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Vertical distribution of the physicochemical parameters in Ethiope River, Delta State, Nigeria: Temperature and Dissolved Oxygen

KI Iloba

Animal and Environmental Biology, Delta State University, Abraka, Delta State, Nigeria

Abstract

The vertical distribution of some physicochemical parameters of Ethiope River in Delta State of Nigeria were studied monthly from February 2003 to January 2005 to determine the existence of stratification in a river contrary to lotic water body uniformity concept. Monthly water samples were collected at 1m depth interval from surface to bottom using a Hydro-Bios water sampler along a longitudinally axis from three stations. Pronounced surface to bottom stratification of the studied parameters with rapid changes were evident in the river. Vertical thermal and oxygen differences from surface and bottom varied between 05- 30ºC and 1.0 – 4.0 mg/L respectively. The upper waters were thermally stratified with higher temperatures (28 - 30˚C) up to about 3.5m while the bottom waters recorded lower temperatures (25 – 27˚C). The Tukey Kramer and Duncan multiple comparison tests also revealed significant differences of these parameters at all depths in some studied stations.

Keywords: lotic environment, temperature, dissolved oxygen, stratification, and River Ethiope

1. Introduction

The distributions of physical, chemical and biological parameters in rivers are strongly emphasized along longitudinal gradients signaturing the river continuum concept as the only important event or process that exists in entire river systems [1, 2, 3, 4, 5, 6, 7]. This concept has been presented for centuries by water biologists as the only significant event in lotic environments and other events such as stratification have been neglected by hydrobiological researchers in rivers [8, 9, 10]. The concept of vertical distribution or stratification or profile is often disregarded and/or considered unimportant event in lotic water bodies based on the limnological views that rivers are turbulent with enough kinetic energy from the wind to mix the water column through resulting in the homogeneity of the water body [11, 12]. This traditional knowledge conclusion is based on the inordinately high number of research on lakes to rivers globally or the limited understanding of the enormous variability's across and down river systems as well as extrapolation of studies on small temperate streams to rivers in general [2]. The homogeneity concept is not exclusive to rivers only but also to lentic waters which sometimes mix up the layers/strata by convection currents depending on the prevailing factors [13, 14, 15, 11, 16, 17, 18, 19, 20]. Thus, the disproportionate emphasis on the vertical distribution of resources in lentic water bodies than in lotic could have led to hasty hydrobiological generalized conclusions about stratification in rivers [8, 21, 22, 16, 23]. One of the most important, relevant parameters in lentic aquatic ecosystems that determines or regulates nearly all physico-chemical parameters which also exist in rivers is depth [11, 24, 23]. The existence of depth allows the exhibition of dramatic physicochemical gradients in relation to the distribution of its resources in the different water column [25]. The product of incomplete mixing of the water column results in the spatial heterogeneity of the water column irrespective of the type of aquatic system [26, 20].

Until now, the variability of physicochemical parameters through the depth of the water column in rivers is still poorly known and investigated [17]. In Nigeria, few studies are available on the vertical distribution of resources in lotic environment [27, 28]. Series of depth related studies have been investigated in this tropical river by the author to contribute to the pattern of distribution of resources in a lotic system. This paper will present the vertical distribution of water temperature and dissolved oxygen in River Ethiope to improve on the dearth of information in this area of study.

2. Materials and Methods

2.1 Study Stations

River Ethiope is an important tropical water body located in Delta State and has been described extensively by Iloba [29]. Three stations were chosen along the river course in relation to depth (Fig 1). Station 1 is the shallowest of the stations. It is located at Abraka, the bridge along Abraka- Benin highway with an average depth of 3m. This station is about 25km from the spring like source of the river while Station 2 is at Igun with an average depth of 9.5m. Station 2 is about 18km from station 3. Its terrain gently slopes towards the river. The substratum consists of sand and silt and sandy clays. Little sheets of erosion are noticed along the terrain. Sawmills are located close to this station as sawdust, wood particles were seen drifting across the surface of the river. A few yards away from the sampling point a functional sand dredging machine was situated. Other anthropogenic activities were fishing, washing, bathing, transportation of man, goods, farm products, timber etc. Station 3 is the widest part of the river and is located at Sapele with an average depth of 9.5m. The bottom sediments consist of sand, silt and sandy clays. There were also little sheets of erosion noticed along the terrain. Situated around the station were Sawmills and floating logs (Timbers) awaiting processing. Other activities include dredging and offloading of white sand from the canoes, transportation, ritual performance and deposition of its materials into the river.

