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Gammarus:Asellus Ratio as an Index of Organic Pollution – (A Case Study in Markeaton, Kedleston Hall, and Allestree Park Lakes Derby) UK

U. Bawa

Abstract**—**Macro invertebrates have been used to monitor organic pollution in rivers and streams. Several biotic indices based on macro invertebrates have been developed over the years including the Biological Monitoring Working Party (BMWP). A new biotic index, the *Gammarus*:*Asellus* ratio has been recently proposed as an index of organic pollution. This study tested the validity of the *Gammarus:Asellus* ratio as an index of organic pollution, by examining the relationship between the *Gammarus:Asellus* ratio and physical chemical parameters, and other biotic indices such as BMWP and, Average Score Per Taxon (ASPT) from lakes and streams at Markeaton Park, Allestree Park and Kedleston Hall, Derbyshire. Macro invertebrates were sampled using the standard five minute kick sampling techniques physical and chemical environmental variables were obtained based on standard sampling techniques. Eighteen sites were sampled, six sites from Markeaton Park (three sites across the stream and three sites across the lake). Six sites each were also sampled from Allestree Park and Kedleston Hall lakes. The *Gammarus:Asellus* ratio showed an opposite significant positive correlations with parameters indicative of organic pollution such as the level of nitrates, phosphates, and calcium and also revealed a negatively significant correlations with other biotic indices (BMWP/ASPT). The BMWP score correlated positively significantly with some water quality parameters such as dissolved oxygen and flow rate, but revealed no correlations with other chemical environmental variables. The BMWP score was significantly higher in the stream than the lake in Markeaton Park, also The ASPT scores appear to be significantly higher in the upper Lakes than the middle and lower lakes. This study has further strengthened the use of BMWP/ASPT score as an index of organic pollution. But additional application is required to validate the use of *Gammarus:Asellus* as a rapid bio monitoring tool.

Keywords**—***Asellus*, Biotic index, *Gammarus*, Organic pollution, Macro invertebrate.

I. Introduction

BIOLOGICAL assessments of running waters have long been incorporated within physical, chemical assessments to provide complete information for an effective water management [1]. This is because biological assessment methods have more advantage over the chemical assessments.

For instance organisms tend to combine environmental conditions over long periods of time, while chemical data represent the present condition of water body and depends upon numerous measurements for accurate result [2]. Furthermore [3], revealed that biological monitoring based on macro invertebrate showed more important pollution then physic-chemical monitoring. According to [4], streams can be assessed by different approaches using macro invertebrates which include: richness measures, enumeration, diversity indices, similarity indices, biotic indices, and multimetric approach.

Several organisms are now been used in biotic in water quality monitoring these include periphyton, diatoms, fish and benthic macro invertebrates [5]. Biotic indices are numerical expressions combining a quantitative measure of species diversity and qualitative information on ecological sensitivity of individual taxa [6]. The aim of biotic indices is to assess the biological quality of running waters, in most cases based on macro invertebrates and to measure different types of environmental stress, organic waters, acid waters [7]. More so, biotic indices take account of the sensitivity or tolerance of individual species or groups to pollution and assign them a value and the sum of which gives an index of pollution for a site [2]. Biotic indices are generally specific to a type of pollution, usually designed to assess organic pollution [8]. However many biotic indices are regional specific, because different taxa are found in different geographical areas. As such a biotic index developed in one country cannot be applied without modification in another [9]. This has led to the development of numerous biotic indices to monitor water quality in different countries [10].

There are a number of biotic indices based on different organisms. For example the Diatom biotic indices which are sensitive towards many environmental factors such as ionic Content, PH, dissolved organic matter and nutrients and have been used to monitor streams, rivers in many regions [11], [12]. Several diatom based indices have been developed and applied such as the trophic diatom index (TDI), which uses a scoring system based on diatom species has been used to assess eutrophication in several European states [13], [14]. Other biotic indices based on fish, such as the fish based index of biotic integrity (IBI) have been used extensively in biological monitoring programs [15], [5]. IBI have also been used to protect endangered species that desire healthy and undisturbed ecosystem conditions [16]. The advantages of biotic indices are that only qualitative sampling is required and that identification is mostly at family or genus level and that there is no need to count abundance per taxon [2].

However biotic indices based on benthic macro invertebrate are the most commonly used and has more advantages than the use of other biotic indices based on diatoms, or fishes

U. Bawa is with the Federal College of Educational Technical, P. M. B 1013, Potiskum, Yobe State. Nigeria (phone: +2348038755737; e-mail: bawa.usman@yahoo.com).

because macro invertebrates are differentially sensitive to pollutants of various types and react to them quickly [17], [4]. Macro invertebrates also have the advantage of being easy to collect and identify because they are confined to a particular aquatic habitat for the most part of their life and are good indicators of changes in water quality [18]. In addition, macro invertebrates can also be used to detect acid stress, habitat loss and overall stream degradation [18]. Macro invertebrates have, furthermore an advantage in bio monitoring, because they are not merely affected by different types of physical-chemical pollution (for example organic enrichment, eutrophication, acidification) but as well by physical changes and anthropogenic manipulation of aquatic habitat such as canalization, impoundment, and river regulation [7]. In addition the Water Frame Work Directive [19] introduced the obligation of surface water bio monitoring with the use of macro invertebrates in EU countries.

