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Mayfly (Insecta: Ephemeroptera) community structure as an indicator of the ecological status of a stream in the Niger Delta area of Nigeria

Francis O. Arimoro · Wilhelmine J. Muller

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Abstract Ephemeroptera is an important group of insects used in the bioassessment and monitoring of freshwater bodies worldwide because of their relative abundance in a wide variety of substrates and their increasing chances of detecting pollution impacts. In this study, their faunistic composition and spatiotemporal variations in density and diversity in River Orogodo (Southern Nigeria) was investigated at five ecologically distinct stations over a 12-month period. The mayfly nymph community responses to environmental variables were evaluated by means of biological measures and multivariate analysis (redundancy analysis [RDA]). Thirteen morphologically distinct taxa belonging to six families were identified. The dominant taxa were *Afrobaetodes pusillus* (23.1%), *Baetis* sp. (13.7%), and *Caenis cibaria* (11.4%). The density of Ephemeroptera differed significantly ($p < 0.05$) both in space and time. Diversity was influenced by substrate heterogeneity which in turn was influenced by catchment processes such as flooding and anthropogenic activities especially abattoir effluent. Based on the RDA ordination and relative abundance data, *Baetis* sp. dominated at impacted stations while a more equitable distribution of species were observed in less disturbed sites. Water velocity, canopy cover, nature of bottom sediments, and the amount of dissolved oxygen also accounted for the variations in Ephemeroptera densities at the different stations. Shannon diversity, taxa richness, and evenness were lowest in station 3 (the abattoir discharge site).

Keywords Ephemeroptera · *Baetis* · River Orogodo · Niger Delta · Diversity · Spatiotemporal variations

Introduction

The importance of Ephemeroptera as part of the functioning lotic ecosystem is recognized worldwide. As shown by many food studies, mayfly nymphs consume epiphytic algae and fine particulate organic matter (Ward 1992; Merritt and Cummins 1996). They are often the most abundant and recognizable freshwater insects especially in riffles, runs, and marginal vegetation and form an important component of fish diets (Miserendino and Pizzolon 2001; Barber-James et al. 2008). Investigations of the distribution patterns of Ephemeroptera as a special group of

F. O. Arimoro (✉) · W. J. Muller
Institute for Water Research, Rhodes University,
P.O. Box 94, Grahamstown, 6140, South Africa
e-mail: fransarimoro@yahoo.com, f.arimoro@ru.ac.za

F. O. Arimoro
Department of Zoology, Delta State University,
P.M.B. 1, Abraka, Nigeria

macrobenthic invertebrates along longitudinal and altitudinal gradients are scarce in Nigeria. Even in the entire West African region, knowledge of Ephemeroptera is still scanty (Gattolliat and Sartori 2006). Outside Nigeria, longitudinal distributions of Ephemeroptera have been well studied (Ward and Berner 1980; Devan and Mucina 1986; Alba-Tercedor 1990; Miserendino and Pizzolon 2001; Fujitani 2002).

The concept of using aquatic insects to assess water quality has proved highly successful, with mayflies forming an integral part of the taxonomic groups currently considered to be especially valuable for biomonitoring (Moog et al. 1997; Rueda et al. 2002; de Moor et al. 2000; Edsall et al. 2004; Menetrey et al. 2008). Numerous studies demonstrate that mayfly community structure effectively reflects the environmental situation of water courses (Gupta and Michael 1992; Bauernfeind and Moog 2000; Medina and Vallania 2001; Ogbogu and Akinya 2001; Baptista et al. 2001; Rueda et al. 2002; Nelson and Roline 2003). In some cases, low mayfly diversity is the result of extreme ecological conditions in the natural environment (Aagaar et al. 2004). A number of factors influence Ephemeroptera species distributions. It has been reported in a number of studies that environmental variables such as stream size, velocity, pH, conductivity, nutrients, amount of dissolved oxygen, riparian forest, and presence of impoundments are associated with Ephemeroptera distribution (Ogbogu and Akinya 2001; Ogbeibu and Oribhabor 2002; Rueda et al. 2002; Buss and Salles 2007).

Investigations of the Orogodo River have so far been based on the ecology of shrimps (Arimoro and Meye 2007), pollution effects of abattoir wastes (Arimoro and Ikomi 2008), and cassava effluent (Arimoro et al. 2008), respectively, on macroinvertebrate communities and studies on the phytophilous macroinvertebrates (Arimoro et al. 2007a). These studies have resulted in the taxonomic composition of Niger Delta streams fauna being fairly well known. The present paper, in contrast, deals specifically with the population dynamics of a special group of invertebrates, Ephemeroptera, in time and space. The river was chosen for this study because it has a typical tropical hydrological regime and it is the main drainage system of Agbor and the immediate surroundings accounting for most of the total run off. The river supports artisanal fisheries and is a spawning and nursery ground for numerous fish species (Arimoro et al. 2008).

The aim of this study is to investigate the ephemeropteran species assemblages in River Orogodo, Nigeria in response to the influences of physical and chemical water quality variables on their abundance and distribution with the ultimate goal of using such an assemblage as a biomonitoring tool.

