

Biota and Environment Interaction in the Lower Volta Estuary, Ghana

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Abstract

The changing physiographical conditions of the Volta estuary (a tropical river estuary) and the response of zooplankton and nektonic biota were examined for a total of 3 years spread over a 6-year period (1999–2005). The Bio-Env, a distribution-free analog of correlation analysis based on the Spearman's rank correlation analysis was used to test the determinant variables responsible for ordering the biota, including all the developmental stages of the shrimps. The Simper analytical tool was used to compare the relative importance of species in two locations and used the discriminant as an index of characterization of the two habitats. The overall picture of species affinity to sampling stations as directed by prevailing physico-chemical variables was tested using the Canonical Correspondence Analysis (CCA). Within the study area of 84.37 km² evidence emerged of existence of two water masses; an oligohaline water mass surrounding a mesohaline water body where, on the average, 11 physico-chemical parameters, including hydrogen ion concentration and salinity determined the choice of habitats for the biota. The CCA results obtained from the pooled physico-chemical variables over the 3-year period for the zooplankton data and the six sampling stations showed that the four ordination axes accounted for 90.7% of the explained total variance of the sample species abundance by the pooled environmental variables data.

Introduction

The shelf off the west coast of Africa is a narrow area at 0.65 million km², approximately 0.046% of the entire area occupied by the Eastern Central Atlantic (FAO, 2005). The narrow continental shelf suggests that habitat for the near-shore crustaceans (shrimps, lobsters, crabs, prawns) and demersal fishes will be relatively limited, and the abundance will also be similarly limited. Thus, the environment type, which includes sub-tropical and equatorial waters with many coastal lagoons, will be the major determinant factor in the distribution of the biota (FAO, 2003).

Adults of the commercially-important penaeid shrimps normally spawn in the sea after which the developing larval stages seek inshore areas and estuaries to settle (Dall *et*

al., 1990). The exact period of planktonic life in the marine and near shore habitats depends on an array of physiological and environmental variables. The environmental variables may include tides and currents that transport the larvae (Thormson, 1961; Shanks, 1985), the nature, distribution and abundance of settlement sites (Miller & Hadfield, 1986) and indirectly by the lunar cycles that control the tides (Tait, 1981). Klyashtorin (2001) showed consistent correlation of climatic and geophysical indexes with manifestation of important processes related to fisheries. The indices are (i) the surface air temperature anomaly (dT), which is the most important index of global climatic change, (ii) the length of day (LOD), a geophysical index that characterizes variation in the earth rotation velocity, and

(iii) the Atmospheric Circulation Index (ACI), which characterizes the periods of relative dominance of directional transport of air masses on the hemisphere scale.

The present work seeks to find the types of biota-associations that prevail in the Volta estuary and how those associations are determined by the environmental variables for 3 years (1999, 2000 and 2005).

Materials and methods

Study area

The main Volta river bifurcates into two major water ways 33 km upstream of the river mouth. This is further divided into many smaller creeks forming about 39 islands of variable sizes in the downstream reaches (Darpaah, 2008). The river finally discharges into the Gulf of Guinea through a narrow mouth bothering an unstable 2-km sand bar (Fig. 1). The general study area comprised the entire area extending from the mouth of the Volta river to 20 km upstream of the main river channel. Detailed sampling was confined to six locations on three major water bodies enclosing an area of 84.37 km² within the estuary. This included three oligohaline areas (stations 1, 5 and 6) designated as zone A (Fig. 1) and three mesohaline areas (stations 2, 3 and 4) designated as zone B. Brief description of the sampling locations is presented.

Description of sampling locations

Sampling Zone A (Sampling stations 1, 5, 6). Station 1 is located on a creek bothering the Ada Township and stretches approximately 1.5 km across the width. It is located 5 km from the mouth of the river. Mean water depth ranged between 2.5 m at low tide to 5 m at high tide. The western

bank bordering the settlement is sandy with no vegetation. The opposite bank is covered with dense strands of submersed and rooted aquatic vegetation.

Station 5 is located at 18 km from the mouth of the Volta river. The banks are strewn with luxuriant growth of the red mangrove, *Rhizophora racemosa*, which forms closed canopy on both banks. Mean water depth is 7 m with maximum tidal displacement of 1.9 m.

Station 6 is located in the main channel, upstream of station 3 and approximately 24 km upstream of the river mouth. Water depth is between 1 m and 2 m with maximum tidal displacement of 0.5 m. The width of the river at this point is 1.7 km. The bottom is covered entirely by rooted and submersed aquatic macrophytes. Large stands of mangrove vegetation cover both banks.

