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IDENTIFYING KEY ENVIRONMENTAL VARIABLES STRUCTURING BENTHIC MACROINVERTEBRATES IN RIVER MEDLOCK, GREATER MANCHESTER

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ABSTRACT
The conservation of freshwater biodiversity is a global issue needed to ensure a sustainable ecosystem. With increasing urbanisation, urban rivers face challenges that affect biotic responses at different scales of the river. In this study, the aim to determine the environmental variables which impact benthic macroinvertebrate assemblages was investigated. The data covered March 2013 to April 2014. Physicochemical variables, sub-catchment characteristics were determined in order to obtain an integrated assessment of variables impacting on benthic macroinvertebrate communities. BIOENV multivatriate statistical technique was used to select the environmental variables structuring the benthic macroinvertebrate communities. Assemblages of the benthic macroinvertebrates were strongly associated with conductivity, discharge, catchment area, altitude and slope. In order to determine the river quality, biotic indices – Biological Monitoring Working Party and Whalley, Hawkes, Paisley and Trigg (BMWP and WHPT) and physicochochemical variables were compared with the European Union’s Water Framework Directive. The results showed that the urban river had not met the “good ecological status”. The results demonstrate a need for integrated water quality monitoring and provide basic information needed to develop strategic management plans against anthropogenic impacts on the river.

Keywords: benthic macroinvertebrates, physicochemical, biotic indices, River Medlock

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1. INTRODUCTION

The River Medlock catchment is one of the most urbanised in the UK (Environment Agency, 2009) that originates from the Pennine Hills of Greater Manchester (National Grid Reference (NGR): SD 95308 05431) in Northwest Manchester. The river passes through a steep-sided wooded region for 10 km before entering a largely urbanised area of Manchester City Centre (NGR: SJ 85781 97858). It drains a catchment area of 58 km², 22 km long and 58% of the catchment is classified as urbanised (CEH, 2017). The Medlock River is one of the five tributaries which drains into the larger Irwell catchment (777 km²), has been an important economic and industrial legacy in Manchester during the 19th century. Following the need to enhance the river channels for transportation ease, the lower sections were culverted and canalized thereby degrading river ecology through loss of natural habitats. In the mid-1980s (Douglas, Hodgson, & Lawson, 2002), more than 97 combined sewer overflows (CSOs) discharge and pollute the river, these CSOs, effluent from wastewater treatment works and diffuse sources (James *et al.*, 2012) have continued to impact the river's quality. Previous studies of the river showed a degraded quality (Frost, Chiu, & Pugh Thomas, 1976). High concentration of phosphate, high organic pollutants threaten the river's quality and compliance with the European Union's water quality standard. The Water Framework Directive (WFD;2000/60/EC) requires Member States to first assess the quality of all water bodies (rivers, lakes, coastal and estuarine), to manage them at an appropriate spatial scale, e.g. River Basin Management Plans, and to engage with the public. In order to achieve the standard water quality protection, the WFD requires Member States to reach a minimum Good Status[1], in as many waters as possible by 2027. More than 35% of the UK rivers including the Medlock still face the challenge of compliance. However, projections to improve water quality by 2027

[1]Status is measured as: High, Good, Moderate, Poor, Bad.

(Priestley & Barton, 2018) are continuously investigated.

In order to contribute to surface water management and improve the quality monitoring of the River Medlock catchment, physicochemical variables and benthic macroinvertebrates are used as indicators of water pollution. While the United Kingdom's environment regulatory body, the Environment Agency monitors the river for water quality and samples the river monthly for physicochemical variables, aquatic organisms are sampled at two seasons of the year (spring and autumn) to represent periods of limited and abundant benthic macroinvertebrates respect-tively. The approach of identifying environmental factors which influence the benthic macroinvertebrates for water quality assessment at the River Medlock will support rivers managers and other interest groups who can apply the outcome of the study to protect the river's quality and identify effective strategies to control pollution. The overall objectives of this study were to determine the relationship between the physicochemical variables and benthic macroinvertebrates and to assess these variables individually in relation to requirements of the EU WFD.