Materials and methods

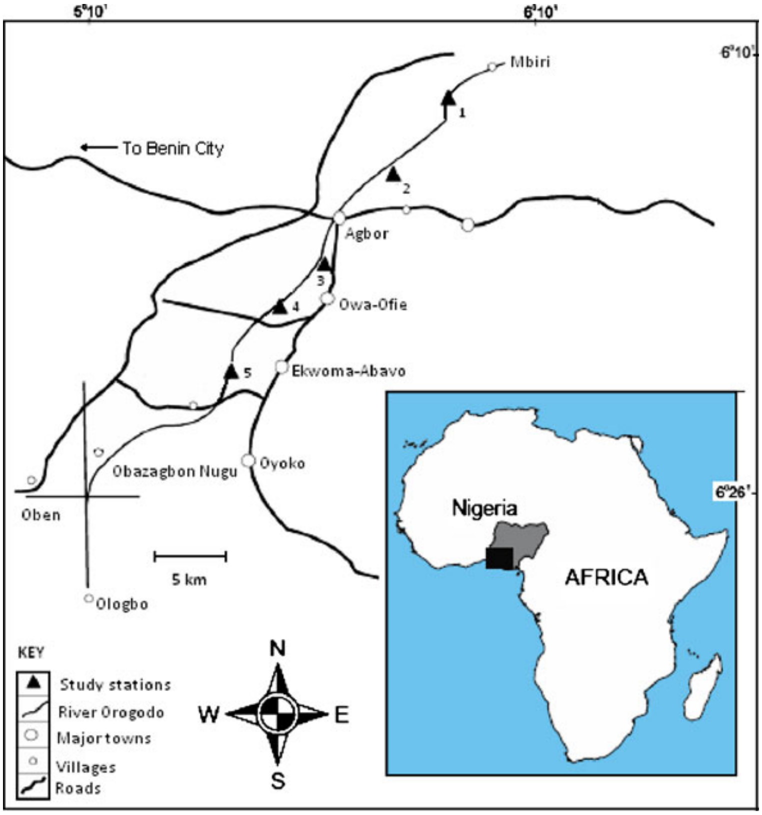
Description of study area

The Orogodo River catchment lies between latitude 5°10′–6°20′ N and longitude 6°10′–6°21′ E (Fig. 1). The climate of the catchment is stable with the wet season from April to October and the dry season between November and March with temperatures ranging from 28°C (wet season) to 32°C (dry season). The rainfall pattern is influenced by the movements of the southwest monsoon winds from the Atlantic Ocean, the timing of which varies from year to year. The river is fed principally by ground seepage from an aquifer in the thick rainforest of Mbiri and secondarily by surface run off which is often polluted with municipal effluence. The river flows through the major town of Agbor in southern Nigeria and dries up at the mouth in the dry season.

The river substratum consists mainly of fine sand mixed with mud and occasionally with coarse sand and pebbles. Decaying macrophytes and debris also form part of the substratum. Five stations were chosen along this river system from the headwater to the downstream reaches.

Station 1 is located approximately 2 km from the river's source (Fig. 1). The water here flows beneath a dense tree canopy in a shallow channel joining shallow pools at various points. Aquatic vegetation is thick consisting of both submerged macrophytes (*Ceratophyllum submersum*, *Nymphaea lotus*, *Azolla africana*, and *Utricularia* sp.) and emergent macrophytes (*Pycreus lanceolatus*, *Cytosperma senegalense*, *Scirpus jacobi*, and

Fig. 1 Map of study area showing the sampling stations in Nigeria



Vossia cuspidate). The streambed is loam and silt with fallen leaves. The water here is considered relatively clean. The marginal vegetation is composed of terrestrial plants including oil palm (*Elaeis guineensis*) and Indian bamboo (*Bambusa* sp.). The land use is mainly for forestry. There is relatively little human activity, although fishing is commonly practiced at this station. This site was chosen as a reference because of the dense riparian vegetation (>65% stream cover) and the absence of anthropogenic stressors. Station 2 is upstream of the town of Agbor, 3 km downstream of station 1. The riparian vegetation consists of mixed forest vegetation and crop farming. The instream vegetation consists mainly of *Commelina*, *Nymphaea* sp., *Panicum repens*, *Pistia stratiotes*, and *Vossia cuspidata*. The streambed is silt and clay. The site is relatively free from human activities perhaps for its location which is far from human settlement. Station 3 is located in the densely populated urban town of Agbor, below the point of discharge of effluents from the Agbor Abattoir. The abattoir effluent is organic, made up of feces, blood, and ashes produced during the slaughter, roasting, and burning of animals (donkeys and cows). This station is exposed to direct heat of the sun and has heavy algal growth in some areas but with very few macrophytes (*N. lotus*, *Azolla* spp, *Utricularia* sp., and *Salvinia* sp.) and duckweeds (*Lemna*) closed to the banks. This site is heavily perturbed by various human activities including laundering, car washing, dumping of refuse, and defecation by both humans and livestock. During the early hours of the day, nomadic cattle herders take their animals to this site to drink and feed on grasses by the side of the river, coincidentally voiding their excreta into the water. The streambed is covered by coarse sand and silt. Rubbish and domestic wastes from the town are emptied few kilometers from this station during heavy downpour.

Station 4 is located 3 km downstream from the Agbor Abattoir at Owa-Ofie village, a semi-urban area. The riparian vegetation is made up