Sampling Zone B (Sampling stations 2, 3, 4). Sampling Station 2 is located on the confluence of two creeks at 5 km from the river mouth. The area is very wide at about 2 km from bank to bank. Water depth ranged between 1 m and 2.5 m. The flow regime is swift and follows no defined course. The area is partially shielded from the ravaging waves of the sea by the Island of Azizakpe. Approximately 30% of the river bottom is colonized by poorly grown *Vallisneria* sp. Other areas of the river bottom were largely sandy but overlain by a thin layer of mud. Sampling Station 3 is situated in the main river channel and approximately 8 km from the mouth of the river. There is mass movement of water at both flood and ebb tides. During periods of spring tides, saline water intrusion reached location 3 at all levels. The average water depth is 7 m with a maximum tidal displacement of 2.1 m. The

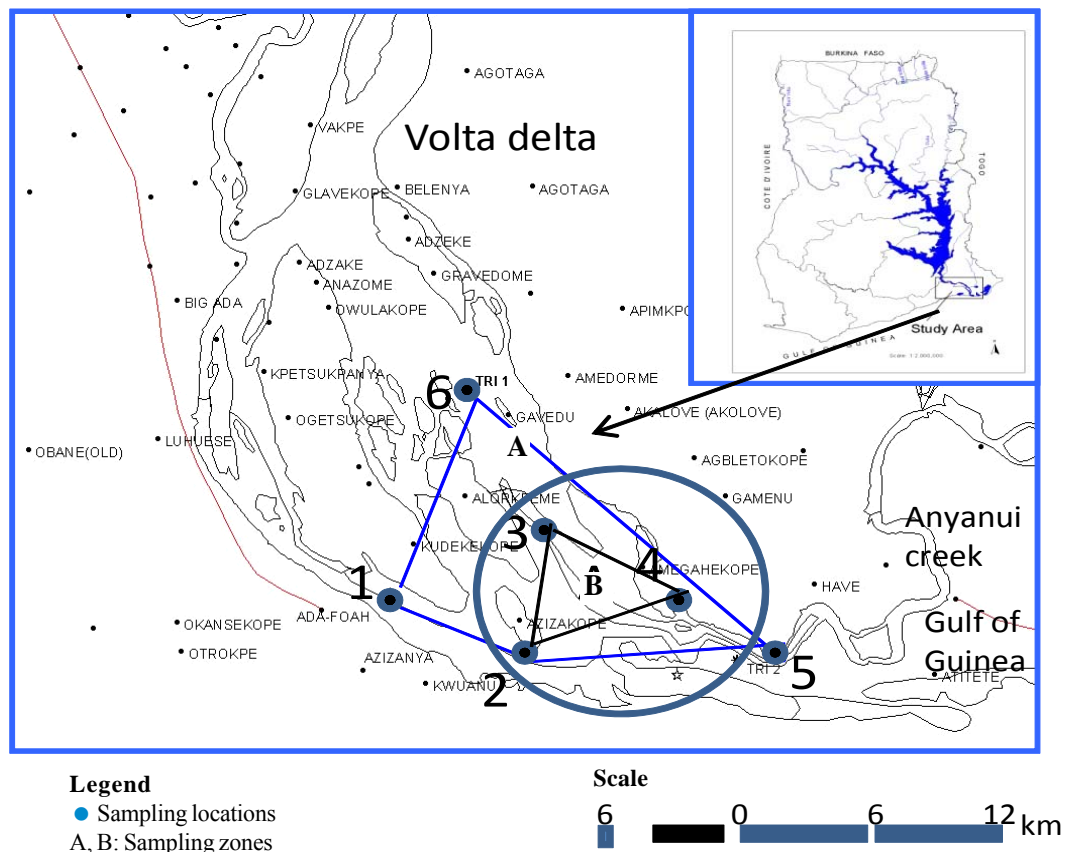


Fig. 1. Sampling locations at the study site (Volta estuary, Ghana)

bottom is sandy but often strewn with large quantities of dislodged aquatic vegetation derived from the upstream reaches. The width of this channel is 3 km. The large fetch supports the development of very high waves, especially during periods of storms.

Sampling location 4 located at 1.5 km from the river mouth marks the front of two waters; the marine water and freshwater derived from the Anyanui creek, the main link between the Volta river and the adjoining 240 km² coastal Keta lagoon. It is characterized by high billows at both flooding

and ebbing tides. The bottom is composed of high density chicocoo (rotten and decomposing mangrove roots). The ebbing tide is especially swift and follows no defined paths.