2.2 Water sampling and Statistical analysis

These stations were visited monthly for twenty four months from February 2003 to January 2005 between the hours of 9.00 - 15.00. Water Samples were collected at intervals of every 1m from surface to bottom using a Hydro-Bios water sampler from a boat to obtain the quantitative samples. Water temperatures were read off the Mercury–in-glass thermometer (0-100˚C) thermometer attached inside of the Hydro-Bios sampler.

The Azide modification of Winkler's method was used to determine the dissolved oxygen values of the water. The Number Cruncher Statistical System 2007 (NCSS Statistical Software) trail version was used for the isopleths.

Statistical analyses were done using the Number Cruncher Statistical System 2007 (NCSS Statistical Software) trail version and Statistix 8. Tukey Kramer and Duncan's multiple comparison tests were used to provide multiple comparison test for all pair wise differences between the means down the water column. All graphs were created using NCSS 2007 trail version.

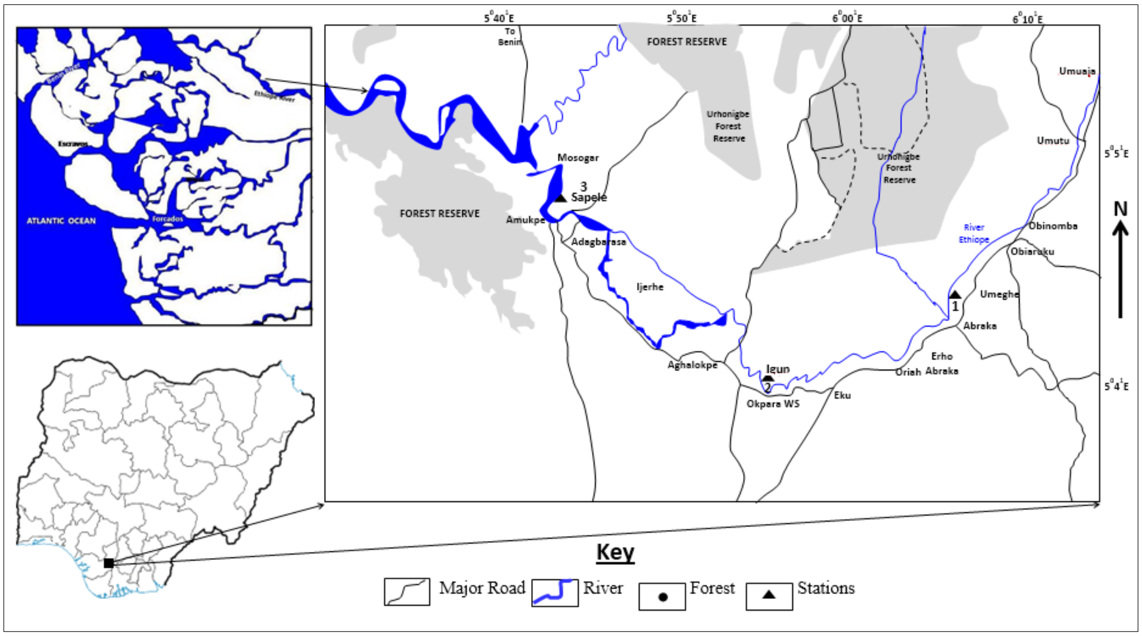

Fig 1: Location Map of the Study Area (Showing Sampled Stations)

3. Results

The water temperature and dissolved oxygen profiles in the three stations are presented in Figures 2 to 7. The graphs revealed rapid changes in the physical and chemical parameter investigated. The isopleths of the three stations surprisingly revealed different distribution pattern down the water column revealing periods of extensive stratification. Destratification periods in the river during this research were mostly during the rainy season.