Table 1 Environmental factors measured at five sampling sites in River Orogodo

Sampling stations	1	2	3	4	5	*F* ANOVA
Canopy cover (%)	65	48	25	45	58	
Stream bed width (m)	5.4	3.2	5.8	7.4	5.4	
Air temperature (°C)	27.26 ± 0.43a (23.4–32.6)	27.98 ± 0.47a (24.6–33.7)	29.35 ± 0.50a (26.2–34.8)	27.07 ± 0.43a (23.6–32.8)	28.26 ± 0.43a (25.4–32.6)	1.01
Water temperature (°C)	24.68 ± 0.34a (22.0–27.5)	25.16 ± 0.30a (24.4–28.6)	25.54 ± 0.39a (25.0–29.4)	24.67 ± 0.33a (22.3–28.4)	25.56 ± 0.34a (23.0–28.5)	0.82
Water depth (m)	0.44 ± 0.07a (0.26–0.53)	0.76 ± 0.09b (0.54–0.96)	0.54 ± 0.12ab (0.36–0.68)	1.12 ± 0.24c (0.78–1.48)	0.46 ± 0.06a (0.26–0.58)	57.70[a]
Flow velocity (m s^{-1})	0.25 ± 0.04a (0.19–0.29)	0.195 ± 0.08a (0.14–0.26)	0.44 ± 0.05c (0.20–0.46)	0.28 ± 0.11b (0.17–0.38)	0.25 ± 0.01a (0.19–0.32)	30.41[a]
Conductivity (μS cm^{-1})	24.47 ± 3.14a (18.4–38.4)	38.52 ± 3.52bc (19.4–52.6)	131.82 ± 10.38d (84.2–248.2)	40.53 ± 9.09c (21.3–84.2)	34.47 ± 4.33b (28.4–48.4)	12.49[a]
Dissolved oxygen (mg L^{-1})	8.12 ± 0.161a (6.8–9.4)	7.61 ± 0.12 ac (6.6–8.4)	5.65 ± 0.20b (3.9–6.0)	6.99 ± 0.16cd (4.8–7.9)	6.12 ± 0.14d (4.8–8.4)	5.07[a]
BOD_5 (mg L^{-1})	2.24 ± 0.10a (1.3–3.1)	2.72 ± 0.12bc (1.9–4.0)	9.59 ± 0.62d (4.4–14.6)	3.21 ± 0.20c (1.5–5.0)	2.54 ± 0.15ab (1.3–3.1)	8.07[a]
Total alkalinity (mg L^{-1})	7.50 ± 0.218a (5.58–8.82)	9.29 ± 0.13b (8.06–10.62)	9.48 ± 0.28b (8.00–11.67)	9.09 ± 0.17b (7.24–10.64)	8.40 ± 0.35ab (7.58–9.82)	3.34
pH	5.4–7.2	5.8–7.4	5.5–7.1	5.4–6.7	5.5–7.2	
Nitrates (mg L^{-1})	0.10 ± 0.01a (0.08–0.17)	0.25 ± 0.04b (0.14–0.32)	2.13 ± 0.15c (1.38–3.92)	0.36 ± 0.07d (0.23–0.47)	0.24 ± 0.04b (0.08–0.37)	29.92[a]
Phosphates (mg L^{-1})	0.011 ± 0.00a (0.009–0.016)	0.024 ± 0.00b (0.018–0.028)	0.085 ± 0.01c (0.06–0.100)	0.064 ± 0.01c (0.038–0.101)	0.011 ± 0.01a (0.009–0.016)	121.28[a]

Data are the means ± SE derived from monthly values with minimum and maximum values in parentheses. The results of ANOVA performed for each factor. Different letters in a row show significant differences ($p < 0.05$) indicated by Tukey's HSD tests

[a] Significantly calculated F value

Table 2 Relative composition (in percent) of Ephemeroptera density in River Orogodo from July 2007 to June 2008

Family	Taxon	Code	Stations				
			1	2	3	4	5
Baetidae	*Afrobaetodes pusillus* Navas, 1930	Afrob	22.7	16.6	–	44.7	33.5
	Baetis sp. Leach, 1932	Bae	5.6	12.1	88.9	33.2	17.7
	Afroptilum bicorne Ulmer, 1909	AfroP	6.3	10.6	–	–	15.8
	Pseudocloeon nr *piscis* Kimmins, 1955	Pseu	–	10.2	–	–	–
	Cloeon smaeleni Lestage, 1924	CoelS	–	6.8	–	–	–
	Cloeon bellum Navas, 1931	CoelB	11.2	4.5	–	–	–
Tricorythidae	*Dicercomyzon femorale* Demoulin, 1954	Dic	17.5	12.2	–	–	–
	Tricorythus sp. Ulmer, 1916	Trico	–	–	–	–	5.6
Oligoneuriidae	*Elassoneuria* sp. Eaton, 1881	Elas	16.9	–	–	–	–
Caenidae	*Caenis cibaria* Eaton, 1879	CaeB	12.4	10.9	–	7.9	13.5
	Caenis sp. Stephens, 1835	CaeS	–	7.0	–	–	6.0
Heptageniidae	*Afronurus* sp. Lestage, 1924	Afron	7.4	–	–	14.2	7.9
Leptophlebiidae	*Adenophlebiodes massirius* Elouard-Hideux and Elouard, 1991	Aden	–	9.1	11.1	–	–

of mixed forest and crop farming. Most of the section of the river is flanked by Indian bamboo (*Bambusia* sp.), palm (*E. guineensis*), *Pandanus* sp., and *Mitragyna ciliata*. The substratum is predominantly clay and silt. Human activities include bathing, fishing, sacrifices by superstitious believers, etc. The water depth is approximately 1.12 m. Station 5 is located 5 km downstream from station 4 at Abavo. Farming and sand dredging are the predominant land uses, so the riparian vegetation of the area could be described as farm bush. Most of this section of the river is flanked by native forest, Indian bamboo (*Bambusia* sp.), palm (*E. guineensis*), *Pandanus* sp., and *M. ciliata*. The substratum is predominantly clay and silt. Human activities include bathing, fishing, sacrifices by superstitious believers, etc.

