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Mapping the Grainsize and Substrate Composition of The Malago river and its Impact on the Ecology

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Abstract

Loss of freshwater habitats and anthropic impoundment through the construction of dams and weirs are some of the most important factors in ecological degradation across the United Kingdom's rivers and streams. Isolation of benthic macroinvertebrates through the alteration of flow regimes, sediment deposition and longitudinal connectivity during summer months are well explored but studies during winter periods are limited. This study explores the effect of grainsize variation and small-scale stream impoundment on macroinvertebrates in a ~650m stretch of The Malago, a river in South West Bristol during the winter period. The results reveal that diversity improved after impoundment and that the mean ($\bar{x}$ = 10.73) number of macroinvertebrates per site was broadly similar to studies conducted in summer months. This study therefore provides a crucial step in furthering the understanding of grain size and hydroengineering controls on macroinvertebrates, with a unique perspective of biodiversity during the winter period.

Acknowledgements

Thanks must go to Max Stockdale, for his help supervising the project, as well as to Simon Cobb and Rowan Dejardin for overseeing all fieldwork and laboratory work. We are grateful to Peter Loy-Hancocks and Martin Grant, for allowing us to study in the Manor Woods Valley Nature Reserve, and for their assistance and enthusiasm throughout the project.

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1. Introduction

1.1 Research Rationale

Biodiversity is decreasing on local, national and global scales (JNCC, 2019). Within the United Kingdom, there has been a substantial decrease in riparian fauna which has a large implication on overall biodiversity (Baxter, et al., 2005). Reciprocal flows of fauna and flora exist between lotic water bodies and riparian zones and this interconnectedness elicits an important relationship between the conservation of fauna and the wider management of urban green spaces (Doi, et al., 2013). The emergence of adult macroinvertebrates from lotic water sources, such as rivers and streams, constitute between 25% and 100% of the energy to riparian carnivores such as birds and higher trophic levels (Baxter, et al., 2005). As a result, the diversity and availability of macroinvertebrates is intrinsic to the overall biodiversity of green spaces and highlights their importance; yet macroinvertebrates remain grossly underrepresented within lotic water studies (Dudgeon, 2000).

Despite their importance within the ecosystem, little is known about macroinvertebrate emergence in winter (Baxter, et al., 2005). It has been demonstrated that warmer winters are associated with a greater abundance of macroinvertebrate grazers (Scrine, et al., 2017) and that consumers prey heavily on insects year-round, especially in lotic water bodies that remain ice free (Baxter, et al., 2005). Despite this, studies comprising of samples collected in winter are not well documented, perhaps due to the low levels of biodiversity expected (Durance & Ormerod, 2007). It is therefore key to study macroinvertebrates during the winter in order to illuminate the impact that a warming climate may have on the relationship between macroinvertebrates and the larger abiotic environment surrounding urban green spaces.

The lotic environment and its accompanying substrate also impact macroinvertebrate communities (Ciutti, et al., 2004; Pereira & De Luca, 2003). Within this, both the taxa and substrate involved in lotic systems are heterogeneous and often display a large degree of variation within a small spatial proximity (Costa & Melo, 2008), supporting the notion that lotic environments have high variability. Different taxa display different tolerances to different substrates (Cummins & Lauff, 1969) and building on the work of Duan et al,. (2008), who found that bed substrate size is an important variable in determining macroinvertebrate habitat in large-scale rivers, it is important to test this conclusion in smaller streams where both flow and substrate exhibit different properties than in larger streams. However, other studies produce results which counter this, suggesting that other abiotic factors such as nutrient availability have greater impacts on macroinvertebrate richness and/or abundance (Ciutti, et al., 2004; Hawkins, et al., 1982). As these conflicting studies also acknowledged substrate as a factor in macroinvertebrate abundance and species richness, the first hypothesis is that:

Grain size exhibits a fundamental control on benthic macroinvertebrate distribution

H_0 – Grain size has no fundamental control on benthic macroinvertebrate distribution
H_1 – Grain size has a fundamental control on benthic macroinvertebrate distribution

Natural substrate variation is extensive within lotic ecosystems (Duan, et al., 2009) but hydroengineering efforts, such as dams and weirs, also have large impacts on both substrate and macroinvertebrate communities (Lessard & Hayes, 2003; Maynard & Lane, 2012). This can result in large variations between up and downstream of stream impoundments and therefore it is important to understand the human impacts that can also occur through the development of urban green spaces and the impact they may have on macroinvertebrates (Maynard & Lane, 2012; Mackie, et al., 2013). There are a variety of conclusions which are present in the literature, with stream flow regulation decreasing macroinvertebrate species richness (Growns & Growns, 2001) or species diversity increasing as the consistent flow provides a more stable habitat (Maynard & Lane, 2012). The study areas of the research that conclude that impoundment has a positive impact on macroinvertebrate biodiversity are more similar to the study area that forms the basis of this research, than those with a negative conclusion, hence the second hypothesis states that:

Stream impoundment increases species richness of benthic macroinvertebrates downstream

H_0 – Stream impoundment has no positive impact on benthic macroinvertebrate richness
H_1 – Stream impoundment has a positive impact on benthic macroinvertebrate richness

1.2 Research Area

For the South West and South Wales region of the United Kingdom, January 2020 was the warmest January for 12 years based on a regional monthly mean of 6.3°C; and accompanied by the warmest winter period for 4 years (MET Office, 2020). Based on the lack of research on macroinvertebrates in lotic water systems during warm winter periods, the study considers the impact that a warming climate may have, thus extending its application beyond the South West region of the United Kingdom.
The Malago river is set within Bristol, Avon, United Kingdom and runs through The Manor Wood Valley Local Nature Reserve (Bristol City Council, 2020). Set within the Bishopston ward and with a population of 11,400 (Bristol City Council, 2019), The Malago is managed by the Manor Woods Valley Conservation Group, comprising of volunteers who manage and maintain the niche habitats that exist within this stretch of The Malago.