The use of biotic indices based on macro invertebrates to assess water pollution and other human impacts on rivers and streams has a long history [20]. Studies of biotic indices based on macro invertebrates are well established [4], [21], [10], [7]. The use of Macro invertebrate has its limitations because some macro invertebrates especially insects may not be found at some times of the year due to seasonality of life cycles, which makes sampling difficult [22], [23].

Gammarus pulex (freshwater shrimp) and *Asellus aquaticus* (water log house) are two of the most commonly occurring benthic crustaceans of British rivers but they react quite differently to organic enrichment [24]. *Gammarus pulex* normally inhabits the well oxygenated riffle reaches of the river bed and is generally intolerant of organic pollution. *Asellus aquaticus*, however, is quite tolerant of low oxygen conditions and is not normally considered to be a member of the riffle community but is usually in the depositing substratum of pools [25], [26]. *Asellus* invades the modified riffle ecosystem as part of the replacement community during organic enrichment and often becomes the dominant species. Large numbers of *Asellus* in the riffles therefore, are considered to be an indication of organic pollution [27]. However, in organically polluted streams *Asellus aquaticus* invades the riffles, where it is not naturally found to replace *Gammarus* and often becomes the dominant specie [24]. Lack of oxygen and low PH are important factors which determines the distribution patterns of *Gammarus* [28]. This is because *Gammarus pulex* showed increased in mortality rate at PH lower than 6.0 and with lower physiological status of surviving individuals, but *Asellus* tends to survive even at lower PH lower than 6.0 [29]. *Gammarus* and *Asellus* also vary in their sensitivity to concentration of dissolve oxygen, *Gammarus* are found in higher proportion at 7.4mg/l or above and can tolerant low dissolve oxygen as low as 2.7mg/l [30].In to contrast to *Asellus* which can tolerates low level of as low as 1.5mg/l and is highly in abundant at 5.8mg/l concentration of dissolve oxygen [31]. Therefore *Gammarus* is intolerant of very low oxygen concentrations and therefore is suppressed by organic pollution, and *Asellus* is quite tolerant of low oxygen conditions [32], [2]. Hence, because of their variation and sensitivity to parameters linked to organic pollution, they are used as an index of organic pollution [33].

The used of *Gammarus:Asellus* ratio as an index of organic pollution has been reported in few papers. Recent studies by [27] revealed using univariate and multivariate analysis that *Gammarus:Asellus* ratio response to changes in parameters associated with organic pollution, and showed a significant positive correlation with water temperature, macrophyte coverage and negative correlation with distance from source, water depth, conductivity and nitrate levels in the spring/ summer ($P<0.05$). While in the Autumn/winter the *Gammarus:Asellus* ratio showed positive correlation with substrate heterogeneity and a negative correlation with Biochemical oxygen demand and nitrate ($P<0.05$). It also correlates well with the community level biotic and richness indices, both in spring and summer. Reference [25] had earlier observed macro invertebrate at riffle sites of four lowland rivers using different biotic indices. The studies found that *Gammarus:Asellus* ratio recorded low values at sites with poor water quality, which also corresponded with the values of Chandler biotic scores and Extended Trent Biotic index. The G:A ratio also revealed significant negative correlation with parameters indicative of organic pollution, BOD, ammonia-nitrogen, nitrate-nitrogen and phosphate-phosphorous. Similar studies by [34] showed that *Gammarus:Asellus* ratio was the most valuable index among other indices in assessing organic enrichment, because it easier to use and also correlate well with other indices and the occurrence of pollution tolerant species. Reference [33] using the *Gammarus:Asellus* ratio also found high proportion of *Gammarus* associated with clean water streams and in contrast to high proportion of *Asellus* found in polluted streams. All these studies have proposed the use of *Gammarus* and *Asellus* ratio as a simple index of organic pollution.

The Biological Monitoring Working Party (BMWP) biotic index has been widely used in the UK and other countries to give a broad indication of the biological condition of rivers [2]. Several studies have found the values of BMWP score to decrease downstream of a river with increasing level of organic pollution [33]. Moreover, the BMWP score and ASPT have proven effective in distinguishing pristine site and site impacted with organic pollution [35]. Both the BMWP and ASPT were showed to correlate negatively with parameters indicative of organic pollution such nitrate, phosphate, ammonium and positively correlating with dissolve oxygen, PH and temperature [36], [37]. BMWP score method is widely used because organisms are identified to family level for uniformity, no account is taken of abundance and families with similar pollution tolerance are grouped together [38]. Moreover BMWP is easier to employ and its generation requires little taxonomic knowledge with minimal time to obtain result in contrast to other indices [37].