Physicochemical analysis of water samples

Water samples were collected monthly from each station for 12 months (July 2007–June 2008)

Table 3 Axis eigenvalues and weighted intraset correlation between axes and environmental variables following RDA of Ephemeroptera species abundance data from River Orogodo, Nigeria

	Dry season			Wet season		
	RDA 1	RDA 2	RDA 3	RDA 1	RDA 2	RDA 3
Eigen values	0.36	0.16	0.10	0.28	0.17	0.041
Species–environment correlation	0.96	0.95	0.95	0.94	0.92	0.90
Percentage of variance of species data explained	35	52	62	28	45	49
Correlation with axes						
Temperature	−0.11	−0.39	0.02	−0.36	0.56	0.57
Flow velocity	−0.69	0.14	−0.07	0.78	0.23	−0.09
Dissolved oxygen	0.78	0.31	0.28	−0.62	−0.18	−0.57
BOD_5	−0.54	−0.17	−0.68	0.42	0.52	0.51
Total alkalinity	0.09	−0.75	−0.26	0.44	0.25	0.35
pH	0.36	0.54	−0.17	0.03	−0.06	0.65
Nitrate	−0.55	−0.28	−0.53	0.63	0.51	0.35
Phosphate	−0.69	−0.08	−0.69	0.75	0.46	0.19

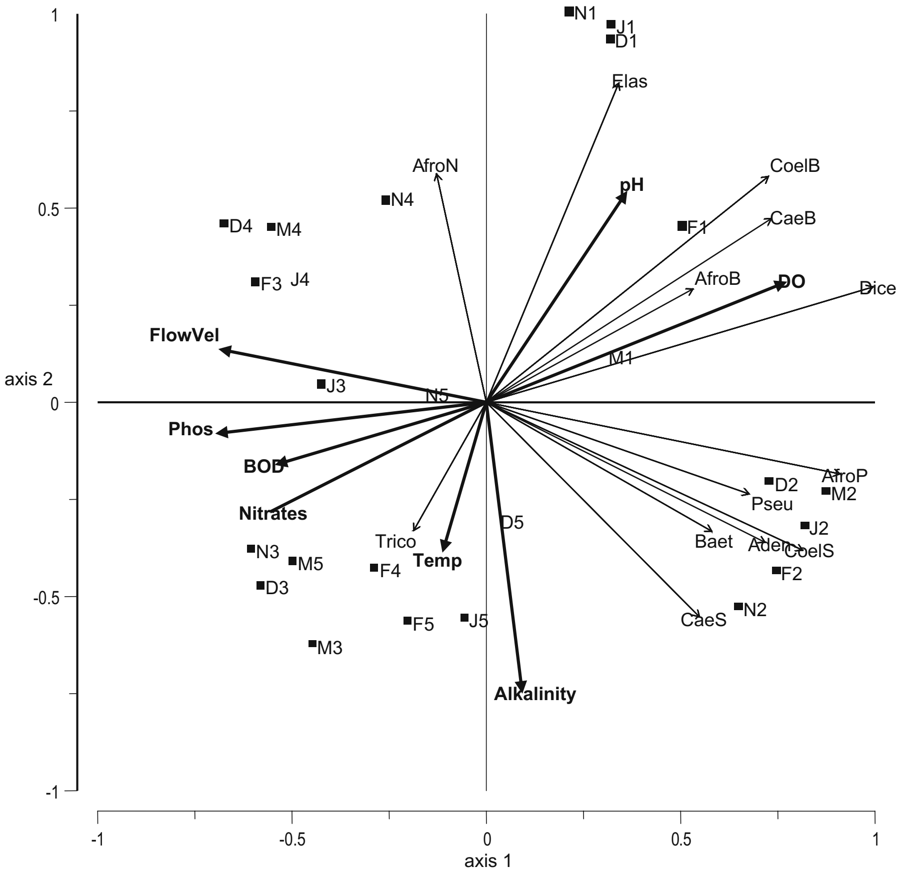
Significance of the axes by Monte Carlo test is given; p values for Monte Carlo test. For the dry season, axis 1: $F = 6.41$, $p < 0.001$. All canonical axes: $F = 5.12$, $p < 0.001$. For the wet season, axis 1: $F = 5.43$, $p < 0.001$. All canonical axes: $F = 4.15$, $p < 0.001$

for laboratory analysis while water temperatures were measured at sampling time using a mercury-in-glass thermometer. Flow velocity was measured in midchannel on three occasions by timing a float (average of three trials) as it moved over a distance of 10 m (Gordon et al. 1994). Depth was measured in the sample area using a calibrated stick. Substratum composition in each 25-m sampling reach was estimated visually as percentage of silt, loam, and sand (Ward 1992). Conductivity, pH, total alkalinity, dissolved oxygen, and biochemical oxygen demand (BOD_5) were determined according to the APHA (1998) methods. Nitrate nitrogen (NO_3–N) and phosphate phosphorus (PO_4–P) were measured spectrophotometrically after reduction with appropriate solutions (APHA 1998).

Ephemeroptera sampling

Samples of macroinvertebrates were collected monthly for 1 year (July 2007–June 2008) using a D-frame net (800 μm mesh) within an approximately 25-m wadeable portion of the river. Four 3-min samples were taken on each sampling visit to include all different substrata and flow regime zones. The four samples were then pooled, representing a single sample for each site. This sampling strategy was evaluated by preliminary test sampling performed and four replicates were established to be sufficient to capture the maximum number of different macroinvertebrate taxa. As the substrate was disturbed, the sampling moved progressively upstream for the required time and the samples collected were preserved in 10%

Fig. 2 Triplot of first and second RDA axes of macroinvertebrate taxa, environmental variables, and their corresponding sampling stations for the dry season. The scale in SD units is −1 to 1 for both the Ephemeroptera and environmental variable scores. The full names abbreviation codes of Ephemeroptera taxa are given in Table 2. *Thick arrows* environmental variable, *filled squares* samples. Monthly codes: *N* November, *D* December, *J* January, *F* February, *M* March. Stations: 1, 2, 3, 4, and 5



formalin. In the laboratory, samples were washed in a 500-μm mesh sieve to remove formalin and macroinvertebrates were sorted with the aid of an illuminated ×10 magnifier. All Ephemeroptera were identified to the lowest identifiable taxon under a binocular dissecting scope following Pennak (1978), Durand and Leveque (1981), Merritt and Cummins (1996), and Barber-James and Lugo-Ortiz (2003) and enumeration.