Field sampling methods

The ecological studies involved the collection and analysis of samples for 24 physical, chemical and biotic parameters for 1999, 2000 and 2005. All procedures followed standard methods of investigations (APHA, 1998)

Laboratory analytical methods

Biota and Environment Matching (Bio-Env). The *Bio-Env* is a distribution-free analog of correlation analysis based on the Spearman's rank correlation analysis. Results of determination of this ordering was presented for the six sampling stations within the two broad sampling zones in the Volta estuary from 1999 to 2005 to establish the determinant variables responsible for ordering the biota, including all the developmental stages of the shrimps.

Simper analysis. The Simper analytical tool was used to compute the average dissimilarity in the occurrence of the species and the dissimilarity/standard deviation ratio as a discriminant index. Between habitats, the statistic compared the relative importance of species in two locations and used the discriminant as an index of characterization of the two habitats. The dissimilarity level determined the homogeneity or heterogeneity of the two habitats. The computation was done at 90% level of significance for important species that was selected by the *Bio-Env* Statistic.

Canonical Correspondence Analysis (CCA). The overall picture of species affinity to sampling stations as directed by prevailing physico-chemical variables was tested using the Canonical Correspondence Analysis (CCA). In this statistic, the distance between the symbols in the diagram approximated the dissimilarity of their species composition, measured by their Chi-square distance. Arrows pointed in the expected direction of the steepest increase of values of environmental variables with the angles between arrows indicating correlations between individual environmental variables. The sample points were in the order of predicted increase of values of the particular

environmental variable. The predicted increase occurred in the direction indicated by the arrow (Fig. 1).

Results

Spearman's rank correlation analysis

Results of determination of this ordering are presented in Table 3 for six locations within the Volta estuary from 1999 to 2005. The highest Spearman correlation ranging from 0.995 to 0.999 occurred with 11 environmental variables in all the sampling locations. In all these stations, air temperature, water temperature, secchi disc transparency, total dissolved solids and percent cloud cover were almost always among the 11 determinant variables for all the 3 years of sampling.

Sampling Zone A (Stations 1, 5 & 6)

At station 1, TA, TW, Alkalinity, and TDS were responsible for the ordering of the biota in 1999 and 2002. In 2005, however, tide, moon phase and dissolved oxygen were additionally important in ordering the community structure of the biota. At Station 5, salinity was not recognized as an important contributor to the biota ordering in 1999. In 2000 and 2005, however, salinity became important in the biota ordering. In Station 6, TA and percent moon phase were not included in all of the 11 parameters that ordered the biota in 1999. PO_4 and NO_3 were relevant in ordering the biota only in 1999 (Table 1).

Sampling Zone B (Stations 2, 3 & 4)

At Station 2, a set of nine parameters run through all the 3 years as the main determinants of the biota ordering. In 1999, H_2S was recognized as an important parameter for the biota ordering.

TABLE 1
Biota and environment matching at zone A in Volta estuary (1999, 2000 and 2005)

| <i>Station</i> | <i>1999</i> | <i>2000</i> | <i>2005</i> |
|----------------|----------------------------|----------------------------|---------------------------|
| <i>I</i> | <i>Variable selection:</i> | <i>Variable selection:</i> | <i>Variable selection</i> |
| | 1 TA (°C) | 1 TA (°C) | 1 TA (°C) |
| | 2 TW | 2 TW | 2 TW |
| | 4 ALK | 4 ALK | 4 ALK |
| | 5 TDS | 5 TDS | 5 TDS |
| | 6 % CLOUD | 6 % CLOUD | 6 % CLOUD |
| | 7 DO | 7 DO | 7 TIDE |
| | 8 pH | 8 pH | 8 DEPTH |
| | 9 COND | 9 COND | 9 MOON(%) |
| | 11 PO4 | 11 PO4 | 10 DO |
| | 12 NO3-N | 12 NO3-N | 14 PO4 |
| | 14 SAL | 15 SAL | 18 SAL |
| | Correlation: 0.996 | Correlation: 0.996 | Correlation: 0.996 |
| 5 | <i>Variable selection</i> | <i>Variable selection</i> | <i>Variable selection</i> |
| | 1 TA (°C) | 1 TA (°C) | 1 TA (°C) |
| | 2 TW | 2 TW | 2 TW |
| | 3 SECCHI | 4 ALK | 4 ALK |
| | 4 ALK 5 | 5 TDS | 5 TDS |
| | 5 TDS | 6 % CLOUD | 6 % CLOUD |
| | 6 % CLOUD | 7 TIDE | 8 DEPTH |
| | 7 DO | 8 DEPTH | 9 MOON(%) |
| | 8 pH | 9 MOON(%) | 10 DO |
| | 9 COND | 10 DO | 12 COND |
| | 11 PO4 | 11 pH | 15 NO3-N |
| | 12 NO3-N | 16 SAL | 18 SAL |
| | Correlation: 0.997 | Correlation: 0.989 | Correlation: 0.998 |
| 6 | <i>Variable selection</i> | <i>Variable selection</i> | <i>Variable selection</i> |
| | 2 TW | 1 TA (°C) | 1 TA (°C) |
| | 3 SECCHI | 2 TW | 2 TW |
| | 4 ALK 6 | 4 ALK | 3 SECCHI |
| | 5 TDS | 5 TDS | 5 TDS |
| | 6 % CLOUD | 6 % CLOUD | 6 % CLOUD |
| | 7 DO | 7 TIDE | 7 TIDE |
| | 8 pH | 9 MOON(%) | 9 MOON(%) |
| | 9 COND | 10 DO | 10 DO |
| | 11 PO4 | 11 pH | 11 pH |
| | 12 NO3-N | 12 COND | 12 COND |
| | 13 SAL | 15 SAL | 17 SAL |
| | Correlation: 0.997 | Correlation: 0.995 | Correlation: 0.996 |