The *Gammarus:Asellus* ratio on the other hand have also been used as an index of organic pollution in fresh waters [25].This is because *Gammarus* is more sensitive to organic pollution than *Asellus*, and their ratio tends to decrease with poor water quality [32]. However studies have suggested the

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use of *Gammarus:Asellus* ratio as a simple and rapid bio monitoring tool of organic pollution, and they correlate negatively with parameters indicated of organic pollution [27]. The use of *Gammmarus:Asellus* ratio has numerous advantages over the use of other biotic indices based on macro invertebrates. Because *Gammarus:Asellus* index easy to use and requires little identification skills and it correlates well with other biotic indices [25]. The generation of *Gammarus: Asellus* index requires small taxonomical skills in comparison to other biotic indices [25]. Because of these reasons it was proposed as a simple rapid assessment tool of organic pollution for scientist and other interested parties such as anglers, fish farmers, recreational users and amateurs [27].

However since the inception of *Gammarus:Asellus* ratio as an index of organic pollution, there are only few validation attempts to investigate its reliability and practicability .So this study is to test the validity of *Gammarus:Asellus* ratio as an index of organic pollution, and it relationship with other biotic indices BMWP/ASPT. Here, we examine relationships between *Gammarus:Asellus* ratio with physic chemical environmental parameters, including those unrelated to pollution over three lakes in Derbyshire (Upper lakes, middle lakes and down lakes). Furthermore, little attempt has been made to relate the *Gammarus:Asellus* ratio to established but more complex biotic indices currently used for the bio assessment of river water quality. Therefore, this study explores corrections of *Gammarus:Asellus* ratio with such indices in order to ascertain if *Gammarus:Asellus* ratio could be used as a more simple alternative.

II. Methodology

The study areas Markeaton Park, Kedleston hall and Allestree Park are all located within Derby, Derbyshire. Allestree Park is located in the north of Derby on OS grid reference SK 345395. The lake is fed by streams running from the woodland in the north and land drainage from the golf course and is essentially divided into two water bodies by a weir .The western water body (Allestree west) covers an area of approximately 11,000 m square and the eastern water body (Allestree East) with an areas of over 34,000 meter square [39]. The lower lake (Allestree East) is well used by anglers and several fishing plat forms have been constructed, while the upper body (Allestree west) is regarded as conservation area no fishing allowed [39].

The kedleston Hall lies some 4 miles to the north and west of Derby, ordinance Survey map grid reference SK 313403. It is located within the civil parishes of Kedleston, Quarnton, Markeaton and Weston wood. The Markeaton Park is centred on grid reference SK 33474 to the east of Derby, Derbyshire. Both the Kedleston Hall Lake and Markeaton Park Lake are fed by the Makeaton brook, in the Kedleston hall the Lake was artificially made from the Cultler brook and joined by 5 other tributaries including Black brook, Hungerhill brook, Green brook and water lag brook. The Markeaton brook also enters rises outside the city and through Markeaton Park, and continuous to join the river Derwent.

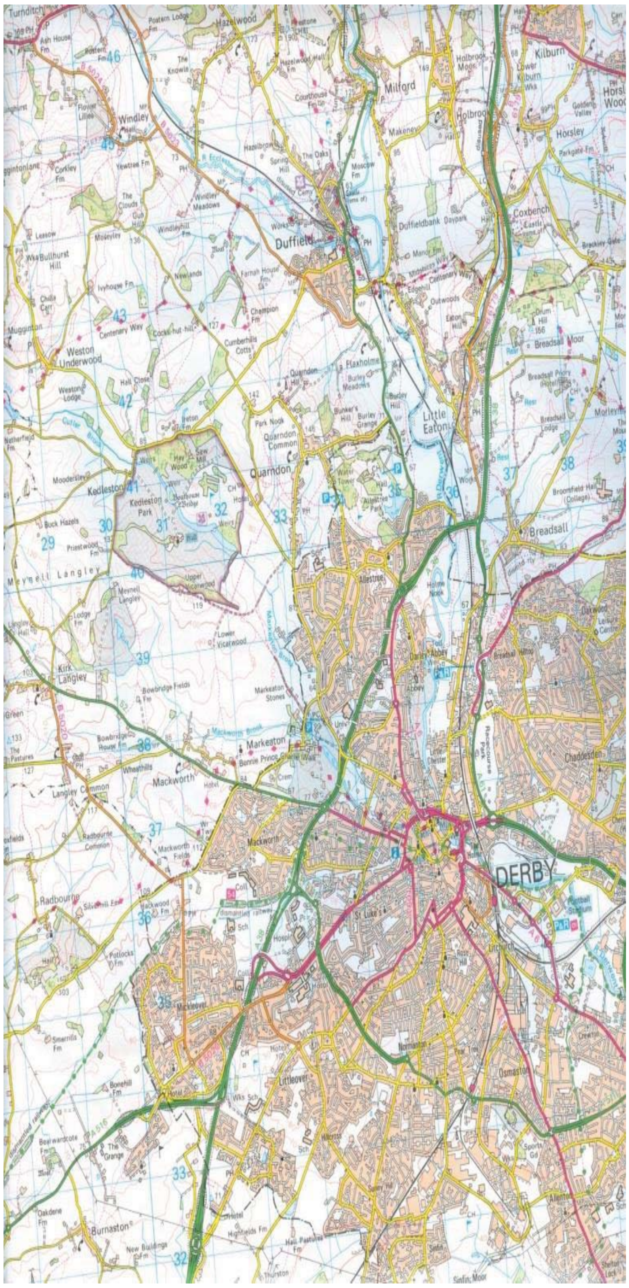

Fig. 1 The location of the study area, Kedleston hall, Markeaton Park and Allestree Park in Derby, Derbyshire [40]