Data analysis

Community attributes and chemical features of stations were compared using repeated-measures analysis of variance (ANOVA). Fixed-effect ANOVAs were performed using dates as replicates on log $(x + 1)$ transformed data. Significant ANOVAs ($p < 0.05$) were followed by Tukey's Honest significant difference (HSD) tests to identify differences between site means. Taxa richness, diversity, and evenness indices were calculated using the computer BASIC program SP DIVERS (Ludwig and Reynolds 1988). Association between physical and chemical variables and total density were tested with Pearson correlation, incorporating Bonferroni corrections (Rice 1989). Hutcheson t test was used in comparing the similarities between the stations. Redundancy analysis (RDA) was used to evaluate relationships between Ephemeroptera communities and environmental variables with the Brodgar statistical package (version 2.0, Highland Statistics, 2000). During the RDA, the species scores were post transformed and divided by the standard deviation to standardize the ordination diagram for species data and correlation instead of covariance.

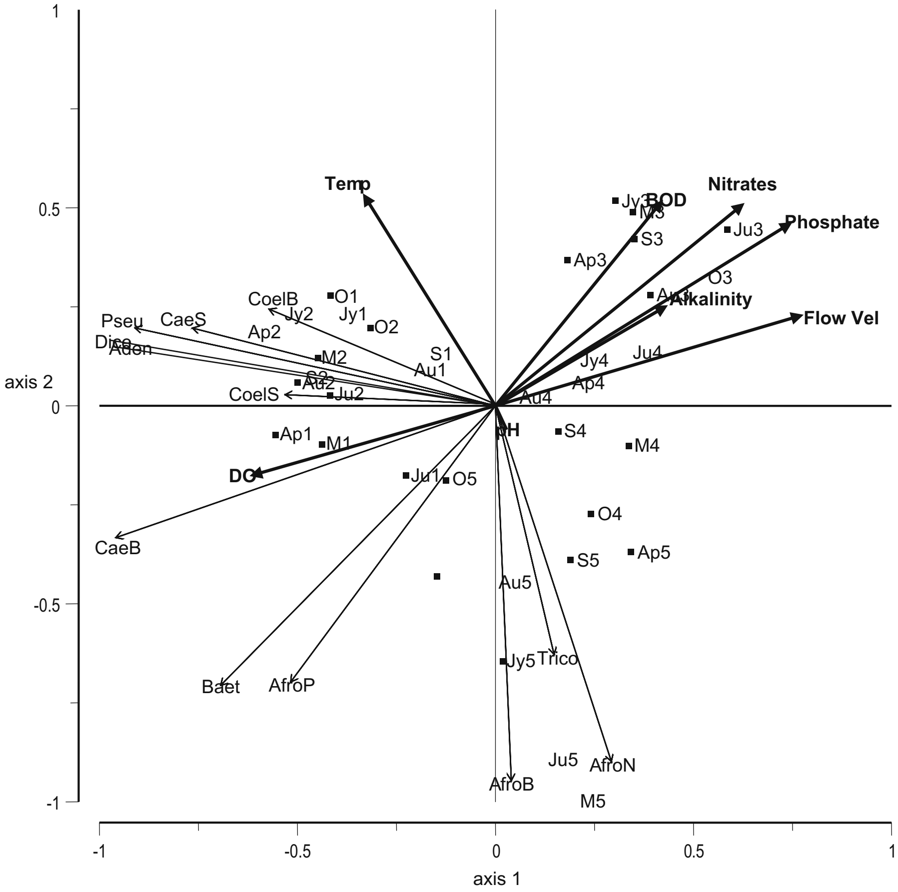


Fig. 3 Triplot of first and second RDA axes of macroinvertebrate taxa, environmental variables, and their corresponding sampling stations for the wet season. The scale in SD units is −1 to 1 for both the Ephemeroptera and environmental variable scores. The full names abbreviation codes of Ephemeroptera taxa are given in Table 2. *Thick arrows* environmental variable, *filled squares* samples. Monthly codes: *Ap* April, *M* May, *Ju* June, *Jy* July, *Au* August, *S* September, *O* October. Stations: 1, 2, 3, 4, and 5

Species abundance data were log transformed {(log (x + 1)} before the RDA to prevent extreme values (outliers) from unduly influencing the ordination. A Monte Carlo permutation test with 999 permutations (ter Braak and Smilauer 2002) was used to assess the significance of the canonical axes extracted. Environmental variables with inflation factor of >10 were not used in the ordination (such as conductivity and depth), identified as an indicator of collinearity in multivariate analysis.

Results

Physical and chemical characteristics of the river

Air and water temperatures, depth, and flow velocity showed wide seasonal variation (Table 1). On the other hand, total alkalinity, pH, and conductivity did not show marked seasonal or station-wise variations. BOD_5, total phosphates, and nitrate concentrations were somewhat higher in stations 3 and 4. Most of the chemical variables (conductivity, dissolved oxygen, BOD_5, total alkalinity, nitrates, and phosphates) were significantly different ($p < 0.05$) among the sampling sites. Again, multiple comparisons using Tukey's HSD test revealed that stations 3 and 4 were significantly different from the other stations.

Ephemeropterans were present along the whole system, except for its middle reaches which recorded very low abundance of Ephemeroptera. A combined total of 13 taxa of Ephemeroptera in six families were present along the whole system. The main families of Ephemeroptera in decreasing frequency and abundance were Baetidae (*Afrobaetodes pusillus*, *Baetis* sp., *Afroptilum bicorne*, *Pseudocloeon* nr *pisces*, *Cloeon smaeleni*, and *Cloeon bellum*) followed by Caenidae (*Caenis cibaria* and *Caenis* sp.) and Tricorythidae (*Dicercomyzon femorale*, *Tricorythus* sp.). Clearly, *A. pusillus* was the preponderant Ephemeroptera at all the stations examined. Oligoneuriidae was represented by *Elassoneuria* sp. and occurred sporadically only at station 1. The family Leptophlebiidae was also poorly represented in the river system. A two-way ANOVA showed significant differences among dates ($F = 25.2$, $p < 0.001$) and sites ($F = 9.6$, $p < 0.001$). Station 2 contributed 35.2% of the total density. This was closely followed by station 5 with 28.5%. Station 3 contributed only 1.19% of the total Ephemeroptera density (Table 2).