The sampling area (~650m) (Figure 1) runs within the reserve and is contained by a culvert at the top and bottom ends. It is encompassed by vegetation that divides the local geographic areas of Bedminster Down, Headley Park and later joins with the Pigeonhouse stream. The underlying geology is Mudstone and comprises superficial deposits of clay and silt (EDiNA, 2020). Two weirs (~90 and ~190m downstream) and a dam constructed in 1976 (~460m downstream) are present within the study area. As these hydro-engineering efforts are located within the sample area, they facilitate the testing of hypothesis 2 due to their potential impact on macroinvertebrates and downstream variation (Wood & Armitage, 1997)**.**

Figure 1. *Map showing the locations of the sampling sites and the stream impoundments. The sites start in the South-West and run to the North-East. Produced in ArcMap 10.7.1*

The testing of these two hypotheses will enable the construction of an in-depth profile of this section of The Malago through an analysis of the substrate and hydro-engineering, and the subsequent effect on macroinvertebrate communities. Exploring these implications facilitate policy recommendations to account for entire ecosystems, not just water quality or substrate compositions, enabling the production of a holistic summary of urban green spaces (Heino, et al., 2005).

If used in conjunction with a recent study of water quality in The Malago (Group 1, 2018), a comprehensive guide can be constructed through combining both the ecological and geographical parameters of The Malago, therefore aiding the aim of Manor Wood Valley Local Nature Reserve to help “protect, maintain and improve [the reserve]…for the benefit of wildlife and people” (Group 1, 2018, p. 1) and to preserve a key green space in South Bristol.

2. Methods

2.1 Field Site

16 sites for sample and data collection were identified along the ~650m stretch of The Malago (Figure 1). Chosen to most accurately represent the heterogeneity of the river with clustering around the three main hydroengineering sites in order to facilitate the hypotheses, the sites are not equidistant downstream. This contrasts the sites sampled by the 2018 Water Quality Study (Group 1, 2018), allowing the study to further the understanding of this stretch of The Malago and provide complimentary data.

2.2 Sample Collection

Volumetric sampling using a 1L sampling bottle allowed a substrate sample from the riverbed for each site to be collected (Bunte & Abt, 2001). This size allowed a representative sample of the surface substrate to be collected at each site, with a mass large enough to perform multiple methods of analysis in the lab. Where the water was too deep to obtain substrate through this method, the sediment grabber (Figure 2) was used. Both allowed for a representative sample of the substrate to be collected from all sites. Samples were drained of excess water and transferred to a sample bag.

Figure 2. T*he sediment grabber used for sample collection where channel depth restricted easy access to the riverbed.*

Macroinvertebrates were collected through an established kick-net sampling method undertaken for 3 minutes per site using a standard 1mm hand net (FBA, 2019). Sampling was conducted by the same researcher to minimize variation in technique. Established methods empty collected contents into a tray and the macroinvertebrates are transferred individually to plastic sample bags by hand, however, this method was adjusted at the first site to transferring a homogenous handful of both sediment and macroinvertebrates into the sample bag, so that results were not dependent on the researcher identifying macroinvertebrates in the field which would likely produce errors due to time constraints.

Macroinvertebrate sample bags were filled with obtained sediment and excess river water for preservation of macroinvertebrates.

2.2.1 Geomorphology

Three physical characteristics of The Malago were also measured: flow velocity, width and depth. Flow velocity was measured at each site using a flow meter (Valeport 801) held ~15cm beneath the surface of the water for 30 seconds allowing for a reading to be calculated (Cobb, 2018). Some of the sites were <15cm in depth due to low water levels, so error could have been introduced here as it was not possible to get a consistent reading at 15cm depth for all sites.

The width of the cross-section at each site was measured using a tape measure stretched across the banks and recorded in meters. The recorded width measurement was divided by ten, producing the distance interval for depth measurements across the channel. At each interval, depth was measured using a metre ruler and a mean depth calculated for each site.

2.3 Grain size

Sediment samples were dried at 50°C for 3 days. The total mass of each sample was recorded in grams (g) and sieved through a 9-level sieve stack. The sieve levels (mm) were: 2.0, 2.8, 3.35, 5.6, 13.5, 26.5, 31.5, 37.5, and 45.0. The respective weights at each fraction were recorded and expressed as a percentage of the overall sample mass.

2.4 Macroinvertebrate Identification

Macroinvertebrates were picked individually from each sample and transferred to a petri dish. Each petri dish was filled, and macroinvertebrates were preserved with 1ml of 5% formaldehyde and left overnight (14 hours). Individual macroinvertebrate taxa were photographed using a high-resolution microscope (Leica M205 C – optical resolution 0.952μm) and the total number of macroinvertebrates in each sample was recorded, along with the total number of species present in each sample (species richness).