Total of 54 sites (upper lakes, middle lakes and lower lakes) were sampled from streams and lakes in Allestree Park, kedleston hall and Markeaton Park from May to August, 2013 in Derbyshire United Kingdom. Three minute kick samplings were taken at each site, using the standard 1mm mesh size net. The substratum upstream of the net was vigorously disturbed to dislodged invertebrates flow into the net, in accordance with [2]. Samples were empty into a white try and macro invertebrates were sorted, and *Gammarus* and *Asellus* were identified to family level, counted and recorded in the field. However, other macro invertebrates were preserved with alcohol and transported back to laboratory for identification as suggested by [41]. Macro invertebrates were further sorted on a petri dish in the laboratory and identified into family level using microscope and identifications keys. The following identification keys were used to identify macro invertebrates to family level [42]-[46]. In accordance to [41], each group or family of macro invertebrates sampled at each site were allocated the BMWP score according to their sensitivity to environmental disturbance. Each scores for each family represented in the sample for sites, were summed to generate the BMWP score. In order to reduce the variation caused by seasonal differences and sample size, the average score per taxon was calculated from the BMWP [38]. The average score per Taxon(ASPT) were obtained by dividing the BMWP score, by the total number of taxa(Families) in the sample.The *Gammarus* to *Asellus* ratio was obtained by dividing the number of *Gammarus* counted at each site to the number of *Asellus* recorded, in accordance with [25], [27].

TABLE I
SAMPLING POSITION WITH GPS GRID REFERENCE

Locations	East	North
Markeaton park	33331	37816
Markeaton Park	33334	37806
Markeaton Park	33632	37692
Markeaton Park	33478	37637
Markeaton Park	33512	37687
Markeaton Park	33548	37668
Kedleston hall	33566	37666
Kedleston hall	30774	41264
Kedleston hall	31402	40461
Kedleston hall	31332	41376
Kedleston hall	30556	41255
Kedleston hall	32127	40109
Allestree Park	30557	41249
Allestree Park	35006	40449
Allestree Park	35133	40424
Allestree Park	35124	40343
Allestree Park	35013	40258
Allestree Park	35091	40435

Prior to kick –sampling, *in situ* values for site level environmental variables were obtained: water temperature (mercury thermometer), PH (Gallen Kampf meter), dissolved oxygen (D02 meter 9071), conductivity (H1-9033 multi range conductivity meter). As each kick sample was taken, water depth and current velocity (geopacks flow meter) was recorded.

Water samples were collected in a plastic laboratory bottles prior to each kick sampling. Samples were transported and store at University of Derby laboratory on the same day of collection, analysis were undertaken to determine Nitrate, Phosphates using Palin test photometer and Calcium concentrations was obtained using Atomic Absorption Spectrometer (A Analyst 200) based the procedure describe by [41].

All the above physical and chemical parameters were selected in this study, because they have influences on the presence, absence and abundance of macro invertebrates [47], [27], [33], [36], [37], [25].

A. Statistical Analyses

Statistical analysis has been carried out using the statistical package SPSS to analyse and present results. The following stages of analysis were carried out:

Kolmogorov-Smirnov test was used to determine whether the variables differ from normally distributed one or not. Results obtained indicated that the data were not normally distributed and hence the Pearson's Product-Moment correlation was not use and the alternative Spearman's rank order correlation was chosen [48].

The Non-parametric spearman's rank order correlation statistical analysis was employed to measure the degree to which one set of variable varies with another. This test was used to determine relationships between the *Gammarus: Asellus* ratio and environment variables, BMWP, ASPT scores and environmental variable in accordance with [48].

Comparative statistical analysis to compare differences in variables and parameters between sites, including the one-way ANOVA, the multiple comparisons Post Hoc test (Tukey), and Homogeneity test [48]. These tests were used to determine the significant mean differences between BMWP, ASPT score and environmental variables between upper lakes, middle lakes and down lakes.

III. RESULTS

The normality of the data was tested using one sample Kolmogorov-Smirnov test the result obtained indicated that P value is less than 0.05 for *Gammarus:Asellus* and dissolve oxygen (indicating the data were not normally distributed). Hence the correlations between biological indices *Gammarus: Asellus* ratio, BMWP score, ASPT score and Chemical variables were computed using the Non-parametric spearman rank correlation.

A. Correlation Analyses

Correlation analysis between *Gammarus:Asellus* ratio (G:A) and environmental variables (Table I) revealed highly significant positive correlations between the *Gammarus: Asellus* ratio and nitrates Fig. 2, phosphates, PH and conductivity ($P<0.01$) and a significant positive correlation with calcium ($P<0.05$).Significant negative correlations were showed between G:A ratio with water temperature (Table II). But a highly significant negative correlation was revealed between the G:A ratio and biotic indices, the BMWP,ASPT (Table II). However, the G:A ratio did not correlate significantly with variables such as flow velocity, depth and dissolve oxygen (Table II).