TABLE 2
Biota and environment matching at zone B in Volta estuary (1999, 2000 and 2005)

| Station | 1999: | 2000: | 2005 |
|--------------------|--|--|--|
| 2 | <i>Variable selection</i> | <i>Variable selection</i> | <i>Variable selection</i> |
| | 2 TW | 2 TW | 4 ALK |
| | 3 SECCHI | 4 ALK | 5 TDS |
| | 4 ALK 2 | 6 % CLOUD | 6 % CLOUD |
| | 5 TDS | 8 DEPTH | 8 DEPTH |
| | 6 % CLOUD | 9 MOON(%) | 9 MOON(%) |
| | 7 DO | 10 DO | 12 COND |
| | 9 COND | 11 pH | 13 H2S |
| | 10 PO4 | 12 COND | 14 PO4 |
| | 11 NO3-N | 15 NO3-N | 15 NO3-N |
| | 12 SAL | 16 SAL | 17 SAL |
| | Correlation: 0.996 | Correlation: 0.978 | Correlation: 0.992 |
| | 3 | <i>Variable selection</i> | <i>Variable selection</i> |
| 1 TA (°C) | | 1 TA (°C) | 1 TA (°C) |
| 2 TW | | 2 TW | 2 TW |
| 3 SECCHI | | 3 SECCHI | 4 ALK |
| 4 ALK 3 | | 4 ALK | 5 TDS |
| 5 TDS | | 5 TDS | 6 % CLOUD |
| 6 % CLOUD | | 6 % CLOUD | 9 MOON(%) |
| 7 DO | | 8 DEPTH | 10 DO |
| 8 pH | | 9 MOON(%) | 12 COND |
| 9 COND | | 10 DO | 14 PO4 |
| 11 PO4 | | 12 COND | 15 NO3-N |
| 13 SAL | | 15 SAL | 18 SAL |
| Correlation: 0.999 | | Correlation: 0.993 | Correlation: 0.999 |
| 4 | <i>1999</i> <i>Variable selection</i> | <i>2000</i> <i>Variable selection</i> | <i>2005</i> <i>Variable selection</i> |
| | 1 TA (°C) | 1 TA (°C) | 1 TA (°C) |
| | 2 TW | 2 TW | 2 TW |
| | 3 SECCHI | 4 ALK | 4 ALK |
| | 4 ALK 4 | 5 TDS | 5 TDS |
| | 5 TDS | 6 % CLOUD | 6 % CLOUD |
| | 6 % CLOUD | 8 DEPTH | 8 DEPTH |
| | 7 DO | 9 MOON(%) | 9 MOON(%) |
| | 8 pH | 10 DO | 10 DO |
| | 9 COND | 11 pH | 11 pH |
| | 11 NO3-N | 12 COND | 12 COND |
| | 12 SAL | 15 SAL | 16 SAL |
| | Correlation: 0.998 | Correlation: 0.988 | Correlation: 0.999 |

At the main channel Station 3, 11 parameters ordered the biota with pH being important only in 2000 while in 2005, NO₃-N became important in the biota ordering. At the Anyanui confluence Station 4, a set of 10 physico-chemical parameters ordered the biota throughout the 3 years. Moon phase was relevant in 2002 and 2005 (Table 2).

Simper analysis of taxa affinity for habitat Type

Results of the determinations for the biota for homogeneity in their occurrence using the Simper analysis is summarized and presented for zooplankton and nekton contributing up to 5% to the community dissimilarity between stations.