Macroinvertebrates were identified to the family, rather than species level, with reference to the Freshwater Biological Association guide (FBA, 2011). Family level identification was selected due to the early life stage of many macroinvertebrates, due to collection in winter, and so any following investigations sampled in the same season would be able to easily identify potential taxa. One exception was an unidentifiable worm at the early stages of development at site 5.

The richness and total abundance were used to calculate the Shannon-Weiner (Shannon, 1948) Index of Diversity (*H'*):

$$H' = -\sum(n_i/N)\ln(n_i/N) \quad (1)$$

Where n_i is the number of a given taxa, N is the total number of organisms present, and $\ln$ is the natural logarithm.

A higher Shannon-Weiner score equates to a greater diversity, accounting for the abundance of each species. Following identification, the family of the macroinvertebrate was used to inform the calculation of the Modified Family Biotic Index (FBI) from Hilsenhoff (1988):

$$FBI = \frac{\sum x_i t_i}{n} \quad (2)$$

Where x_i is the number of individuals within a taxon, t_i is the tolerance value of the taxon and n is the total number of individuals contained in the sample. The FBI calculated is compared against an index to categorise the quality of the water (Table 1).

Table 1. *Water quality index relation to the modified family biotic index. Reproduced from Hilsenhoff (1988).*

Family Biotic Index (FBI)	Water Quality	Degree of organic pollution
0.00 – 0.375	Excellent	Organic pollution unlikely
3.76 – 4.25	Very Good	Possible slight organic pollution
4.26 – 5.00	Good	Some organic pollution probable
5.01 – 5.75	Fair	Fairly substantial pollution likely
5.76 – 6.50	Fairly Poor	Substantial pollution likely
6.51 – 7.25	Poor	Very substantial pollution likely
7.26 – 10.00	Very Poor	Severe organic pollution likely

3. Results

Site 14 is immediately downstream of the dam and has a substrate formed of concrete. As this site is not representative of the natural riverbed, it has been removed from all results, with upstream and downstream of the dam represented by sites 13 and 15 respectively.

Calculating error for grainsize has not been possible due to time constraints and sediment volume limitations which prevented multiple sieving attempts.

3.1 Very Fine Sediment (<2mm)

The first ~250m of The Malago reveal an inverse relationship between very fine sediment proportion and species richness (Figure 3). At site 10 (284m downstream) this relationship is reversed with a spike in very fine sediment accompanied by a spike in species richness. The subsequent sites downstream uphold this inverse relationship.

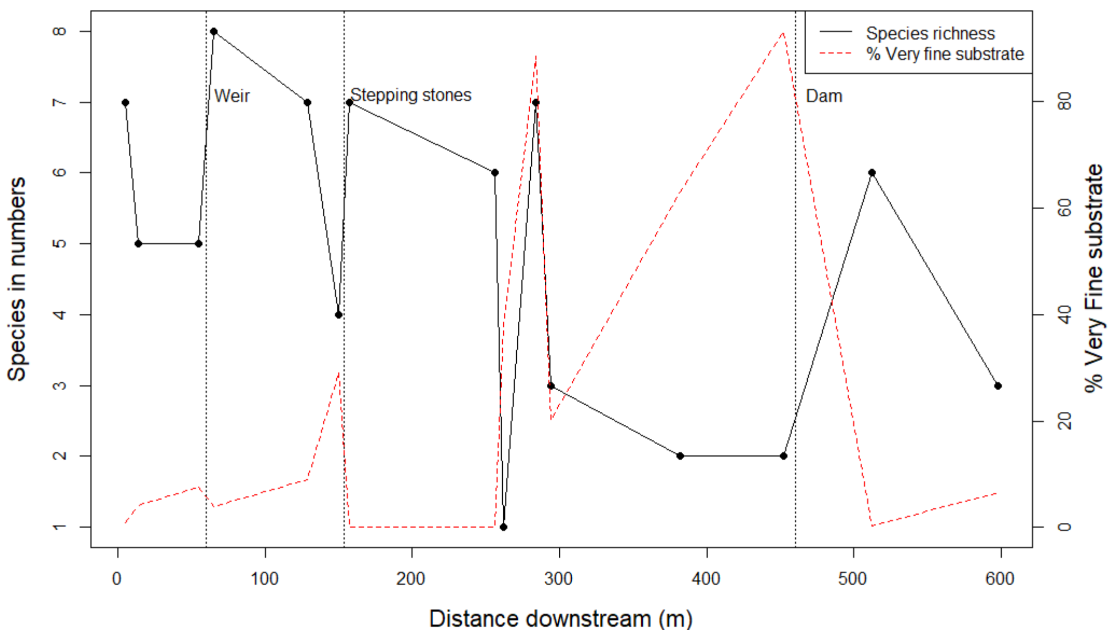

Figure 3. *The species richness variation downstream (black) against the proportion of bed substrate classified as very fine (<2mm). The vertical, grey dotted lines indicate the locations of stream impoundments.*

3.2 Fine Gravel (2-5.6mm)

Across the study site, an inverse relationship between species richness and the proportion of sediment classified as fine gravel (Figure 4) is seen. Most notably, at sites 9 and 10 (262m and 284m downstream respectively), where the increase in fine gravel at site 9 corresponds with a sharp decrease in the species richness while the decrease in fine gravel at site 10 coincides with an increase in species richness.

