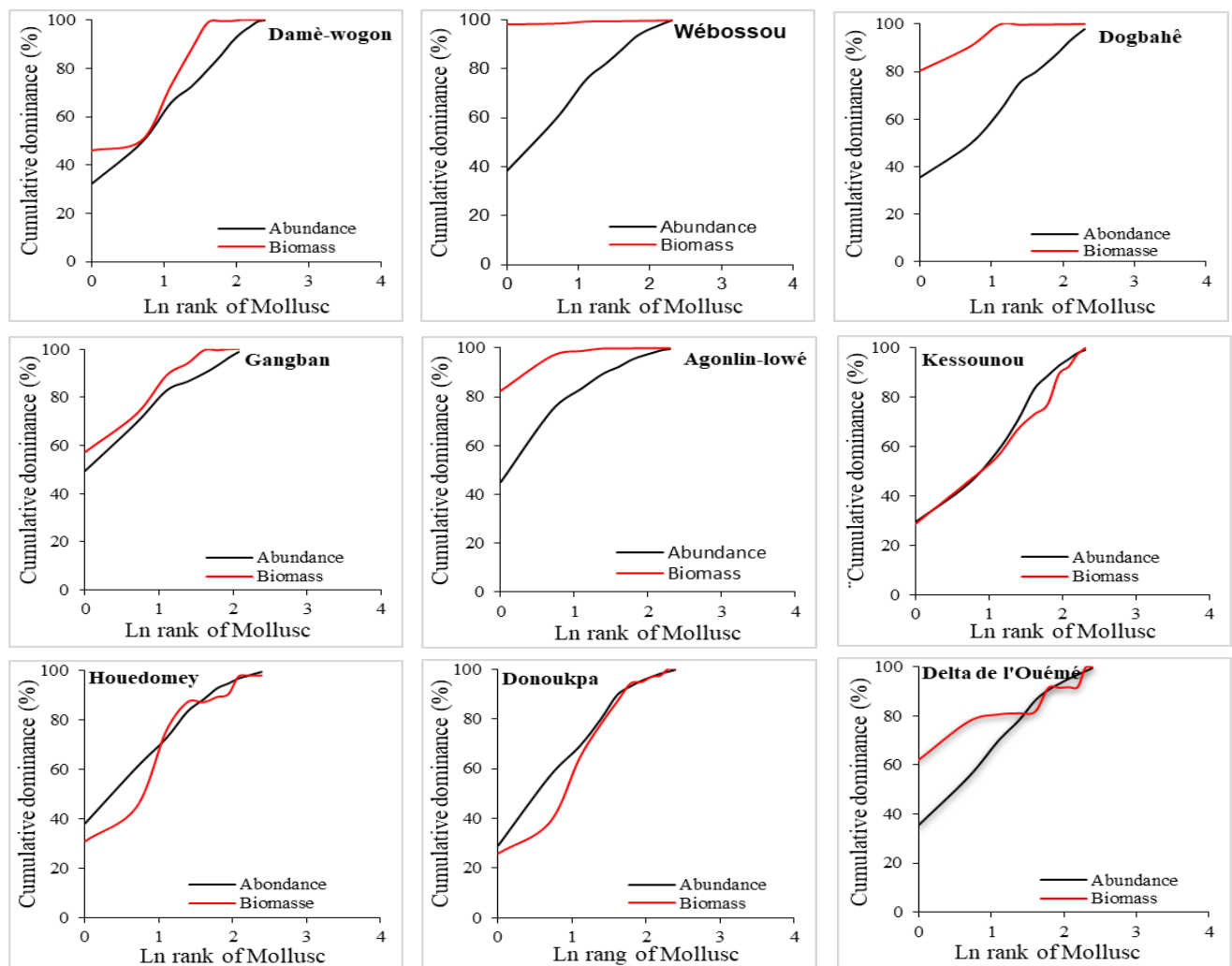
Benthic populations are often used to evaluate the impact of pollution on fresh water aquatic ecosystems (Pinto *et al.*, 2009). As indicated, the use of Abundance/Biomass Comparison (ABC) curves method developed by Warwick (1986), enabled to notice stress underwent by communities. With the use of double comparison of DAP and logarithm (SEP) in different stations, stress level along delta was quantified. The analysis of benthic communities' structure of delta of Ouémé showed that different values of ecological stress indexes observed were relatively higher downstream than upstream of delta. Indeed, the distribution curves indicate that population dynamics tend to be dominated by smaller species with low biomass, even though the abundance curve exceeded the biomass curve, particularly at stations located downstream in the delta. Results from this study showed mean DAP - 0.03 ( $\pm$ 0.18) revealing macro-benthic community characterized by ecological stability and moderate stress. According to Warwick (1986), values tending to zero indicate imbalance.