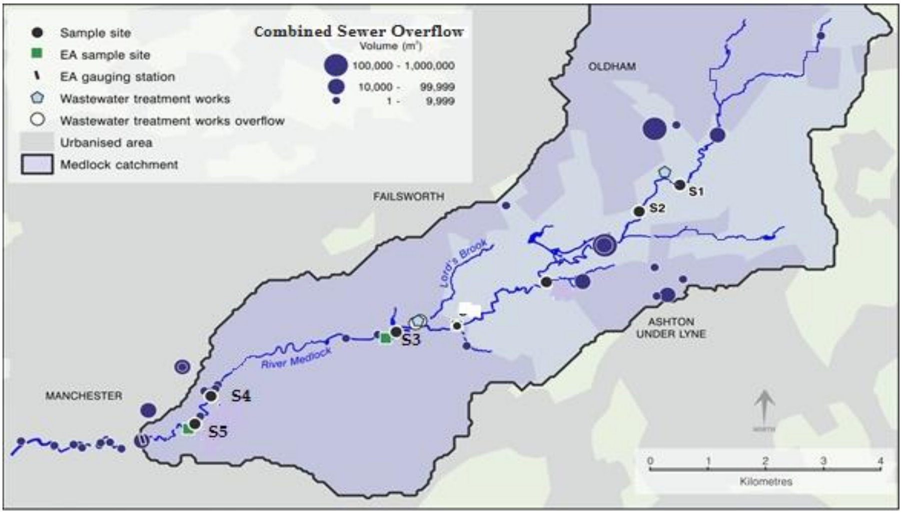


Figure 1: Map showing the sample sites (S1-S5) of the River Medlock including the River's Gauging Station, numerous Combined Sewer Overflows (CSOs) and the Waste Water Treatment Work

2. Materials and Methods

2.1 Study site

From March 2013 to April 2014, five sites (S1-S5) at the river Medlock (Figure 1) were monitored monthly for physical, chemical and benthic macroinvertebrates.

2.1.1 Sampling and processing of benthic macroinvertebrate samples

The surveyed reach has a continuously operational wastewater treatment works (WwTW) (NGR: SJ 89674 99800), about 30 combined sewer overflows, numerous storm water overflows and outfalls (EA, personal communication 2013). Therefore, the sites were identified due to proximity to the point sources and safe access to sites. The sample points S1 and S2 were upstream of the WwTW while S3-S5 were downstream of the river (Figure 1). Benthic macroinvertebrates were obtained by using the standard kick-sampling and preservation method (Murray-Bligh, 2002) and sample replicates were obtained over a 14-month duration. The benthic invertebrates were identified to family in order to determine their quality status through the biotic indices Biological Monitoring Working Party indices (BMWP) and Whalley Hawkes Paisley and Trigg (WHPT) (Environment Agency, 2015; Hawkes, 1997). Families investigated were present in >1% of samples.

2.1.2 Physicochemical variables

Spot samples were obtained for suspended solids (mg/L); Biochemical Oxygen Demand (BOD) (mg/L); nutrients(mg/L): NO_3-N (nitrate-N), NH_3-N (ammonia-N), PO_4-P (phosphate-P) and analyzed by using the Standard Committee of Analysts Publications (2011). The physicochemical variables including pH, temperature (°C), dissolved oxygen (% saturation; mg/l), conductivity (μScm^{-1}) and discharge (m^3s) were obtained by using a pre-calibrated hand-held multiparameter water quality meter (YSi 556 Multi probe system YSI, Yellow Springs, Ohio, USA). The Area Ratio

(AR) method (Archfield & Vogel, 2010) was used to estimate river discharge at each sampling site. Other environmental variables including catchment area, altitude and slope were determined by information obtained from ArcGIS Geoprocessing toolbox (Jenson and Dominque,1988).

2.2 EU Water Classification

The physicochemical and biological parameters were compared with the EU-WFD and Freshwater Fisheries Directive (for suspended solids) (UKTAG Water Framework Directive, 2013). For BOD, dissolved oxygen and un-ionised ammonia, the EUWFD requires the application of the 99th percentile to the results and classification while 98th percentile was applied for temperature, 95th percentile for PO_4-P, 10th percentile for pH and 90th percentile for dissolved oxygen.