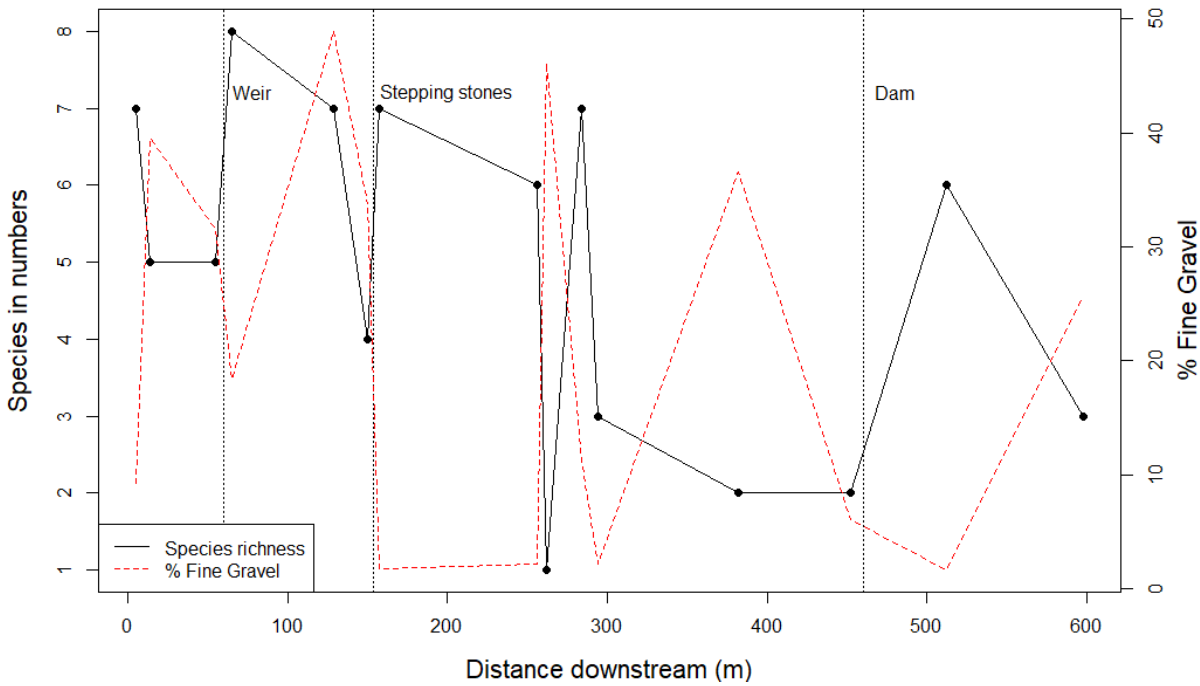

Figure 4. *The species richness variation downstream (black) against the proportion of bed substrate classified as fine gravel (2-5.6mm). The vertical, grey dotted lines indicate the locations of stream impoundments.*

3.3 Medium Gravel (5.6-16mm)

In the first ~250m of the study area, there is a direct relationship between proportion of medium gravel and species richness (Figure 5). At site 10 (284m downstream) however, this relationship is not evident as the percentage of medium gravel decreases but species richness increases. Further downstream, the direct relationship returns with the notable exception of the final site (598m downstream).