Zooplankton community

A combination of all the six sampling stations shows that the pair of stations that are most dissimilar in the occurrence of the zooplankton are stations 4 and 6 (58.92%); 2 and 6 (54.57%). The station combinations that showed highest affinity for each other in terms of the occurrence of the zooplankton biota were stations 2 and 4 (79.95%) and 1 and 5 (69.84%). The major zooplankton species contributing up to 5% of the various levels of associations is presented for each station pair (Table 3).

Nektonic community

Results obtained from the Simper analysis for the nektonic community collected from six locations within the Volta estuary is summarized and presented in Table 6. On the basis of the occurrence of the nekton, the most dissimilar stations in the Volta estuary was observed to be stations 1 and 4 (72.75%) and 3 and 5 (69.07%). On the other

hand, the combination of stations that showed marked similarity in the occurrence of the nekton were stations 3 and 4 (80%) and 2 and 4 (78.68%) (Table 4).

Canonical correspondence analysis (CCA) for taxa - habitat selection

The CCA results obtained from the pooled physico-chemical variables over the 3 year period for the zooplankton data and the six sampling stations showed that the four ordination axes accounted for 90.7% of the explained total variance of the sample species abundance by the pooled environmental variables data. The variance in the species occurrence as explained by the environmental variables on the first canonical axis (Axis 1) was 58.7%. On the second canonical axis (Axis 2), the environmental variables accounted for 21.3% of the explained variations in the species occurrence (Table 7). The contribution of the specific environmental variable (Lambda) and their marginal effects are presented in Table 8 and Table 9, respectively.

The plot of the canonical correspondence test (CCA) results indicated that the most preferred habitat for the shrimp developmental nauplii stages and the post larval (PL) stages was Station 3 (Zone B). The set of environmental variables that tended to order the occurrence of the shrimp developmental stages, in the order of importance, were the water depth, salinity, hydrogen ion concentration, conductivity and dissolved oxygen. The occurrence of biota in Station 6 was not influenced by the environmental variable measured (Fig. 2).

Discussion

Biotic species association

Estuarine ecosystems are usually characterized by a dynamic exchange of

TABLE 3
 Simper analysis for major discriminants of zooplankton communities in Volta estuary (1999–2005)

| No. | Stn. combination | Average dissimilarity % | Average similarity % | Major species contributing up to 5% of dissimilarity to average dissimilarity index |
|-----|------------------|-------------------------|----------------------|---|
| 1 | 1&2 | 41.36 | 58.64 | <i>Sagitta</i> , <i>Oikopleura</i> , Cladocera <i>Brachionus</i> , Crab Lv. Prawn PL, Mysid shrimp. |
| 2 | 1&3 | 37.82 | 62.18 | Shrimp PL, Mysid shrimp, Cladocera, Prawn PL, <i>Brachionus</i> |
| 3 | 1&4 | 46.64 | 53.36 | <i>Sagitta</i> , <i>Oikopleura</i> , Cladocera, Polychaete Lv. Crab Lv, <i>Brachionus</i> , Mysid shrimp, Prawn PL |
| 4 | 1&5 | 30.16 | 69.84 | Mysis I-III, Shrimp PL, Gravid copeps, Prawn PL, Copepodite, Fish eggs, Calan copep, Oligochaetes, Crab LV, Cladocera, Cyclo copep |
| 5 | 1&6 | 39.92 | 60.08 | Harptacoid copep., Mysis I-III, Tot. rotifers, Oligochaetes, shrimp PL, Calan copep, Cyclo copep, Prawn PL, Copepodite |
| 6 | 2&3 | 30.52 | 69.48 | <i>Sagitta</i> , <i>Oikopleura</i> , Shrimp PL, Crab Lv. Copepodite, Medusae |
| 7 | 2&4 | 20.05 | 79.95 | Polychaete Lv., Cyclopoid copep, copepodite, Medusae, Shrimp PL, Gravid copeps |
| 8 | 2&5 | 41.64 | 58.36 | <i>Sagitta</i> , <i>Oikopleura</i> , Mysis I-III, <i>Brachionus</i> , Mysid shrimp, cladocera, Crab Lv. |
| 9 | 2&6 | 54.57 | 45.43 | Prawn PL, <i>Sagitta</i> , <i>Oikopleura</i> , Mysis I-III, <i>Brachionus</i> , Harptacoid copep, cladocera, Mysid shrimp |
| 10 | 3&4 | 33.54 | 66.46 | <i>Sagitta</i> , <i>Oikopleura</i> , Polychaete Lv, Shrimp PL, Cyclo copep, Crab Lv. |
| 11 | 3&5 | 38.65 | 61.35 | Mysid shrimp, Mysis I-III, <i>Brachionus</i> , Shrimp PL, Medusae, Prawn PL |
| 12 | 3&6 | 50.94 | 49.06 | Mysid shrimp, Mysis I-III, Harptacoid copep, Cladocera, <i>Brachionus</i> , Oligochaetes, |
| 13 | 4&5 | 47.33 | 52.67 | <i>Sagitta</i> , <i>Oikopleura</i> , Polychaete Lv. Mysid shrimp, Mysis I-III, Cyclo copep, <i>Brachionus</i> , Crab Lv, Cladocera. |
| 14 | 4&6 | 58.92 | 41.08 | <i>Sagitta</i> , <i>Oikopleura</i> , prawn PL, Mysid shrimps, Polychaete Lv., Mysis I-III, <i>Brachionus</i> , Harptacoid copep. |
| 15 | 5&6 | 37.32 | 62.68 | Total rotifers, harptacoid copep. Cyclo copep., prawn PLs, oligochaetes, calan copep, Prawn PL, Oligochaetes, calan copep, Shrimp PL, Fish eggs, Bivalve Lv, Cladocera, Gravid copeps, Crab Lv., Copepodite |