Concerning insects, spatially, k-dominance curves showed the biomass curve above the abundance curve at stations located upstream in the delta, indicating a balanced situation where large, long-lived taxa dominate the population, as described by Warwick (1986). In the contrary, in downstream stations including mid-delta abundance curves were higher than those of biomass. This trend shows increasing moderate stress meaning that population dynamic is made of small size species. In the insect group, this phenomenon results from the high proportion of small-sized and lightweight taxa such as Dipterans, Chironomids, Coleopterans, Noteridae, and Hydrophilidae. The abundance of pollution tolerant species like chironomidae shows not only nutrients enrichment but also the increase of primary production during flood periods (Ali *et al.*, 2003). Mean value of DAP (0.04 $\pm$ 0.16) with its crescent spatial trend upstream (-0.07) to downstream (0.06) confirms stress progression upstream to downstream deducted from k-dominance curves. Lack of significant difference shown by the analysis of variance reveals important heterogeneity of habitat in each sample zone. By the same way, Log<sub>e</sub>(SEP) though mean value is -0.21 $\pm$ 0.27, showed progressive decrease -0.11 upstream to -0.29 downstream revealing imbalance situation downstream fostering the interpretation of DAP. However,

low linear relationship observed in both indexes suggests that individuals' number and weight diversity is less affected in insects (Vereecken *et al.*, 2021; Sabbahi *et al.*, 2022). These observations corroborate with results from Adandedjan *et al.*, (2018) who applied these indexes to lake Toho with DAP and Log<sub>e</sub>(SEP) showing stress progression with dominance of tolerant insect taxons and the absence of pollution sensible taxons.

### 3.3 Variation trends of ecological stress indexes in mollusks

Concerning mollusks (bivalves and gastropods), the study focused on 12 taxa, comprising 6,975 individuals with an estimated total biomass of 83.77 g. Compared analysis of distribution of biomass and abundance as presented by Figure 3 showed similar trends related to insect population. Thus, in upstream stations and the central of delta, biomass curves were above those of abundance. In the contrary, for all downstream stations of the delta, biomass curve was below that of abundance.



**Figure 3.** Abundance and biomass dominance-K curves in mollusks taxons of delta of Ouémè

Values of DAP and Log<sub>e</sub>(SEP) indexes in mollusks were presented in Table 2. So, DAP values were negative in upstream stations and in the central of delta with transition to positive values in downstream stations. DAP was -0.29 (±0.16) upstream, -0.15 (±0.10) in the central, and 0.06 (±0.02) downstream. Mean DAP recorded was -0.12±0.19 with minimum value -0.41 at Dogbahè and maximal 0.08 at Donoukpa. Concerning Log<sub>e</sub>(SEP), mean value recorded was -1.61±1.14, with minimum -3.73 upstream and maximum -0.49 downstream. The analysis of variance was significant (F-statistic

=7.61; p=0.03) though for Log<sub>e</sub>(SEP) no significant difference was observed (F-statistic = 2.14; p=0.213). Pearson correlation was high (r=0.85) showing significant relationship between DAP and Log<sub>e</sub>(SEP).