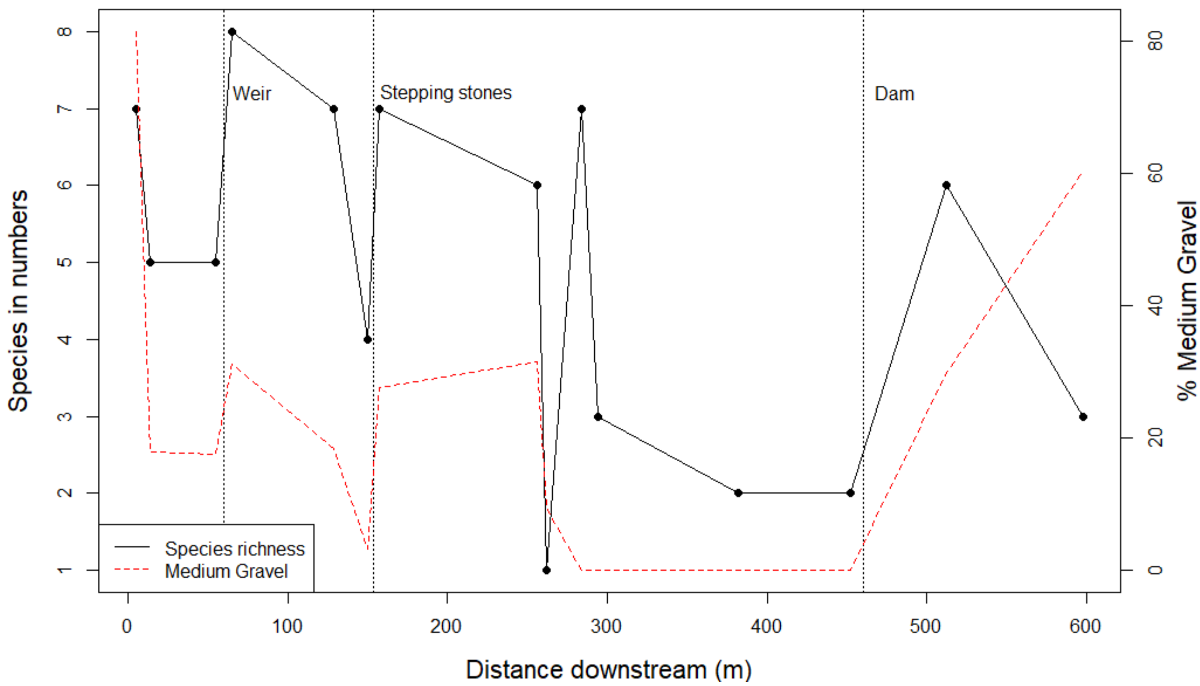

Figure 5. *The species richness variation downstream (black) against the proportion of bed substrate classified as medium gravel (5.6-16mm). The vertical, grey dotted lines indicate the locations of stream impoundments.*

3.4 Coarse Gravel (16-64mm)

A direct relationship between the coarse gravel proportion and species richness is visible between sites 4 and 5 (65-129m downstream), 7 and 9 (157-262m downstream) and 14 – 16 (513-643m downstream) (Figure 6).The exception to this trend is the first 3 sites (5-55m downstream) where no relationship is seen and at site 10 (284m downstream) where an inverse relationship is visible.

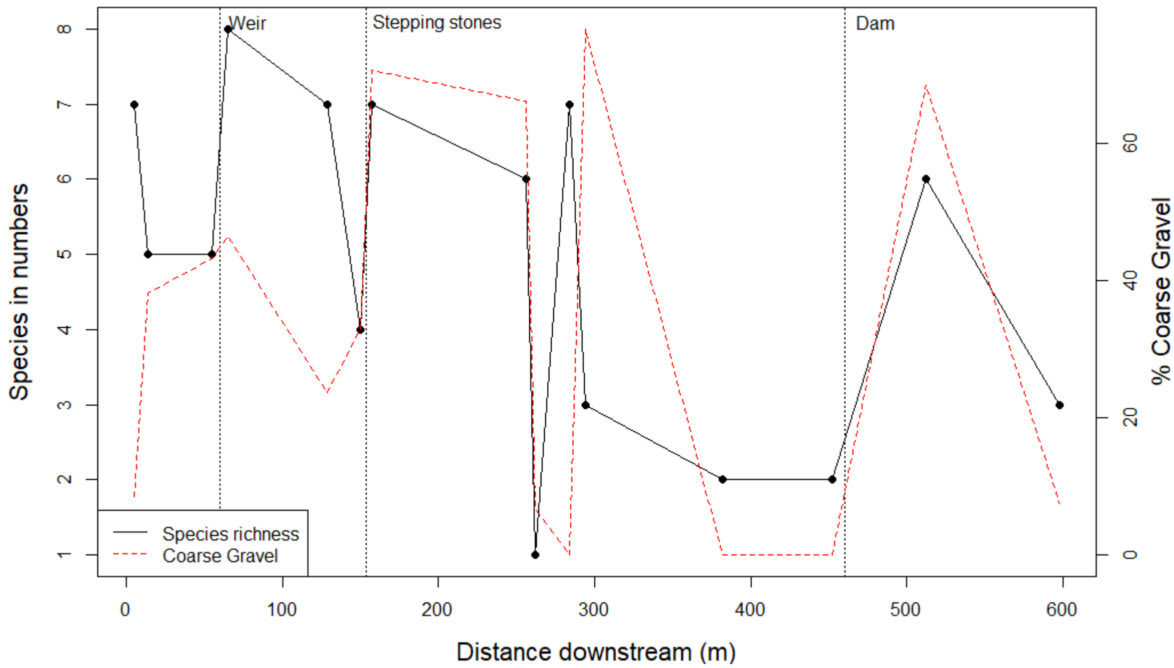

Figure 6. *The species richness variation downstream (black) against the proportion of bed substrate classified as coarse gravel (16-64mm). The vertical, grey dotted lines indicate the locations of stream impoundments.*

3.5 Total Macroinvertebrates

Macroinvertebrates are not evenly distributed downstream in the samples. The decrease in total macroinvertebrate count with distance downstream is significant (Linear Regression Model, $p<0.05$) and shown in Figure 7, where macroinvertebrate numbers are higher in the upper sampled section (5-157m downstream) before staying consistently low downstream from site 11 (294-598m downstream).

The total number of macroinvertebrates collected was 161 individuals ($\bar{x}$ = 10.73) across the 16 sites. Although this sample size is small due to temporal constraints of the project, Table 2 presents previous studies on similar water bodies that produce a similar $\bar{x}$ value and therefore, although comparatively the results of this study are small in sample size, corresponding studies suggest the data is robust.