freshwater and saline waters, the sources being the riverine discharges and the marine incursions, respectively. Both systems usually carry large quantities of sedimentary materials with them and these are deposited, usually, at the front of the freshwater and marine water flows in the estuary. The

resultant accumulation of the fine sedimentary materials results in the formation of mudflats, mainly in the intertidal areas, which may be very rich in foods but low in dissolved oxygen, and may even be anoxic sometimes (McLusky, 1981). Within the water body itself, the inputs and exchange

TABLE 4:
Simper analysis for major discriminants of nekton communities in Volta estuary (1999-2005)

| No. | Stn combination | Average dissimilarity % | Average similarity % | Major species contributing up to 5% of dissimilarity to average dissimilarity index |
|-----|-----------------|-------------------------|----------------------|---|
| 1 | 1&2 | 64.66 | 35.44 | <i>Tilapia zilli</i> , <i>Penaeus notialis</i> , <i>Macrobrachium vollenhoveni</i> <i>M. macrobrachion</i> , <i>Hemichromis bimaculatus</i> |
| 2 | 1&3 | 66.57 | 33.43 | <i>Tilapia zillii</i> |
| 3 | 1&4 | 72.75 | 27.25 | <i>Tilapia zillii</i> |
| 4 | 1&5 | 48.9 | 51.1 | <i>Galeoides decadactylus</i> , <i>Penaeus notialis</i> , <i>P. karathurus</i> , <i>Callinectes gladiator</i> , <i>C. amnicola</i> , <i>Hemichromis bimaculatus</i> , <i>H. fasciatus</i> , <i>Pellonura</i> sp. <i>Sardinella</i> spp. |
| 5 | 1&6 | 41.33 | 58.77 | <i>Galeoides decadactylus</i> , <i>Sphyraena barracuda</i> , <i>Penaeus notialis</i> , <i>P. monodon</i> , <i>P. karathurus</i> , <i>Mugil cephalus</i> , <i>Mugil</i> sp 2, <i>Liza falcipinis</i> , <i>L. grandisquamis</i> , <i>Pomadasy peroteri</i> , <i>Lutjanus goreensis</i> |
| 6 | 2&3 | 22.1 | 77.9 | <i>Pseudotolithus auritus</i> , <i>Dentex gibbosus</i> , <i>Sphyraena barracuda</i> , <i>Caranx hippos</i> , <i>Chloroscombrus chrysurus</i> , <i>Decapterus punctatus</i> , <i>Parapenaeus longirostris</i> , <i>M. macrobrachion</i> , <i>M. trispinosa</i> , <i>H. Bimaculatus</i> |
| 7 | 2&4 | 21.32 | 78.68 | <i>Sphyraena barracuda</i> , <i>Caranx hippos</i> , <i>C. chrysurus</i> , <i>Decapterus rhonchus</i> , <i>D. punctatus</i> , <i>Elops</i> sp, <i>Hyporhamphus picarti</i> , <i>Pseudotolithus typhus</i> |
| 8 | 2&5 | 64.19 | 35.81 | <i>Macrobrachium vollenhovenii</i> , <i>M. macrobrachion</i> , <i>T. zilli</i> , <i>Cynoglossus</i> sp. <i>Callinectes gladiator</i> , <i>C. amnicola</i> |
| 9 | 2&6 | 36.18 | 63.82 | <i>Cynoglossus</i> sp., <i>S. barracuda</i> , <i>M. vollenhovenii</i> , <i>M. macrobrachion</i> , <i>T. zilli</i> , <i>H. bimaculatus</i> , <i>G. decadactylus</i> , <i>T. guineensis</i> , <i>B. auritus</i> , <i>Elops</i> sp. <i>Pollonura</i> sp., <i>sardinella</i> spp. <i>H. picarti</i> <i>Pseudotolithus typhus</i> |
| 10 | 3&4 | 20 | 80 | <i>Pseudotolithus seneganlensis</i> , <i>Dentex gibbosus</i> , <i>Parapenaeus longirostris</i> , <i>M. macrobrachion</i> , <i>M. trispinosa</i> , <i>Hemichromis bimaculatus</i> , <i>H. fasciatus</i> , <i>Elops</i> sp. <i>H. picarti</i> , <i>Pseudotholithus typhus</i> |
| 11 | 3&5 | 69.07 | 30.93 | None |
| 12 | 3&6 | 37.37 | 62.63 | <i>Macrobrachium vollenhovenii</i> , <i>Tilapia zillii</i> , <i>Brachydeuterus auritus</i> , <i>Pseudotolithus auritus</i> , <i>Galeoides decadactylus</i> , <i>Dentex gibbosus</i> , <i>Cynoglossus</i> sp., <i>Caranx hippos</i> , <i>Chloroscombrus chrysarus</i> |
| 13 | 4&5 | 65.33 | 34.77 | <i>Macrobrachium vollenhovenii</i> , <i>M. macrobrachion</i> , <i>Tilapia zilli</i> , |
| 14 | 4&6 | 36.81 | 63.19 | <i>Macrobrachium vollenhovenii</i> , <i>M. macrobrachion</i> , <i>Tilapia zilli</i> , <i>Hemichromis bimaculatus</i> , <i>H. fasciatus</i> , <i>Galeoides decadactylus</i> , <i>Cynoglossus</i> sp. <i>Caranx hippos</i> , <i>Chloroscombrus chrysarus</i> , <i>Decapterus rhonchus</i> , <i>D. punctatus</i> , <i>T. guineensis</i> , <i>Brachydeuterus auritus</i> , <i>Pellonura</i> sp. <i>Sardinella</i> spp |
| 15 | 5&6 | 52.94 | 41.16 | <i>Pellonura</i> sp., <i>Sardinella</i> spp. <i>S. barracuda</i> , <i>P. monodon</i> , <i>Callinectes gladiator</i> , <i>C. amnicola</i> , <i>Hemichromis bimaculatus</i> . |