The Correlation analysis results between the BMWP and environmental variables (Table III) indicated a significant positive correlation with dissolve oxygen (Fig. 4) ($P<0.05$) and a highly significant positive correlation with flow velocity (Fig. 3), ASPT ($P<0.05$) (Table III). However such relationship is expected because, increased in dissolve oxygen is associated with increased in the abundance of oxygen

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sensitive macro invertebrates. More over the BMWP score index revealed a significant negative correlation with PH (Table III). But the BMWP also showed no significant relationship with other environmental variables such as nitrates, calcium, phosphate, temperature, depth and conductivity (Table III).

TABLE II
SPEARMAN RANK CORRELATION COEFFICIENT BETWEEN *GAMMARUS:ASELLUS* RATIO AND ENVIRONMENTAL VARIABLES

Environmental variables	*Gammarus:Asellus ratio*
Water Temperature	**-0.470** ^{x}
PH	**<u>0.553</u>** ^{xx}
Flow	0.100
Depth	-0.180
Dissolve Oxygen	-0.343
Nitrates	**<u>0.762</u>** ^{xx}
Phosphate	**<u>0.719</u>** ^{xx}
BMWP	**<u>-0.673</u>** ^{xx}
ASPT	**<u>-0.632</u>** ^{xx}

Note: Corrections highly significant (P<0.01) are in bold and underlined and corrections with p<0.05) are in bold. (n=29 for all variables).

TABLE III
SPEARMAN RANK CORRELATIONS COEFFICIENT BETWEEN BMWP SCORE AND ENVIRONMENTAL VARIABLES

Environmental variables	BMWP
Nitrate	0.003
Dissolve Oxygen	**0.309** ^{x}
Flow	**<u>0.359</u>** ^{xx}
Calcium	-0.151
Phosphate	-0.051
Temperature	0.049
Depth	-0.091
Conductivity	-0.098
PH	**<u>-0.357</u>** ^{xx}
ASPT	**<u>0.736</u>** ^{xx}

Note: Corrections highly significant (P<0.01) are in bold and underlined and corrections with p<0.05) are in bold. (n=29 for all variables).

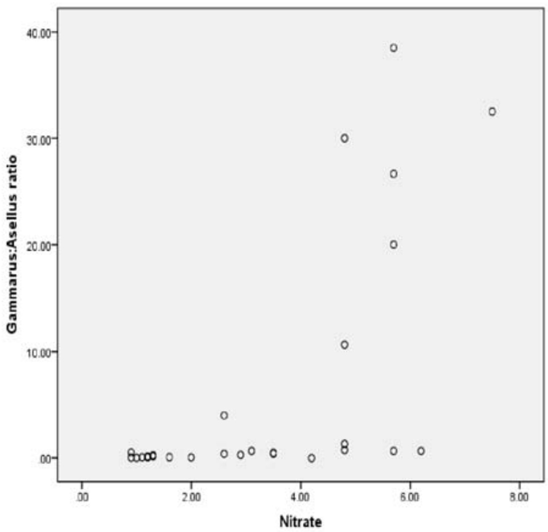

Fig. 2 Correlation between *Gammarus:Asellus* ratio plots against nitrate values across all site

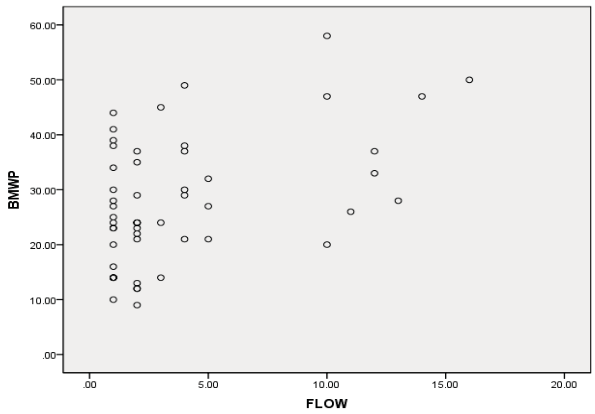

Fig. 3 Correlation between BMWP score plots against flow velocity

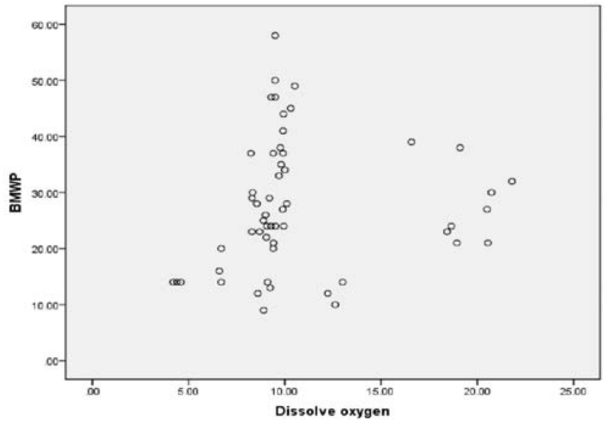

Fig. 4 Correlation between BMWP score plots against dissolve oxygen

TABLE IV
SPEARMAN RANK CORRELATION COEFFICIENT BETWEEN ASPT AND ENVIRONMENTAL VARIABLES

Environmental variables	ASPT
Water Temperature	-0.108
PH	-0.266
Flow	0.225
Depth	-0.048
Dissolve oxygen	0.010
Nitrates	0.038
Phosphate	0.008
Calcium	0.010
Conductivity	-0.047
BMWP	**<u>0.736</u>** ^{xx}

Note: Corrections highly significant (P<0.01) are in bold and underlined and corrections with p<0.05) are in bold. (n=29 for all variables).