2.3 Data analysis

2.3.1 Biotic indices

The average score per taxon (ASPT) was determined as the sum of all BMWP scoring families divided by the number of taxa. BMWP scores which were less than 40 were classified as *polluted or impacted by pollution,* between 41 and 70, these were interpreted as *moderately impacted by pollution* while scores between 71 and 100 were classified as *clean, but slightly impacted* and, *pristine waters* have BMWP scores ≥ 100 (Murray-Bligh, 2002). The Whalley Hawkes Paisley and Trigg (WHPT) score assessed the number of taxa and average score per taxa by using the River Invertebrate Classification Tool (RICT). The RICT compares observed WHPT scores with expected (predicted) values if the river were to be in pristine condition. The outcome of the comparison produces an Ecological Quality Ratio (EQR) where EQR values close to 1 indicate invertebrate communities are close to their natural states while those near to zero indicate a high level of pollution or disturbance.

2.3.2 BIOENV Analysis

The BIOENV (biological and environmental) procedure (Warwick & Clarke, 2001) was based on Spearman's correlation matrix. It was applied to environmental variables including dissolved oxygen, pH, temperature, conductivity, BOD, NH_3-N, NO_3-N, PO_4-P, suspended solids, discharge, velocity, catchment area, altitude, slope and substrates and the benthic macroinvertebrate individual taxa. All environmental data matrix were log-transformed and ordinations were executed on the basis of a Euclidean distance matrix while benthic macroinvertebrates were square root transformed and normalised (using Bray-Curtis similarities) to allow comparison at the same scale. The Spearman rank correlation coefficient (ρ) with the largest ρ was taken to identify the best match with the benthic invertebrates. (Clarke & Warwick, 2001).

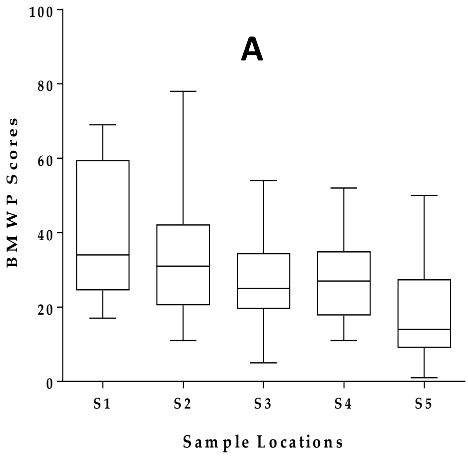
3. RESULTS

3.1 Benthic macroinvertebrates

Thirty-two benthic macroinvertebrate families (a total of 3753 individuals) were recorded at the river and distributed across six classes, eleven taxonomic orders and three phyla as follows: Annelida (worms and leeches), Mollusca (Gastropods and bivalves) and Arthropoda (insects and crustaceans). Arthropods contributed 23 invertebrate families, which made up 72% of the total composition and, among the insects; the Ephemeroptera taxa dominated the invertebrate assemblage especially at the upstream stations. Plecoptera was absent at the downstream stations S3 to S5. Overall, the taxa which occurred at all the sites were largely Oligochaeta making up 52% (comprising of Lumbriculidae, 14% and *Tubificidae*, 38%) of the total organisms followed by *Baetidae* which accounted for 19% of the total counts and *Chironomidae*, contributed 17% of the total composition.

The families identified and their corresponding taxonomic orders include Erpobdellidae **(Order Arhynchobdellida);** Glossiphonidae (**Order Rhyncobdellida);** Lumbricidae, Tubificidae (**Order Haplotaxida);** Lumbriculidae **(Order Lumbriculida)**; Gammaridae, Asselidae **(Order Amphipoda)**; Rhyacophilidae, Hydropsychidae, Polycentropodidae, Limnephilidae **(Order Tricoptera);** Haliplidae, Dytiscidae, Hydrophilidae(**Order Coeleoptera);** Baetidae, Ephemerellidae, Heptageniidae, Leptophlebiidae, Caeniidae **(Order Ephemeroptera);** Perlodidae, Nemouridae, Leuctridae, Psychomyiidae, Hydroptilidae (**Order Plecoptera);** Chironomidae, Simulidae, Tipulidae, Paediciidae(**Order Diptera**); Sphaeridae, Viviparidae, Physidae, Lymnaeidae (**Order Veneroida).**

3.2 Biological indices



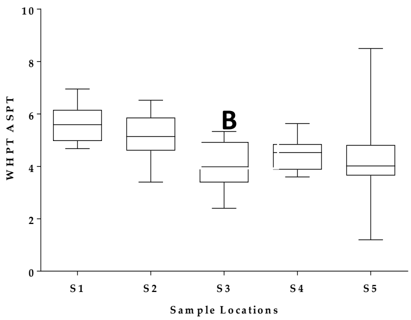


Figure 2: Box and whisker plot with 25% and 75%, median, minimum and maximum values of BMWP score (A) and WHPT ASPT (B)