TABLE 5
Euclidian distance matrix for physico-chemical parameters/zooplankton species in Volta estuary

| Axes | 1 | 2 | 3 | 4 | Total inertia |
|---|-------|-------|-------|-------|---------------|
| Eigen value | 0.339 | 0.123 | 0.062 | 0.029 | 0.578 |
| Cumulative percent variance of biota-environment relationship | 58.7 | 80 | 90.7 | 95.7 | |

TABLE 6
Contribution of physico-chemical variables to zooplankton species ordering in Volta estuary

| Variable | Var. No. | Lambda I |
|----------------------|----------|----------|
| Water depth (m) | 2 | 0.14 |
| % Cloud cover | 1 | 0.13 |
| NH3-N (mg/L) | 11 | 0.12 |
| NO3-N (mg/L) | 9 | 0.12 |
| Salinity (‰) | 12 | 0.11 |
| pH (pH units) | 5 | 0.08 |
| Conductivity (µS/cm) | 6 | 0.07 |
| NO2-N (mg/L) | 10 | 0.07 |
| DO (mg/L) | 4 | 0.06 |
| PO4 (mg/L) | 8 | 0.04 |
| % MOON phase | 3 | 0.03 |
| H2S (mg/L) | 7 | 0.03 |

TABLE 7
Marginal effects of physico-chemical variables on biota in Volta estuary

| Variable | Var. no. | Lambda A |
|----------------------|----------|----------|
| water depth (m) | 2 | 0.14 |
| Salinity (‰) | 12 | 0.16 |
| Conductivity (µS/cm) | 6 | 0.21 |
| % Moon phase | 3 | 0.04 |
| % Cloud cover | 1 | 0.03 |

of materials from the two water types also cause high levels of turbidity, reduce the degree of penetration of solar irradiance and, consequently, limit the productivity levels in these habitats. The local climatic conditions and changing water regimes determine the whole metabolism and, consequently, the ecology of the system, a factor which is regulated by the size of the estuary and the extent of its opening into the sea.