In station 1, the profile revealed an almost equal homothermy from surface to bottom (Fig.2). Pockets of strata existed from September 2003 to September 2004 at the surface waters thereby creating a weak thermal and oxygen differential of about 8.0ºC within 3m. However, these were immediately destratified. Rapid fluctuations in temperature were also evident in the first few months of sampling thereafter changes became gradual. A reduction in temperature was observed from surface with a mean of 28.8˚C, 1m (28.8˚C) to bottom (28.7˚C) . No significant spatial (depth) variations was established (p>0.05).The dissolved oxygen isopleths in station 1 revealed that the dissolved oxygen were near uniformity from surface to bottom waters (Fig 3). However, these changes were rapid except between May and December 2003 as well as between May and December 2004. During these periods, changes were gradual, although pockets of low levels of dissolved oxygen were at the surface and bottom waters. The mean dissolved oxygen at surface waters was 3.4mg/L, 1m (3.5mg/L) and bottom 3.4mg/L. These means showed spatial (depth) significant difference (P<0.05).

In station 2, the isopleths revealed a well-stratified water body from surface to bottom during the first twelve months(2003) with higher temperature values at the surface (29.5- 30˚C) and the lower waters having lower temperatures (25 - 27˚C) (Fig. 4). A 1ºC differential was observed at 4m depth. Vertical thermal differences between the surface and the bottom were 3.0ºC with 0.5ºC variation down the water column. The process of desertification followed immediately, this brought about a homothermal condition of 28.0°C from surface to about 6m. An almost equal temperature distribution from surface to bottom was thereafter observed until the end of study. The mean temperature at the surface and 1m was 28.4˚C, it then decreased gradually from 28.2˚C (2m)- 28.1˚C (3m), 27. 9˚C (4m) - 27.7˚C (5m), 27.7˚C (5m) - 27.6˚C (6m) and 27.3˚C (7m) - 27.2˚C at the 9.5m.The comparison of vertical variability in temperature with analysis of variance revealed that all means were not equal and the Tukey and Duncan's tests revealed thermal difference at all depths (P< 0.05).

The dissolved oxygen isoclines in Station 2 (Fig.5) showed partial stratification of the water body with high dissolved oxygen values in the first few months (February and March) (dry season months) of both 2003 and 2004 with 1ºC variation at 4 m. Subsequently, the water body became destratified resulting in near uniform dissolved oxygen from surface to bottom particularly during the rainy season. Higher oxygen concentrations were also observed at the water surface. The mean dissolved oxygen at the surface was 1.8 mg/L, (1m) 2.2 mg/L, (2m) 2.6 mg/L, (3m) 2.6 mg/L, and 2.5 mg/L at 4m, 5m was 2.1 mg/L, 6m was 2.1 mg/L, 2.0 mg/L at 7m and bottom waters was 1.7 mg/L. These means of dissolved oxygen at the different depths were not statistically different from each other (P > 0. 05).