B. Difference in BMWP/ASPT and Other Variables across Lakes

The normality of the data was tested using the one sample Kolmogorov-Smirnov test, the results obtained, indicated that

P value is more than 0.05 for almost all the variables (indicating the data were normally distributed). But P value was less than 0.05 for dissolved oxygen and flow velocities, indicating there were not normally distributed.

Statistical analysis using the one way ANOVA was used to determine whether there is significant mean difference between the biotic indices BMWP, ASPT scores and environmental variables between the upper lakes (site 1), middle lakes (site 2) and lower lakes (site 3). Multiple comparisons using post hoc test (Tukey) were also employed to shows the significance mean differences between biotic indices BMWP, ASPT and environmental variables between the upper lakes, middle lakes and lower lakes. Analysis of variance one way ANOVA was also used to compare the difference between the BMWP biotic index score of streams and lakes in Markeaton Park.

Analysis of variance ANOVA showed that the BMWP score is not significantly different between the upper lakes, middle lakes and lower lakes (Tables IV and V). Comparisons between the assessed physic-chemical/Biotic characteristics (ANOVA test) between the upper lakes, middle lakes and lower lakes (Table IV and Figs. 3, 4) reveal that parameters such as ASPT and PH had significant mean difference between the upper lakes, middle lakes and lower lakes. In addition the post hoc test Tukey also showed, for the ASPT significant mean difference occurred between the upper lakes and middle lakes (Table VI) and upper lakes and down lakes. Post hoc test (Tukey) also showed a significant difference in PH values between the upper lakes and lower lakes (Table VII). However, other parameters such as the BMWP, phosphate, nitrate, dissolve oxygen, calcium, and conductivity showed no significant difference between the upper lakes, middle lakes and down lakes (Tables V and VI).

TABLE V
THE ANALYSIS OF VARIANCE RESULT OF ENVIRONMENTAL VARIABLES BETWEEN THE UPPER LAKES, MIDDLE LAKES AND LOWER LAKES

Variables	F	df	P
BMWP	1.536	2	0.227
ASPT	5.011	2	**0.011**
Phosphate	1.307	2	0.281
Nitrate	0.097	2	0.908
PH	4.691	2	**0.014**
Dissolve oxygen	2.896	2	0.066
Calcium	0.326	2	0.724
Conductivity	2.566	2	0.089

TABLE VI
POST HOC TEST OF ASPT MEAN VALUES BETWEEN THE UPPER LAKES (SITE 1), MIDDLE LAKES (SITE 2) AND LOWER LAKES (SITE 3)

(I)Groups	(J)Groups	Mean difference (I-J)	S. Error	Sig
1.00	2.00	0.98667 ×	0.36612	0.027
2:00	1.00	-0.98667 ×	0.36612	0.027
3.00	1.00	-1.02000 ×	0.36612	0.021

TABLE VII
POST HOC TUKEY'S RESULT OF PH MEAN DIFFERENCE BETWEEN THE UPPER LAKES (SITE 1), MIDDLE LAKES (SITE 2) AND LOWER LAKES (SITE 3)

(I)Groups	(J)Groups	Mean difference (I-J)	Standard. Error	Sig
1.00	2.00	-0.17867	0.13151	0.372
2.00	1.00	0.17867	0.13151	0.372
3.00	1.00	0.40200 ×	0.13151	0.011

Analysis of variance for the BMWP biotic score index between the stream and lakes in Markeaton Park showed BMWP score was much higher for the stream than for the lake.

IV. DISCUSSION

A. Relationship between Gammarus:Asellus Ratio with Physical Chemical Parameters and Other Biotic Indices

In this studies, the abundance of *Gammarus:Asellus* ratio showed a significant positive correlations with nitrates, phosphates, conductivity, calcium, PH and a significant negative correlations with water temperature. The *Gammarus: Asellus* ratio also revealed a significant negative correlation with the BMWP and ASPT biotic indices, and showed no significant correlations with flow velocity, depth and dissolved oxygen. This result indicates that the abundance of *Gammarus:Asellus* ratio increases with increased concentration of chemical parameters indicative of pollution, nitrates, phosphate, conductivity, calcium, PH and increases with decrease in water temperature. The result also implies that *Gammaru:Asellus* ratio do not correlate together with other pollution indices, the BMWP and ASPT.