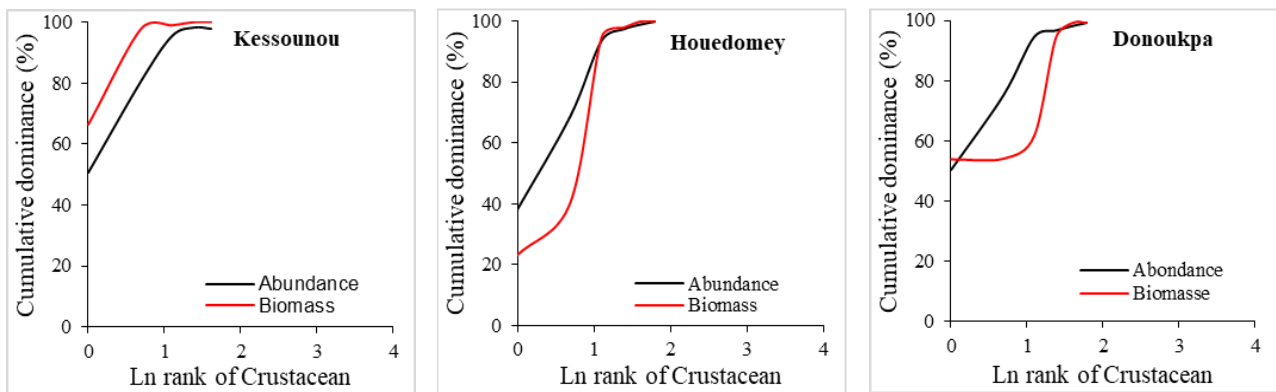
**Table 2.** Mean and extreme values of ecological stress indexes in mollusks

<b>Stations</b>	<b>DAP Mollusks</b>	<b>Log<sub>e</sub>(SEP) Mollusks</b>
Dame-wogon	-0.11	-0.86
Wébosou	-0.35	-2.68
Dogbahê	-0.41	-3.73
Gangban	-0.08	-2.21
Agonlin-lowé	-0.22	-1.16
Kessounou	0.04	-1.06
Houedomey	0.06	-0.69
Donoukpa	0.08	-0.49
Mean±standard dev	-0.12±0.19	-1.61±1.14
Minimum	-0.41	-3.73
Maximum	0.08	-0.49

Concerning mollusks, the spatial distribution of k-dominance curves shows biomass curves are above those of abundance upstream and in the central of delta, though the contrary is observed in stations located mid and downstream delta. This observation is strengthened by mean DAP (-0.12±0.19) indicating healthy medium upstream with crescent progression of stress downstream DAP (0.06±0.02) and probably tied to pollution due to human activities. Furthermore, the analysis of variance of DAP among zones (p=0.03) indicated a eutrophic environment, favoring the establishment of gastropod taxa such as Thiaridae and Corbulidae. In addition, the mean Log<sub>e</sub>(SEP) (-1.61±1.14), with values ranging from -3.73 upstream to -0.49 downstream, and the non-significant statistical difference, confirm this trend of increasing and moderate stress, characterized by the dominance of pollution-tolerant taxa. These sediment-associated taxa are favored by the accumulation of domestic effluents. Besides, high linear relationship between indexes (r=0.85) reveals cumulating effects of pollution on individuals and their biomass. According to Adesakin *et al.*, (2023), the used indexes revealed mollusks as sensitive biological indicators. Their study in Lagos lagoon in Nigeria showed dominance of gastropods and annelids in nutrient rich zones with high links between species diversity and metals.