The BMWP scores declined from the upstream to the lower sites (Figure 2A) and indicated that only site 1 was *moderately polluted* while other locations with lower BMWP scores were *impacted by pollution*. For WHPT Average Score Per Taxon (WHPT ASPT), a significant difference (repeated measures one-way ANOVA, $F_{2.2,24}$ = 4.6, p=0.0177) at S1 (*Post hoc Tukey*).

Classification of WHPT with expected values showed that Environmental Quality Ratio (EQR) for WHPT index, classified S1 as "Good" (0.73), "Moderate" at S2 (0.63) and "Bad" from S3 to S5 (<0.42) while WHPT ASPT were classified all sites as "Moderate" S1(0.85), S2(0.86), S3(0.78) and S5(0.76) excluding S4(0.75). In order to achieve a high/good category at the river, the number of taxa (NTAXA) must be close to an EQR of 0.8 and the ASPT must be close to one. Therefore, on the basis of the EU WFD standard, the river had "moderate" pollution status.

3.3 Environmental variables

Table 1 showed environmental variables which were compared with the standard EU WFD requirement. Given that some interpretations of the variables were "moderate", the overall physicochemical results were classified with the lowest interpretation which was "moderately" polluted.

Table 1: Sample site characteristics, physico-chemical variables and EU WFD Classification.

Variables	**S1**	**S2**	**S3**	**S4**	**S5**	EU Standards met – Yes/No
Distance from source(km)	6.6	8.5	12.2	13	16.1	
Average slope (%)	10.72	9.45	7.56	7.24	7.21	
Altitude (m)	140	107	78.9	31.1	33.6	
DO%sat	103.7	101	101.5	100.9	99.5	Yes, *Excellent*
pH	7.85	7.79	8.01	8.04	8.06	Yes, *Excellent*
Temperature (°C)	9.8	9.5	10.4	10.5	10.3	Yes, *Excellent*
Conductivity (µScm^{-1})	484	559.7	650	684.5	694	Not available
Suspended solids (mgL^{-1})	4.18	6.03	11.59	15.03	12.05	Yes, *Excellent*
River Discharge (m^{3}s^{-1})	0.15	0.23	0.43	0.53	0.53	Not available
BOD_5 (mgL^{-1})	13.68	13.1	14	16.13	2.5.1	No, Moderate
NH_3-N (mgL^{-1})	2.48	2.18	2.50	2.18	2.55	No, Moderate
NO_3-N (mgL^{-1})	0.9	1.1	4.0	4.3	4.1	Not available
PO_4-P(mgL^{-1})	0.023	0.027	0.462	0.444	0.447	No, Moderate

All sites classified based on median values for EU WFD variables and Mean values for suspended solids. The values were interpreted as *High= Excellent; Very Good; Good; Moderate; Poor; Very Poor; Bad.*

Classification of the river based on the EU WFD showed that both biological and environmental variables were moderately polluted and have not met the "good ecological status".

3.3.1 Relationship between benthic macroinvertebrates and physicochemical variables

The biological and environmental (BIOENV) analysis showed a weak correlation coefficient (ρ) to be 0.274 (Table 2) indicating a minimal significant difference between sites. Conductivity, river discharge, catchment area, altitude and slope were the environmental variables that most strongly associated with the benthic macroinvertebrates. Several permutations of the variables also showed that concentration (mgL^{-1}) of NH_3-N, BOD, suspended solids; pH, temperature (°C) and dissolved oxygen (%saturation) were associated.