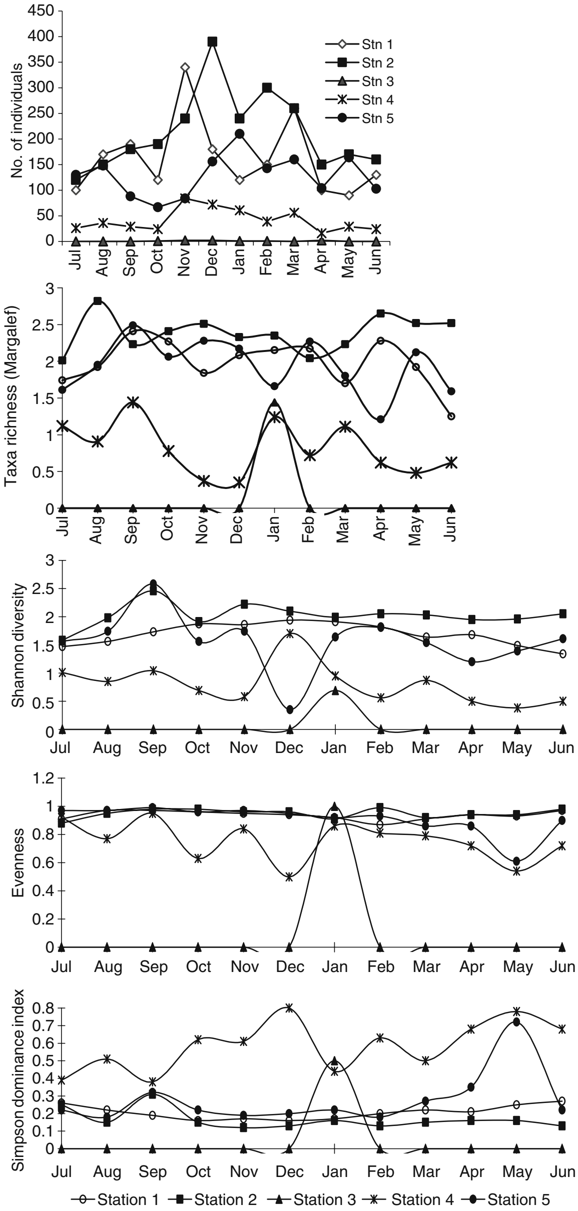


Fig. 4 Number of individuals caught, taxon richness, Shannon diversity, evenness, and Simpson dominance indices at the five sampling stations of River Orogodo

Multivariate analysis

Results of the RDA (first three axes) are summarized in Table 3 and shown in Figs. 2 and 3 for the dry and wet seasons, respectively. The environmental variables selected in the analysis are represented in the triplot by thick arrows, which point in the direction of maximum change in the value of the associated variable (Figs. 2 and 3). The species–environmental correlation data for both seasons indicate strong relationships with the environmental variables selected (>0.90) and Monte Carlo tests were significant for all axes in the dry and wet seasons, respectively (Table 3).

For the dry season analysis, the strongest explanatory factors were dissolved oxygen, flow velocity, phosphate, nitrate, and BOD_5 and accounted for 62% of variation in the species data. RDA axis 1 strongly reflected the distribution of sites along the pollution gradient. Dissolved oxygen had the strongest correlations with axis 1, followed by nutrients (phosphate and nitrate). These variables were strongly related with stream impairment. Samples taken at stations 1 and 2 were clearly located at the positive end of axis 1 (samples from station 1 in the first quadrant and samples from station 2 in the second quadrant, respectively), whereas sites showing higher nitrates, BOD_5, and phosphates were positioned at the negative end of the axis (Fig. 2). Axis 2 showed strong correlation with total alkalinity and pH. Temperature and dissolved oxygen were also correlated with axis 2 but the correlation was rather low. Clearly, most of the Ephemeroptera species, such as *Pseudocloeon*, *Afroptilium*, *C. smaeleni*, and *Caenis* sp. were mostly associated with station 2. On the other hand, *Elassoneuria*, *Afrobaetodes*, *Dicercomyzon*, *C. cibaria*, and *C. bellum* were strongly associated with station 1. *Tricorythus* was mostly associated in the ordination with station 5.

In the wet season ordination analysis, the explanatory factors accounted for 49% of variation in the species data; the strongest explanatory factors were flow velocity, phosphate, nitrate, and dissolved oxygen. Others were total alkalinity, BOD_5, and temperature. RDA axis 1 reflected the distribution of sites corresponding to rainfall and discharge patterns. This explains why flow velocity was the strongest explanatory factor and also the slight influence of temperature changes were noticeable (Fig. 3). Samples taken at stations 3 (first quadrant), 4, and 5 (located mostly in the second quadrant) were located at the positive end of axis 1, whereas samples from stations 1 and 2 where located at the negative end of axis 1. Most of the Ephemeroptera species were strongly associated with station 2. However, *Afroptilim* and *Tricorythus* species were mostly associated with station 5. Stations 3 and 4 were not strongly associated with any of the Ephemeroptera species.