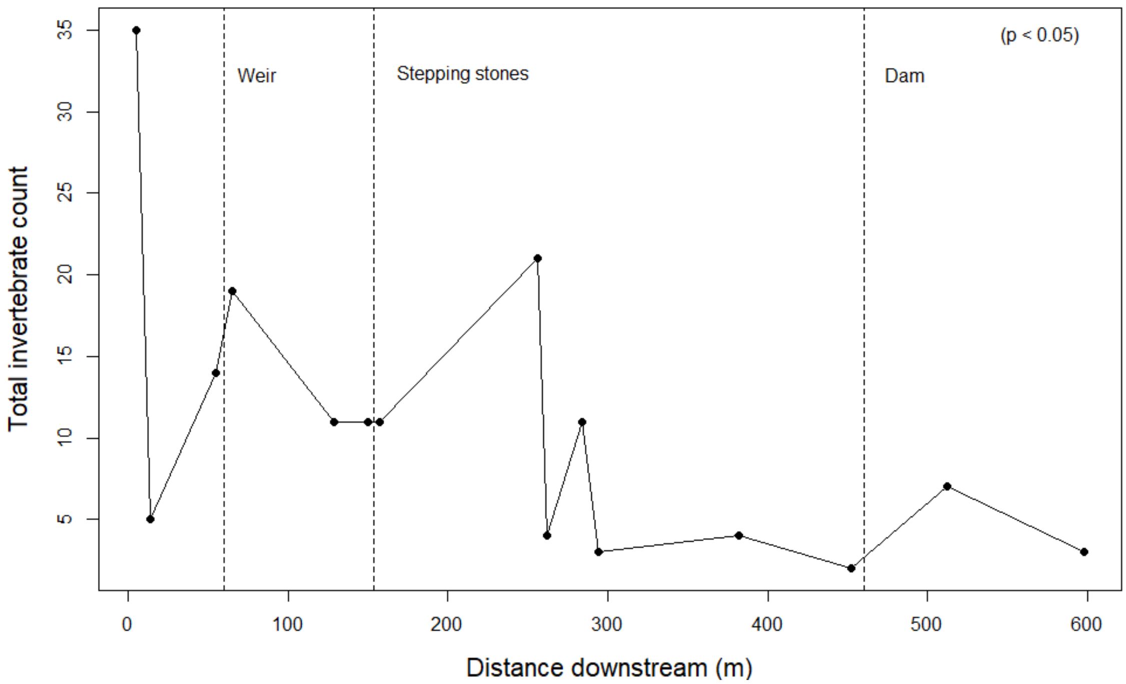

Figure 7. *The variation in total macroinvertebrate numbers at each site downstream. The vertical, grey dotted lines indicate the locations of stream impoundments.*

Table 2. *Summary of mean taxa richness for this study and other macroinvertebrate studies. Lompart and McCowan (2014) and Fletcher (1992) are unpublished, but both studies are broadly similar in methods and scale and so are included as a more similar comparison. Durance and Omerod (2007) was conducted over a much larger scale and collated substantially more data but was included as a comparison as the study was completed in the Avon region. A breakdown of data was not available for Durance and Ormerod, 2007 and therefore only a mean figure is present. Lompart and McCowan (2014) and Fletcher (1992) are available in Appendix 8.2.*

x̄ (mean) of taxa per site sampled	Study details	Season sampled	Reference	Published
10.73	***15 sites over a ~600m stretch of The Malago, 1 kick sample collection.***	***Winter***	***Group 9, 2020. Unpublished.***	**No**
29.8	1116 kick samples over the entire Avon region over the course of 18 years.	Spring/Summer	(Durance & Ormerod, 2007)	Yes
11.805	8 sites sampled over 15 years of a lotic system in London, United Kingdom	Summer	(Lompart & McCowan, 2014)	No
10.44	25 sites sampled in the North East of England	Summer	(Fletcher, 1992)	No

3.6 Biotic Index

The biotic index as calculated with the Family Biotic Index (FBI) indicated that 10 out of the 15 sites are ‘Fairly Poor’, ‘Poor’ or ‘Very Poor’. The lowest reported result is at site 12 with only two recorded species (*Erpobdellidae* and *Talitridae*), both of which have high tolerance values for organic pollution.

Sites with a higher FBI rating are characterised as having rare or species less tolerant of organic pollution, for example family *Gomphidae* at site 5 (Table 3). Identification revealed an abundance of burrowers such as leeches and worms of family *Erpobdellidae* and *Oligochaeta* respectively. There was only one failure amongst the identification at site 5: a worm of an unknown family could not be classified using the appropriate guide used for the rest of the macroinvertebrates.

At each stream impoundment, the biotic rating increased downstream of the obstruction, the largest increase being from site 13 to 15 (upstream and downstream of the dam respectively)

Table 3. *Macroinvertebrates identified at sampling sites and modified biotic index rating. Site 14 is excluded due to the high concentration of concrete at the bed and is therefore not representative*

Site number	Taxa present (family)	Biotic rating
1	*Talitridae, Corophidae, Leptoceridae, Erpobdellidae, Sialidae, Baetidae, Glossiphonidae*	Fairly Poor
2	*Erpobdellidae, Oligochaeta, Leptoceridae, Baetidae, Glyceridae*	Fair
3	*Tautridae, Oligochaeta, Erpobdellidae, Perlidae, Leptoceridae*	Fairly Poor
4	*Talitridae, Psychonomidae, Perlidae, Oligochaeta, Erpobdellidae, Certopogonidae, Glossophonidae, Chironomidae*	Fair
5	*Glossiphoniidae, Oligochaeta, Perlidae, Erpobdellidae,* ***Unidentified worm****, Glyceridae, Gomphidae*	Good
6	*Ceratopogonidae, Erpobdellidae, Chironomidae, Goeridae*	Poor
7	*Leptoceridae, Goeridae, Erpobdellidae, Oligochaeta, Limnephilidae, Talitiridae, Perlidae*	Fair
8	*Erpobdellidae, Talitridae, Perlidae, Leptoceridae, Glyceridae, Ceratopogonidae*	Poor
9	*Ceratopogonidae*	Fairly Poor