Table 2: Relationship between environmental variables and benthic macroinvertebrate communities by using the BIOENV procedure

Number of variables	Weighted's Spearman's rank	Variables
5	0.274	Conductivity, Discharge, Catchment area, altitude, slope
4	0.273	Conductivity, Discharge, Catchment area, altitude
5	0.272	Conductivity, Phosphate-P, Discharge, Catchment area, altitude
2	0.272	Conductivity, Catchment area,
5	0.271	Conductivity, Nitrate-N, Discharge, Catchment area, altitude

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4. DISCUSSION

General characteristics of the benthic macroinvertebrate community

The upstream sections (S1 and S2) of the river had some pollution sensitive taxonomic groups including Ephermeroptera, Plecoptera and Trichoptera while at the downstream locations, fewer members of Ephermeroptera and Trichoptera were counted. The presence and dominance of pollution tolerant organisms including Lumbriculidae, Tubificidae, Baetidae and Chironomidae at all sites. However, higher numbers were found at the sites downstream of the treatment works and at the more urbanised sections of the river. A similar pattern was reported by Pham *et al.* (2015) at the Lower Dongnai River where Tubificidae and Chironomidae were found near urban and industrial sites and, tolerant individuals tended to increase at the urban areas where access to sewage pollution was in constant supply as found in the streams in Korea (Jun *et al*., 2016). Values for biotic indices decreased at the sites closer to the urban areas (S3-S5) and these locations also showed increasing concentration of physicochemical variables. The biodiversity and stability of the benthic macroinvertebrate ommunities tended to decrease in urban areas and thereby suggest the impact of land use at these sections of the river.

Relationship between benthic macroinvertebrates and physicochemical variables

The correlation analysis showed that conductivity, discharge and hydrogeomorphological actors (catchment area, altitude and slope) were the major environmental factors which influenced the diversity and patterns of benthic macroinvertebrate assemblages at the Medlock. This pattern aligns with other related studies including identification of catchment, altitude, water discharge (Skoulikidis *et al*., 2009), altitude (Jun *et al*., 2016; Soldner *et al*., 2004) where each identified the importance of local variables in explaining the variance of macroinvertebrate ssemblages. In the UK, slope has been linked to the distribution of benthic macroinvertebrates in undisturbed streams (Wright *et al*., 1984). While pH, BOD, NH_3-N, NO_3-N, dissolved oxygen were not associated, Murphy and Davy-Bowker (2005)'s report on selected UK rivers stated that most physical characteristics/geographic locations influence assemblage composition much more than the impact of pollution and habitat modification which are secondary. This result emphasises the difference between the upstream and the downstream river quality and the fauna assemblage.

The impact of conductivity on benthic invertebrate assemblages suggest the contribution of increased of urban runoff, overflows and outfalls which are often contaminated with high concentrations of salts (Paul & Meyer, 2001). Hence, it could be used as a surrogate chemical signal for non-point pollution sources (Melo, 2009).

This study has shown that limited numbers of benthic macroinvertebrates, low biotic scores do not only show organic pollution, but reflect an impact of local hydrogeomorphological actors including urban-induced discharge, altitude, catchment area and slope which influence the abundance and diversity of benthic macroinvertebrates. The cumulation of these impacts is collectively termed " urban stream syndrome" (Meyer *et al*., 2005; Walsh *et al*., 2005).

Considerations to improve monitoring programme

The UK Environment Agency's national biomonitoring programme presents field sampling in a cost-effective way, reacts to pollution incidences and carries out rapid bioassessment. It remains debatable whether to monitor both physicochemical and benthic macroinvertebrates at the same time would be useful for better interpretation of river quality. To satisfy the effect of continuous monitoring of benthic macroinvertebrates on a regular basis, the catchment-based approach (CaBA) (Defra, 2013) could be adopted. This process will involve training interested volunteers as citizen scientists who will ensure the availability of replicate samples for benthic macroinvertebrates that could be analysed with the EA's monthly sampling of benthic macroinvertebrates. This approach could provide continuous and effective data that would be available for future data analysis and to inform sound decision making processes.

5. CONCLUSION

The relationship between environmental variables and benthic macroinvertebrates were shown to be a useful method for informing the quality of the river. The knowledge that physicochemical variables alone do not necessarily impact on benthic macroinvertebrates is necessary for developing effective management strategies needed to protect and sustain the diversity of the freshwaters. The outcome of this study helps to widen the scope of monitoring and presents a need to integrate river management plans with collaboration with partnership groups. The integration of end-users and the cooperation of the various stakeholders through the Catchment Based Approach (CaBA) would help to mitigate the impact of local environmental variables on the urban river. Furthermore, interested members of the local community could be trained as citizen scientists to obtain benthic macroinvertebrates from the river thereby providing enough replicates needed to support the physicochemical variables obtained by the Environment Agency on a monthly basis.

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