Spatiotemporal changes in density and indices

Changes in the abundance of Ephemeroptera nymphs (spatial and temporal) in the study area during the period of the study are shown in Fig. 4. There were two major populations build up: from November to December and February and March. Periods that coincided with heavy rainfalls (July–October) had considerably lower densities of Ephemeroptera. The diversity, taxa richness, evenness, and dominance indices of the various sampling stations showed that stations 1 and 2 had better evenness values than the other stations (Table 4, Fig. 4). Station 3 recorded very low values of evenness, taxa richness, and Shannon

Table 4 Summary of diversity, evenness, and dominance indices of Ephemeroptera at the different sampling stations of River Orogodo for the entire period of the study (cumulative from July 2007 to June 2008)

	Station 1	Station 2	Station 3	Station 4	Station 5
No. of individuals	1,951	2,550	9	496	1,594
No. of species	8	10	2	4	7
Taxa richness {Margalef's index(d)}	1.33	1.62	0.46	0.66	1.18
Shannon diversity	1.97	2.25	0.35	1.20	1.77
Evenness index (E)	0.95	0.98	0.50	0.86	0.91
Simpson's dominance (C)	0.15	0.11	0.80	0.34	0.20

Table 5 Pearson correlation between Ephemeroptera density and environmental variables at River Orogodo, July 2007–June 2008

Environmental variable	Water temperature	Water velocity	Conductivity	Dissolved oxygen	BOD	Alkalinity	pH	Nitrates	Phosphates
Afrobaetodes pusillus	0.62**	−0.23	−0.85**	0.69**	−0.31	0.04	0.32	−0.33	−0.08
Baetis sp.	0.34*	−0.069	−0.77**	0.56*	−0.48*	0.65**	0.36*	−0.98**	0.13
Afroptilum bicorne	0.47*	−0.35*	−0.44*	0.46*	−0.52*	0.31	0.66*	−0.45*	0.24
Pseudocloeon nr *pisces*	0.58*	0.52	−0.39*	0.22	−0.56*	0.09	0.12	0.57*	0.08
Cloeon smaeleni	0.05	0.03	−0.54*	0.75**	0.08	−0.24	0.09	0.32	−0.08
Cloeon bellum	0.02	0.25	−0.25	0.21	−0.36*	0.44*	0.44*	0.21	−0.76**
Dicercomyzon femorale	0.65*	−0.46*	−0.52*	0.05	−0.28	0.10	0.05	−0.66*	−0.06
Tricorythus sp.	0.77**	−0.52*	−0.08	0.37*	0.21	−0.09	0.09	−0.42*	−0.54*
Elassoneuria sp.	0.70**	−0.49	−0.03	0.68**	−0.55*	0.48*	0.48*	−0.39*	−0.22
Caenis cibaria	0.09	0.21	−0.56*	0.08	−0.54*	0.16	0.08	0.11	0.03
Caenis sp.	0.12	0.31	0.09	−0.07	0.46*	−0.32	−0.22	0.08	−0.41*
Afronurus sp.	0.23	0.08	−0.54*	0.14	0.11	0.09	0.13	0.14	0.03
Adenophlebiodes massirius	0.47*	0.33	0.08	0.18	−0.32	−0.45*	0.18	−0.09	−0.06

* $p = 0.01$; ** $p = 0.05$

diversity. Dominance index calculated as Simpson's dominance index was significantly higher in station 3. The *t* test for comparison of diversity between the sampling stations showed that stations 3 and 4, stations 3 and 5, and stations 4 and 5 as well as stations 1 and 2 were statistically not significant ($p < 0.05$).

Ephemeroptera relationships with abiotic variables

Exploratory analysis showed positive correlations (Pearson) between the abundance of different Ephemeroptera species and temperature, and dissolved oxygen (Table 5). Negative correlations were recorded for Ephemeroptera density and flow velocity, nitrates and phosphates. Nitrates and phosphates were highly negatively correlated with Ephemeroptera density. Conductivity and pH values were negatively correlated with Ephemeroptera densities especially in the preponderant species (*A. pusillus* and *Baetis* sp.).

Discussion

Changes observed in air and water temperatures as in most physical and chemical parameters are primarily governed by the local climatic conditions. For instance, rainfall as a major ecological factor that influences the physical and chemical hydrology of rivers has been documented in a number of studies (Ikomi et al. 2003; Arimoro and Osakwe 2006). Besides water temperature, dissolved oxygen, and flow velocity, the availability of suitable mesohabitat structures is clearly one of the most important factors influencing the occurrence and distribution of Ephemeroptera nymphs (Bauernfeind and Moog 2000). The high levels of BOD_5 values, total alkalinity, conductivity, nitrate, and phosphates and low values in dissolved oxygen observed at station 3 is an indication of the deterioration of water quality as a result of various anthropogenic activities taking place there. Zabbey and Hart (2006) observed a similar trend in Woji Creek in the Niger Delta which receives organic wastes. The nutrients concentration measured in this study are high compared with low-titer values reported for a similar natural unimpacted stream within southern Nigeria (Ogbeibu and Oribhabor 2002; Edokpayi and Osimen 2001; Edema et al. 2002; Imoobe and Oboh 2003; Arimoro and Ikomi 2009).

Generally, the upstream stations 1 and 2 showed relatively clean water status as indicated by the physical and chemical quality of the water at these stations. In addition, the rich fauna diversity of Ephemeroptera at these stations lends more evidence to the clean water conditions observed there. Station 3, affected by the discharge of abattoir effluents and associated wastes, recorded high values of BOD_5, conductivity, and nutrients (that is, nitrates and phosphates), indicating that the water was impacted at this point. Station 4 recorded marginal values of BOD_5, conductivity, and nutrients but not up to the level constituting pollution. Station 5 also recorded moderate amounts of nutrients and BOD_5, signifying that these were rich sites for macroinvertebrates especially Ephemeroptera that require fine particulate organic matter as food source. Another point of difference among stations was the degree of silt–sand deposition and the degree of heterogeneity of mineral substratum. Anthropogenic disturbances at station 3 resulted in increased siltation, reduction of substratum heterogeneity, and elimination of shelter and shade for nymphs. The reduction of benthic Ephemeroptera diversity through the elimination of more sensitive taxa is evident at the site, indicating the overwhelming impact that anthropogenic influences has upon lotic ecosystems. This has been occurring increasingly worldwide. These influences change the energy flux of the system by modifying the riparian vegetation and, consequently, affect the input of allochthonous matter, thus affecting nutrient cycling (Roy et al. 2003; Novotny et al. 2005).