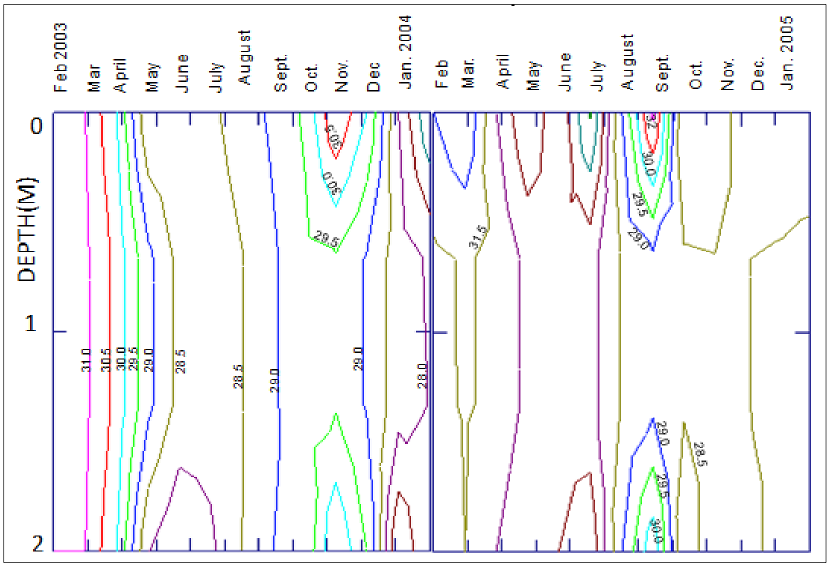

Fig 2: Seasonal and vertical distribution of temperature (°C) in Station 1

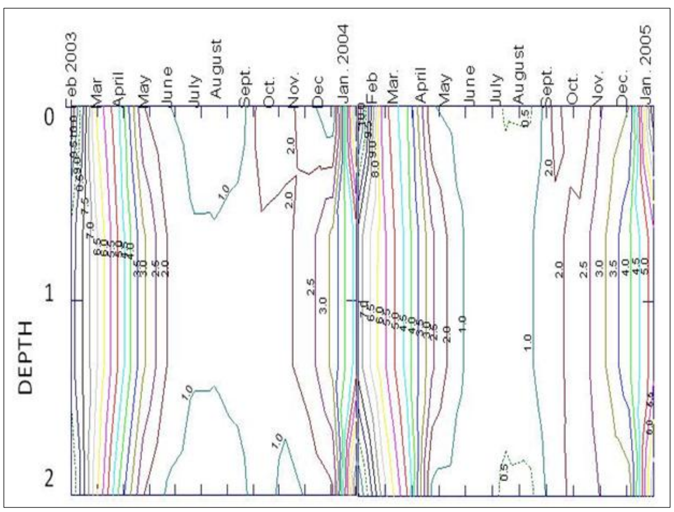

Fig 3: Seasonal and vertical distribution of dissolved (mg/L) in Station 1

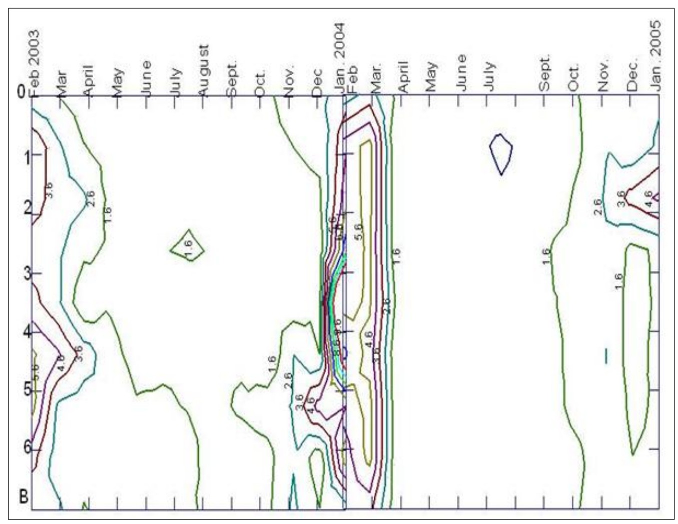

Fig 5: Seasonal and vertical distribution of dissolved oxygen (mg/L) in Station 2

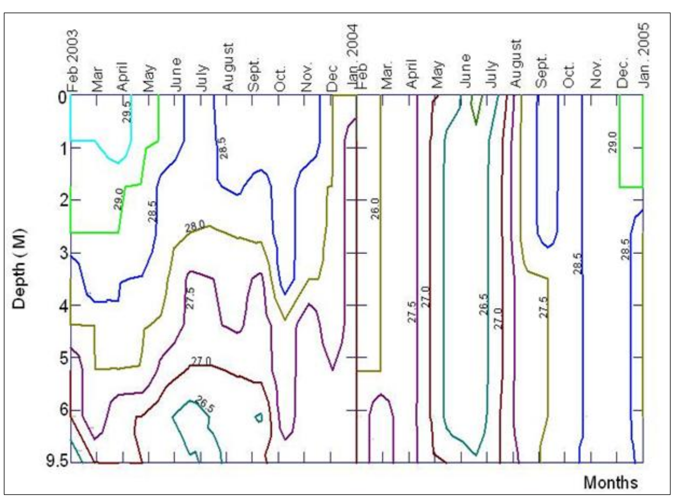

Fig 4: Seasonal and vertical distribution of temperature (°C) in Station 2

In station 3, the isopleths revealed a rapid fluctuation in temperature as well as pronounced thermal stratification (Fig. 6). During the first five months of sampling, the upper waters were thermally stratified with higher temperatures (28- 30˚C) up to about 3.5m while the bottom waters recorded lower temperatures (25 – 27˚C). In June and November 2003, the bottom waters were well stratified to about the surface but became almost homogenized in the next five months (Fig.6) with gradual changes in temperature. Thereafter, a season of rapid changes were evident resulting to a near homothermy from surface to bottom then followed by another phase of stratification from surface to bottom. The upper layers were of higher temperature values (29.5- 30˚C) than the lower layers (25 - 27˚C). Vertical thermal differences between the surface and the bottom were 3.5ºC. The vertical thermal differences in temperature down the water column were statistically different

($p < 0.05$). All paired means also tested different ($p < 0.05$) with the Tukey and Duncan's tests in this station ($P < 0.05$).