10	*Glossophoniidae, Goeridae, Erpobdellidae, Ceratopogonidae, Talitridae, Glyceridae, Limnephilidae*	Poor
11	*Oligochaeta, Talitridae, Glyceridae*	Fairly Poor
12	*Erpobdellidae, Talitridae*	Very poor
13	*Glyceridae, Ceratopogonidae*	Fairly Poor
15	*Corophidae, Ceratopogonidae, Leptoceridae, Limnephilidae, Hydropsychidae, Leptoceridae*	Good
16	*Oligochaeta, Erpobdellidae, Thaumaleidae*	Fairly Poor

3.7 Species Richness

This general trend of a decrease downstream is also seen in species richness (Figure 8) which is also significant ($p < 0.05$). There is variation around this trend ($R^2 = 0.22$), with the lowest species richness value at site 9 (262m downstream). The species found at each site are recorded in Table 3 with certain species pictured in Figure 9.

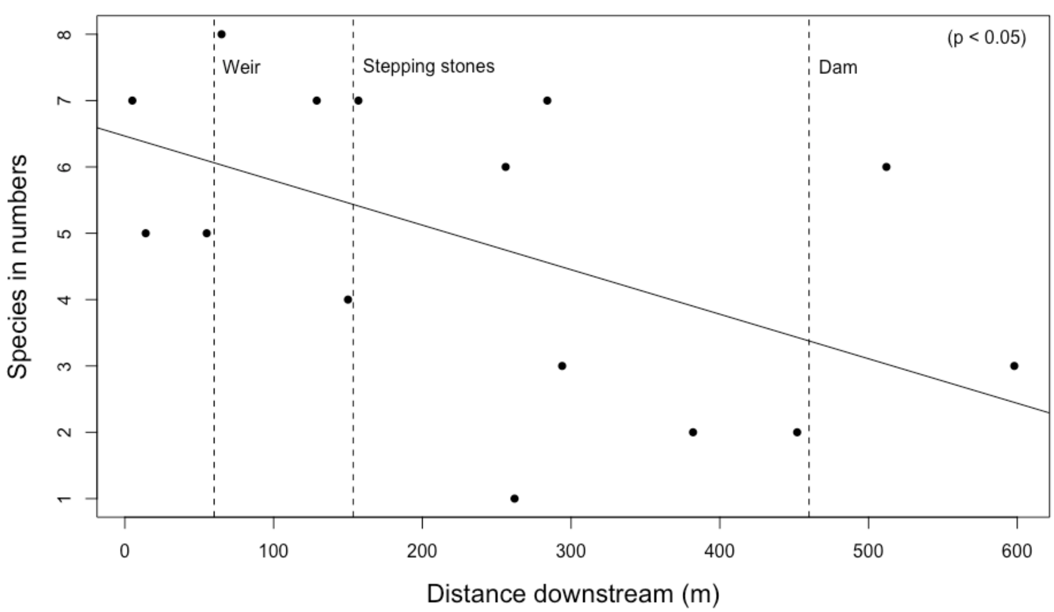

Figure 8. *The variation in species richness downstream. The straight line plotted is the output of a linear regression model (p<0.05). The vertical, grey dotted lines indicate stream impoundments.*