This finding is quite opposite to our hypothesis and contrary to the findings of previous studies by both [25], [27]. Reference [27] studied on the rivers, streams in the Lough Neagh catchment, Northern Ireland, showed a significant a negative correlations between the *Gammarus:Asellus* ratio with parameters, nitrates, water depth and conductivity. The *Gammarus:Asellus* ratio were also showed to significant positively correlates with biotic indices, the ASPT and EPT). Earlier studies by [25] on four lowland rivers (Rivers Ader, Ouse, Chess stream, sussex and the Eridge stream) also showed that *Gammarus:Asellus* ratio had a significant negative correlations with chemical parameters such as Biochemical Oxygen Demand(BOD), ammonia, nitrate and phosphate. This Indicates that the *Gammarus:Asellus* ratio appears to be most sensitive to changes in water quality, resulted from increases in levels of these parameters.

The finding of this study is different from the results obtained by [27] and [25]. This might be due to the effect of small sample size used in this study, in contrast to large number of sample size used by the previous studies in their research. A further study with the use of large sample for equitable comparison would be desirable. More so, in this study macro invertebrates were sampled using the standard 1mm mesh size net (three minute kick sampling). While a study by [25], uses a surber sampler for macro invertebrate sampling. The differences in macro invertebrate sampling method might also be a reason for the differences in our findings. More research should be should be carried out to compare the use of these two different sampling methods. This research was carried out on artificial streams and lakes, in contrast to the research by both [27], [25] which were conducted on rivers. This might also be the reason for the difference in our finding and that of the previous studies. Dissimilarities in the operating regime in artificial lakes, streams [49], which contrast to continuous flow characteristic of river [50] may account for the difference in biological response to physic chemical parameters. However, further study to verify this suspicion is required. Sedimentation might also be a factor that may cause such differences in our results. This is because sediment deposit in lakes and streams has been showed to alter the substrate composition, and changes the suitability of substrate for some macro invertebrate taxa [51]. More so increased level of sedimentation has also resulted in an increase in the number of drifting macro invertebrates [52]. However further research is needed to relate the effect of sediment of sedimentation on the abundance of *Gammarus: Asellus* ratio.

B. The Relationship between the BMWP/ASPT in Relation to Physic-Chemical Parameters

In this study, the BMWP score index showed a significant positive correlation with dissolve oxygen, flow velocity and ASPT, but showed a negative correlation with PH. And no correlation with other environmental variables such as nitrates, calcium, phosphate, temperature, depth and conductivity. Also the ASPT only revealed a significant positive correlation with biotic index BMWP and showed no correlation with other environmental variables such as water temperature, PH, flow velocity, depth, dissolve oxygen, nitrates, phosphates, calcium, and conductivity. This finding indicates that the BMWP score increases with increase concentration in dissolve oxygen levels and flow velocity.

The significant positive correlation revealed in this study between the BMWP score, dissolve oxygen, flow velocity and ASPT are in conformity with our hypothesis. But the significant negative correlation between BMWP and PH, and no correlation showed between BMWP and other environmental variables, nitrates, calcium, phosphate, temperature, depth and conductivity are not with agreement with our hypothesis.

The finding of this study is in agreement with the results of similar study by [36], on the Zayandeh Rud River basin Iran. Their findings showed the BMWP, ASPT, have significant positive correlations with oxygen saturation, water flow and PH, but showed no significant correlation with chemical parameters such as phosphates and nitrates. This is also similar with the earlier research by [37] on the Tajuna River in Central Spain, using the adopted version of BMWP/ASPT index for the Iberian Peninsula. Revealed a significant positive correlation with dissolve oxygen and showed no significant correlation with nitrate, phosphate and ammonia.

However these studies are not in conformity with the findings of other studies, which found BMWP/ASPT to have a significant negative correlation with all the chemical parameters indicative of organic pollution [53], [54], [6], [55], [56].

Research by [53] on the Genil River (southern Spain) using the adopted version of BMWP/ASPT for Iberian Peninsula. Their findings showed a significant negative correlation between the BMWP/ASPT with all the chemical parameters indicative of pollution (nitrites, nitrate, ammonium, phosphates, calcium, copper, potassium and temperature). They also revealed a significant positive correlation with PH. This is also same with a similar study by [6] using a modified version of BMWP called BMWP (PL) in the lower Nysa Klodzka River in Poland. Their findings revealed a significant negative correlation with all the chemical parameters (Nitrates, ammonia and phosphate). The study also showed a significant positive correlation with dissolve oxygen. This trend was also noted in a study by [56] on Rivers Kisian and Kisat in the catchment of Lake Victoria Basin Kenya. Their findings also showed a positive correlation between the BMWP/ASPT with dissolve oxygen, PH and significant negative correlations with physic chemical parameters such as conductivity, temperature, turbidity, phosphate and total nitrogen.

The difference in the findings of this study and the studies by [53], [6], [56] might be due large number of sample size and their studies were conducted over a longer period. In contrast to this study, that was done using smaller sample size and within a shorter period of one time. However further work should be carried out with larger sample size and over a longer period of time to prove this assertion.