In station 3, the oxygen profiles of the river show continuous decrease in oxygen concentration from surface to bottom. The isoclines also revealed rapid fluctuations in dissolved oxygen concentrations with a layer of high oxygen values at the upper waters (Fig.7). The water showed complete destratification from late September to early December 2003 as well as from July to November 2004. The oxygen concentrations decreased with depth and showed a 2.0mg/L differential between 1m and 4m and 1mg/L between 4 and 5m depth. The surface waters had mean dissolved oxygen of 3.8mg/L, 1m 3.2mg/L, 2m (3.0mg/L), 3m (3.1mg/L), 4m (3.0mg/L), 5m (2.5mg/L), 6m (2.4mg/L), 7m (2.3mg/L) and the bottom waters 1.4mg /L. The variations in vertical means were not statistically different from each other ($P > 0.05$).

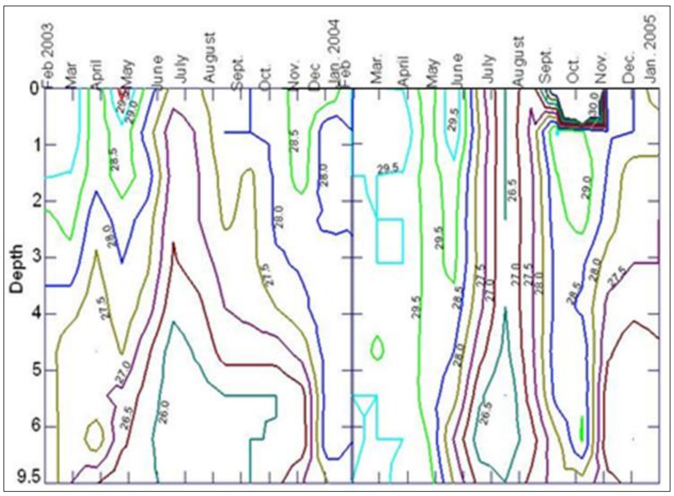

Fig 6: Seasonal and vertical distribution of water temperature (°C) in Station 3

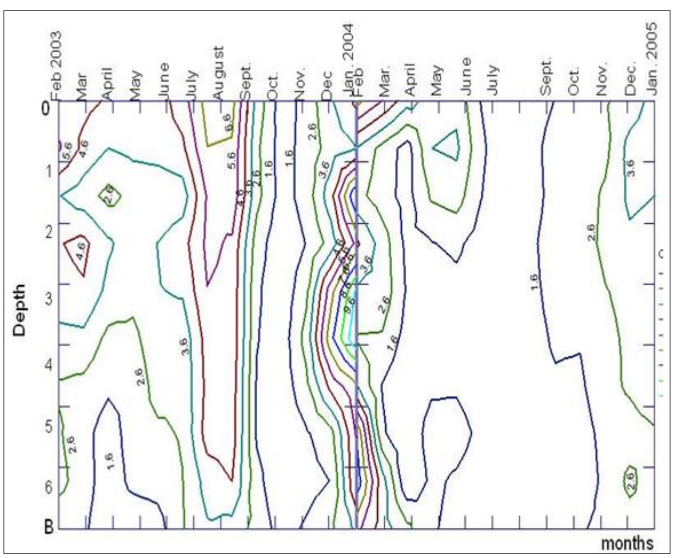

Fig 7: Seasonal and vertical distribution of dissolved oxygen (mg/L) in Station 3

4. Discussion

Rapid fluctuations in water temperature noted in this study are typical of rivers which usually fluctuate within a tight range [30, 13, 31]. The water temperature in the present study ranged from 25 to 30°C and this has also been reported by other researchers in other tropical water bodies [32]. The surface water temperature showed relatively higher temperature values (30°C) with variations down the water column. Similar high surface temperatures of greater than 28ºC have been reported as a permanent feature of tropical fresh water ecosystems [33].