Klyashtorin (2001) showed consistent correlation of climatic and geophysical indices with manifestation of important processes related to fisheries. The indices of (i) the surface air temperature anomaly (dT), (ii) the length of day (LOD), and (iii) the Atmospheric Circulation Index (ACI), which characterizes the periods of relative

dominance of directional transport of air masses on the hemisphere scale, were of paramount importance. Such parameters as water depth, pH, salinity, conductivity and, to a lesser extent, dissolved oxygen (Fig. 2) were portrayed as the major set of variables with closest affinities for each other, and, in the current study, determined the best habitat preferences for the shrimp PLs as confirmed on the CCA plot.

Adults of the commercially-important penaeid shrimps normally spawn in the sea after which the developing larval stages seek inshore areas and estuaries to settle (Dall *et al.* 1990). The exact period of planktonic life in the marine and near shore habitats varies greatly from species to species, and depends on an array of physiological and environmental variables. (Barnes & Hughes, 1992). The environmental variables may include tides and currents that transport the larvae (Thomson, 1961; Shanks, 1985), the nature, distribution and abundance of settlement sites (Miller & Hadfield, 1986)

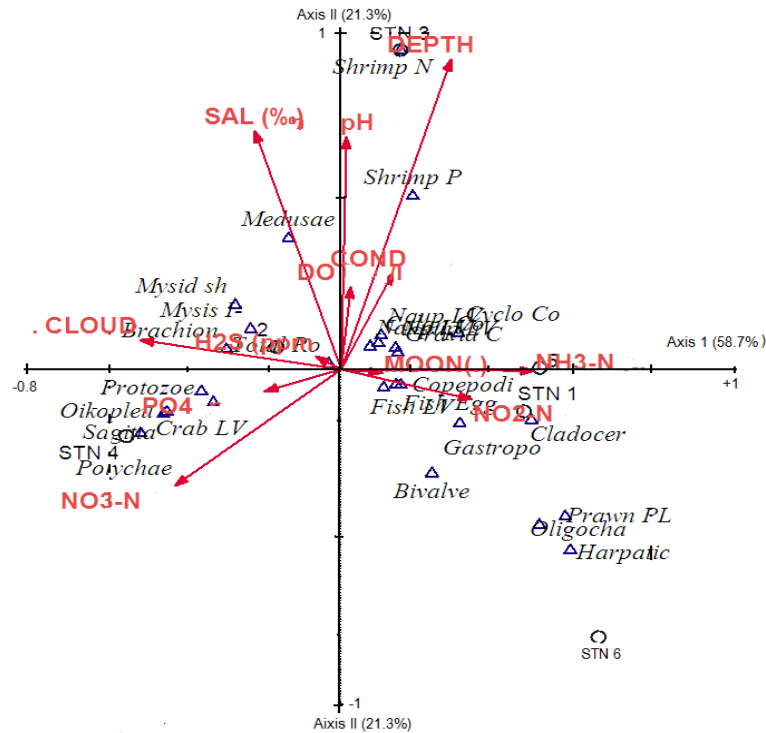


Fig. 2. CCA Tri-plot of physico-chemical variables, sample species and sampling locations in Volta estuary (1999, 2002, 2005)

and indirectly by the lunar cycles that control the tides (Tait, 1981). The phase of the moon and the cloud cover were consistently important, among other variables, in the selection of biota in sampling locations in the present study (Tables 1 and 2)

Simper analysis for major discriminants of the nektonic community that contributed at least 5% of the dissimilarity among the six sampling stations for 3 years (1999, 2000 and 2005) had stations 3–4 pair emerging as the most similar stations (20% dissimilarity level). On the same basis of the Simper analysis statistic, station pairs 2–4 and 2–3 emerged, respectively as the 2nd and 3rd most similar stations at similarity levels of 78.68% and 77.90%, respectively. The least

similar stations were stations 1 and 4 (27.25% similarity) and 1 and 3 (33.43 similarity), respectively.

Although the zooplankton Simper analysis provided a slightly different result from the station similarity pairings, the overall picture is fundamentally the same as that of the nekton similarity analysis. It only re-enforces the knowledge of habitat change associated with larval development, especially, the planktotrophic meroplanktonic shrimp larvae.

In the latter analysis, stations 2 and 4 emerged as the most similar station-pair at 79–75% similarity level. This was followed by stations 1 and 5 at 69.84% similarity level; 2 and 3 at 69.64% similarity level, and 3 and 4 at 66.46% similarity level. Matching the

biota associations with the station/habitat type provides first hand information on the growth requirements of the shrimp larval development forms.

The pairing of the stations as emerged using the occurrence of the zooplankton and nekton data and the subsequent characterization of the estuarine waters is a reflection of the existence of some prominent hydrographical features in the estuary with their associated hydrodynamic estuarine waters.

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