More, so both studies by [53] and [56] were conducted in Rivers associated with direct discharge of untreated sewage and effluents from industries. In contrast to this study, that was conducted on artificial lakes and streams with suspected evidence of agricultural run-off from surrounding farm lands. Such differences in study area might also be responsible for the difference in our findings, however further work is required on lakes and streams associated with untreated sewage disposal to prove this.

C. The Difference in Biotic Scores Index (BMWP/ASPT) and Physic Chemical Parameters between the Upper Lakes, Middle Lakes and Lower Lakes

This study showed no significant difference in BMWP score between the upper lakes, middle lakes and down lakes. The study also found a significant difference in ASPT score between the upper lakes and middle lakes and down lakes, and a significant difference in PH values between the upper lakes and down lakes. However no significant difference was found in the phosphate, nitrate, and dissolve oxygen, calcium, and conductivity values between the upper lakes, middle lakes and down lakes. This finding indicated that the ASPT score is higher in the upper lakes than in the middle lakes, and down lakes.

The decreased in the ASPT scores from the upper lakes to middle and down lakes, may be associated with the effects of reduced flow velocity. The upper lakes had higher flow velocity with fast flowing water, than the middle and down lakes. Fast flowing waters are well oxygenated, and are inhabited by sensitive macro invertebrate taxa (EPT) [50], [57]. In contrast to the middle lakes and down lakes, with reduced flow velocity. Hence lower flow or still waters are associated with less oxygen, and with the abundance of tolerant macro invertebrate taxa such as *oligochaeta*, *chironomidae* [58]. Therefore the effect of reduced flow rate, associated with reduced oxygen from the upper lakes to the middle and down lakes, may have cause the replacement of sensitive macro invertebrate taxa with the tolerant taxa. These might subsequently lower the ASPT scores, since tolerant macro invertebrate taxa have lower scores in the BMWP score index [38].

The decrease in flow rate, may also contribute to increase sedimentation in the middle and down lakes. This is because reduced flow rate have been showed to increase the rate of sedimentation [59]. Increased sedimentation can also alter the suitability of substrate for some macro invertebrate taxa [60]. Sediments deposits have been showed to favour the abundance of tolerant macro invertebrates taxa such as *oligochaeta*, *chironomidae* [61]. Therefore increased sediment deposits in the middle and down lake due to reduced flow velocity, might alter the substrate composition. This might cause the replacement of sensitive macro invertebrate taxa, with tolerant macro invertebrate taxa, and subsequently lowering the ASPT scores.

Similar studies have also showed the effects of increased sedimentation on macro invertebrate's abundance. Reference [62] studied in seven Applachian streams showed consistent negative relationship with finest substrate particles (<0.25mm) that exceed 0.8-0.9% of riffle substrate composition and EPT sensitive taxa richness. In contrast to taxa such as *chironomidae*, *oligochaeta*, which are associated with fine sediment. Similar study by [63] in the Lake Tanganyika, Africa also found lower abundance of macro invertebrate at the mouth of the Lunzua River, due to significantly higher sediment loads.

The high phosphate values recorded in the middle and down lakes in this study, might have contributed to nutrient enrichment of the lakes. Even though this study do not revealed any significant difference in phosphate value between the upper lakes, middle lakes and down lakes. But the higher phosphate values in the middle and down lakes might be the cause of poor water quality and the abundance pollution tolerant macro invertebrate's taxa and subsequently cause of the lower ASPT scores in the middle and down lakes.

The decrease in ASPT values from the upper lakes to middle and down lakes may be due the presence of large number of water fowls in the middle and down lakes. This is because water fowls faeces or droppings on lakes have been showed to have contributed significantly to nutrient enrichment [64]-[66]. The presence of water fowls, may have contributed to the addition of nutrients on the middle lakes and down lakes which may cause nutrient enrichment and subsequently the abundance of tolerant taxa. This may resulted in the decrease in ASPT scores in the middle, down lakes. This is also supported by [64] which found that bird faeces at Wintergreen Lake in Michigan have led to degraded water quality, through the addition of estimated 27 per cent nitrogen and 70 per cent of phosphates. Similar study by [67] have also showed that water fowl, particularly the lesser Snow geese were found to contribute up to 40 per cent of nitrogen and 75 per cent phosphorous annually in a wild life refuge area in Mexico.

D. The Variation in the BMWP Scores between the Stream and Lake in Markeaton Park

This study showed a significant difference in the BMWP score between the stream and lake in the Markeaton Park. This is indicating that the BMWP score is much higher for the stream than for the lakes. However such difference in the BMWP scores might be due to the presence of large number of water fowls in lake, than the stream. Water fowls droppings on the Markeaton lakes may have contributed to the addition of nitrates and phosphate, and subsequently to nutrient enrichment. This may result in the abundance of tolerant macro invertebrate taxa, and hence the low BMWP scores than the stream. This because tolerant macro invertebrate taxa are associated with organic polluted water [50]. This is supported by the findings of many studies which also showed water fowls droppings, to have contributed to the nutrient enrichment of lakes [64]-[66]. Studies by [65] in a Mexico wetland showed that Waterfowls have increased the rate of nitrogen and phosphate loading by 40 and 75 per cent respectively.

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