Recent studies carried out in most freshwater streams in Nigeria show that Ephemeroptera are among the insect groups with the highest densities in the macrobenthic community (Ogbeibu and Oribhabor 2002; Egborge et al. 2003; Ikomi et al. 2005; Arimoro et al. 2007b; Olomukoro and Ezemonye 2007; Arimoro and Ikomi 2009). Although well represented in River Orogodo, mayflies were drastically reduced in polluted reaches and in high conductive waters. The highest species richness was recorded in the upper stations 1 and 2. In spite of the high diversity recorded in station 5, densities were very low, probably owing to the high conductivity of the waters flowing in from station 3.

The distribution of the mayfly species along the longitudinal gradient was quite marked in the river system. The restricted presence of *Elassoneuria* sp. in the headwaters was expected, since the species belonging to this genus have been recorded as dwellers of highly oxygenated waters (Gattolliat and Sartori 2006). Throughout the period of this investigation, only nine individuals of Ephemeroptera were recorded in station 3 (with eight individuals of *Baetis* sp.). This species is reportedly resistant to organic pollution (Timm 1997; Buss and Salles 2007; Menetrey et al. 2008). *Pseudocloeon* nr *pisces* was restricted to the backwater biotope at station 2, confirming Pennak's (1978) submission that this species inhabits the quiet waters of ponds and backwaters of streams. Station 2 exhibited a wide variety of mesohabitats suitable for both rheophilic species and those that prefer slow water conditions such as pools and backwaters. This may account for the high density and diversity of Ephemeroptera at that site.

The family Baetidae from this study can be proposed as an indicator of water quality and ecosystem health primarily because of its presence in both the polluted and unpolluted reaches of the river. However, it appears to be sensitive to pollution as numbers are significantly reduced at sites that are regarded as disturbed sites (stations 3 and 4). The genera *Baetis* and *Caenis* from earlier studies have been reported to be tolerant to organic pollution (Timm 1997; Menetrey et al. 2008). However, in our study, *Caenis* was never recorded at the impacted site.

The total number of ephemeropteran taxa obtained in this study is high (13) when compared with other studies undertaken in the Niger Delta. Umeozor (1996) and Edema et al. (2002) each reported five taxa while Egborge et al. (2003) reported six taxa in various freshwater bodies of the Niger Delta. This may be due to the larger and more diverse littoral zone in the River Orogodo, resulting in high faunal diversity. Studies with similar results are those of Arimoro and Ikomi (2009) and Edokpayi and Osimen (2001) who reported eight taxa each in upper Warri River and Ibekuma River both in Southern Nigeria, respectively.

The overall composition and density of Ephemeroptera fauna varied both spatially and temporally in response to physical, chemical, and biological factors of the environment. The significantly lower densities in the distribution and abundance of Ephemeroptera fauna at stations 3 and 4 can be ascribed to combined influences of changes in substrate composition as a result of anthropogenic activities at these stations as well as impaired water quality at these sites. Seasonal variation in the abundance of Ephemeroptera density observed in this study can be explained by the changes in water level and increased turbidity of the inflowing floodwaters. This probably caused the destruction of the periphytic algae and a subsequent decline in the amount of phytoplankton in the river. The resulting food shortage reduced the standing crops of the nymphs greatly.

Our results indicate that multivariate analysis based on Ephemeroptera communities were useful to identify different degrees of pollution and disturbance in the studied stream. Station 3 was shown to be most disturbed by the anthropogenic activities as evidenced by impaired water quality and reduced Ephemeroptera diversity and abundance. Pearson correlation and RDA suggest that the factors determining Ephemeroptera distribution in River Orogodo were both physical and chemical. Temperature, pH, dissolved oxygen, and nutrients seem to be important for the abundance of Ephemeroptera. Ephemeroptera abundance on the other hand was negatively correlated with conductivity and BOD. We also detected a seasonal trend in Ephemeroptera abundance; correlations with temperature as well as flow velocity were significant, and these two variables explained in part the observed temporal patterns in total abundances and assemblage composition. This is consistent with the observations made by Arimoro and Ikomi (2009) that numbers of taxa and the mean abundances of aquatic insects increased in the dry season and decreased in the wet season in the upper reaches of Warri River, Niger Delta.

Ephemeroptera taxa richness and diversity remain at a relatively high level in the upper reaches of the Orogodo River (stations 1 and 2), but reduced drastically in station 3. The main ecological stresses being land use and anthropogenic activities. The downstream reaches (stations 4 and 5) showed that ephemeropterans are able to recover from environmental stressors. In conclusion, this study revealed that Ephemeroptera communities responded to changes in substrate composition, habitat, and water quality along its length. There were marked shift in dominance and composition at the various stations. The headwater stations (stations 1 and 2) were dominated by taxa associated with unimpacted waters. Station 3 showed a sharp decrease both in density and diversity of Ephemeroptera taxa. The improved taxa richness and diversity at station 5 is an indication of recovery. According to Miserendino and Pizzolon (2001), organic load dilution is known to occur downstream, generating a species composition and abundance similar to the upstream stations. The results of this study allow for a better understanding of the regional diversity and distribution of mayflies in the Niger Delta Rivers. Such information will provide a solid basis through which we can obtain a better understanding of the structure and functioning of the complex ecosystem. Data collected on mayflies can be used toward the development of bioassessment protocols that are regional specific and indices used for estimating ecosystem health. In addition, research on other groups of aquatic invertebrates is also required to gain a better understanding of the overall structure and function of rivers in the Niger Delta.

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