### 3.4 Variation trends of ecological stress indexes in crustaceans

With regard to crustaceans, 10 taxa comprising 820 individuals with a total biomass of 32.68 g were used to assess the ecological stress affecting these communities in the delta. The distribution of biomass and abundance k-dominance curves for crustacean taxa was carried out only at the three downstream stations of the delta (Figure 4), due to their presence and exclusive predominance in these sites, influenced by marine water inflow through the Totché channel. It results from this analysis that abundance curve is above that of biomass in Donoukpa and Houedomey stations. Regarding Kessounou station, reverse trend was observed with biomass curve that is above that of abundance. Mean DAP was 0.07±0.17. The minimum recorded was -0.13 and maximum 0.18. Concerning Log<sub>e</sub>(SEP), mean recorded was -0.51±0.53, with minimum -1.11 and maximum de -0.13. Besides, due to the absence of data upstream and in the central of delta, the analysis of variance was not carried out. There was also high relationship between both of indexes (r=0.99).



**Figure 4.** Abundance and biomass k-dominance curves in crustacean taxa

It results from crustaceans that distribution of ABC curves shows abundance curve above that of biomass in stations of Houedomey and Donoukpa, and contrarily in Kessounou station. The spatial heterogeneity observed can be explained by high salinity in the delta favoring the installment of euryhaline species. This observation is corroborated by mean DAP ( $0.07 \pm 0.17$ ) and mean  $\text{Log}_e(\text{SEP})$  ( $-0.51 \pm 0.53$ ) revealing moderate ecological pressure dominated by r strategy species according to Warwick (1986) such as Amphipods and Decapods which presence reveals habitat reconstitution (Adandédjan, 2012). Besides, lack of data downstream the delta doesn't enable application of the analysis of variance. Indeed, the high correlation between indexes strengthens on r strategy species that multiply more in estuary conditions.

The ABC method tend to assess efficiently changes in population structure and height composition (Blanchard *et al.*, 2004 ; Yemane *et al.*, 2005). So, stations located downstream the delta undergo marine water influence through the channel Totché representing the communication link between the complex Porto-Novo lagoon – lake Nokoué. This input generates stress in population located downstream the delta due to salinity. These observations confirm studies of Villanueva (2004) showing that stress is higher in stations near the sea in Gambia but also in Ebrié lagoon in Côte d'Ivoire and in stations under direct influence of marine input. Besides, the author shows that certain stations of lake Nokoué are stressed referring to ABC index than DAP and SEP indexes. Ecological stress effects cans also result from seasonal fluctuations as the delta case undergoing the influence of flood and dry season. These different water periods provoke variations of physico-chemical parameters that affect organisms' distribution but also diversity (Ikomi *et al.*, 2005). It's the case of Ephemeroptera, plecoptera and good water quality indicator taxa that don't support high climate change and are not pollution tolerant.

Overall, different macro-invertebrate groups are undergoing moderate stress condition indicating relative pollution of the delta. Indeed, this pollution generated by human activities seems to diffuse due to the presence of Acadjas installed along the delta and limits risks of predation (Villanueva, 2004; Gnohossou, 2006). Different stress conditions observed are influenced by the position of each station along the delta with best population organization upstream compared to those in downstream under influence of human activities.

## Conclusion

This study conducted on the Ouémé River delta allowed, on one hand, the assessment of benthic macroinvertebrate populations within this ecosystem and the determination of their abundance and biomass. On the other hand, the ecological state of these communities was evaluated using the ABC, DAP, and  $\text{Log}_e(\text{SEP})$  indices to determine levels of ecological stress.

The results indicate that the spatial patterns of these indices follow the longitudinal pollution gradient from upstream to downstream, affecting community structure and favoring the emergence of pollution-tolerant taxa such as Chironomidae, Thiariidae, and Corbulidae. Upstream stations exhibited relatively healthy and ecologically balanced conditions. In contrast, downstream sites, characterized by higher nutrient and organic matter loads, showed functional imbalance due to continuous and increasing stress.

These findings confirm the relevance of using k-dominance curves and associated indices to assess ecological stress in benthic populations. Furthermore, the study enhances understanding of the adaptive strategies employed by benthic organisms in response to environmental pressures, providing valuable knowledge for the prospective management and conservation of the Ouémé River delta ecosystem.

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*Compliance with Ethical Standards:* This article does not contain any studies involving human or animal subjects.

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