The vertical temperature and dissolved oxygen (DO) profiles observed in this River particularly in Stations 2 and 3 with marked depth related changes is of interest revealing an incompletely mixed river which is contrary to the traditional mixing paradigm hypothesized in lotic systems particularly in a river with depth as low as 9m [13, 34]. This finding is an indication that whatever event that is responsible for stratification in lentic water bodies does occur in lotic [34, 6, 35].

The non-homogeneity of temperature and dissolved oxygen down the water column further confirms that the distribution of parameters in a river is not only current- driven in a unidirectional pattern in rivers [36]. Such heterogeneity in a river ecosystem could be better explained when viewed as the resultant effects of the interactions between other several driving factors such as geomorphology and hydrology which could be dynamic both in space and time either longitudinally, laterally and vertically [37, 38, 25]. Shading, ground water inflow, hyporheic exchange and bed conduction were also noted as the possible/plausible causes of thermal heterogeneity in streams water column, smaller lotic ecosystems [26]. These could be significant factors also responsible for stratification in this present study. Benda *et al.* [39] on the network dynamics hypothesis remarked that variation in riverine environment is virtually unique as well as uniquely individual imposing heterogeneity in the river system due to diverse interactions in the river basin. Furthermore, the marked significant differences in temperature at the different depths in both Stations 2 and 3 particularly in the first twelve months could have been enhanced by tidal influence in these stations leading to an unstable thermal environment observed in the studied system [40, 36].

The noticeable low oxygen concentrations particularly in stations 2 and 3 bottom waters could have resulted from thermal stratification of the water body during this period as noted by the report of Gonzalez [33] that stratification results in substantial deoxygenation of water bodies with higher temperature values at the surface (29.5- 30 ˚C) and the lower waters having lower temperatures (25 - 27 ˚C) which is a permanent feature of tropical waters which is similar to the records of the present study. Thus the existing differences in dissolved oxygen concentration down the river column are probably not due to the river's lotic nature but as a result of other factors interacting with each other to form a heterogeneous environment as earlier discussed [35]

Destratifications of the river were mostly observed during the rains indicating the effects of rain which could have resulted in the complete mixing of the water body [28, 36]. The perennial river's flow with its highest level of discharge during the flood (July - November) could equally have enhanced the destratification processes in the second year of sampling.

In addition to this, the shallow nature of the river in Station 1 probably would have generated the homoeocline observed in this section of the river due to greater degree of circulation by wind- induced waves [12]. Despite the shallow depth, slight reduction in temperature was noticed from surface to bottom.

The distribution of temperature could have been modified by the reflection, refraction and absorption of heat by the water. The vertical homogeneity observed in rivers is also common features of lentic environment and other waters bodies [41, 15, 35] and does not indicate uniformity of the lotic environment. More so, the non persistence and unequal distribution and duration of homogeneity of these parameters down the water column suggest that uniformity/homogeneity is a concept shared by all aquatic ecosystems and that stratification could be transitory depending of the prevalent environmental conditions [42, 36].

The lower temperature characteristics of deep waters could be due to heat absorption by the sediment [25]. Despite the small depths in the studied sites, the river till experienced incomplete mixing of the water column, contrary to the hypothesis of uniformity in lotic environments with depths greater than depths of the studied stations [28]. This is a strong implication that stratification in lotic environment is an important event in rivers and could help in understanding the hydrologic workings of this unique habitat irrespective of its peculiar complexities. It is difficult to deny extensive existence of stratification in the lotic environment irrespective of depth. Rather than discard/ignore this phenomenon in rivers for lack of complete information or understanding of this ecosystem, search for the mechanisms involved should be pursued.

Since significant depth variability was observed in the distribution of temperature and dissolved oxygen down the water column in this river in the present study, it is reasonable to consider that stratification could be an important driving force in rivers, directly or indirectly influencing various operative processes and biotic components of rivers since these parameters are known to mediate key processes in any aquatic ecosystem [4, 23]. No doubt vertical variations in lotic environment will have strong influence on the ecological characteristics/ activities of rivers whether directly or indirectly in rivers like in the lentic [43, 12].

5. Conclusion

It is therefore impossible to disregard or consider stratification an unimportant event in the lotic environment since the environment is not characterized by only longitudinal gradation but by the interaction of both the longitudinal and vertical gradation. I therefore suggest an extension of the studies applied to lentic environment to the lotic as the discovery could be more revealing and interesting than expected.

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