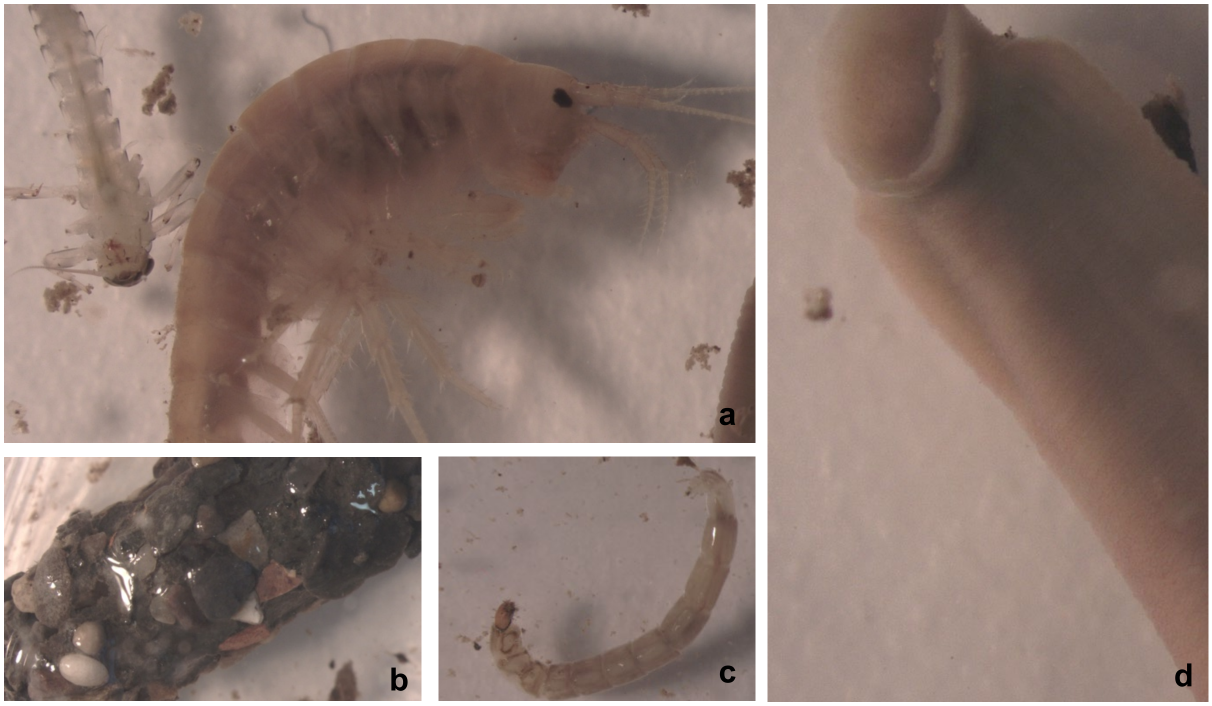

Figure 9. Ma*croinvertebrates identified from sites in The Malago: a)* Corophidae *and* Talitridae *in early stages of development. b)* Limnephilidae *(caddisfly) larvae in protective casing c)* Ceratopogonidae *larvae d)* Erpobdellidae *(leech)– present at almost every site sampled.*

3.8 Species Richness Variation with Stream Impoundment

The general downstream negative trend of species richness is interrupted by spikes in species richness across the three examples of stream impoundment. These three increases are identified as they are unique within this stream section. Sites 9 and 10 (262-284m downstream) reveal a large increase in species richness (Figure 10) across two sites recorded despite there being no stream impoundment present.

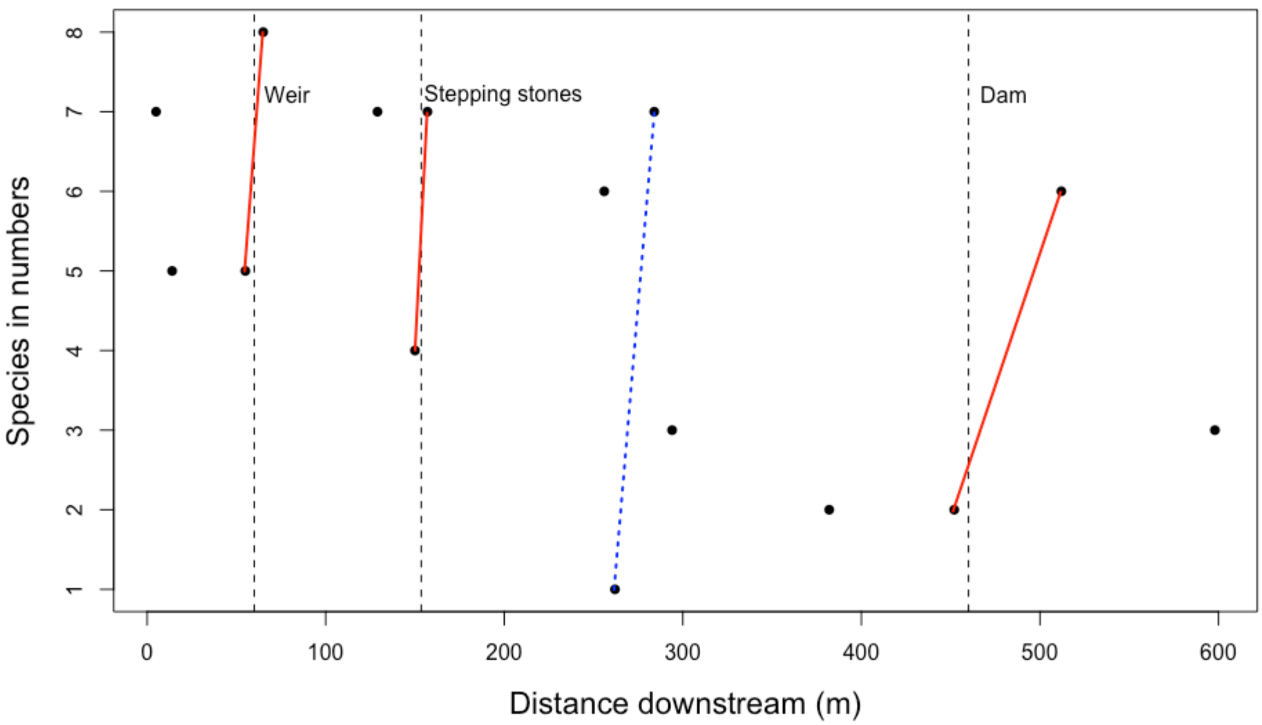

Figure 10. *Variation in species richness downstream. The red lines indicate the species richness increase across the stream impoundments and the blue dotted line represents an unexplained increase in species richness across sites 9 and 10 (262-284m downstream). The vertical, grey dotted lines indicate the locations of stream impoundments.*

3.9 Shannon-Weiner Index of Species Diversity

There is little trend in species diversity downstream, but there are clear increases in species diversity across each stream impoundment. The species richness increases across sites 9 and 10 (262-284m downstream) are also present (Figure 11).

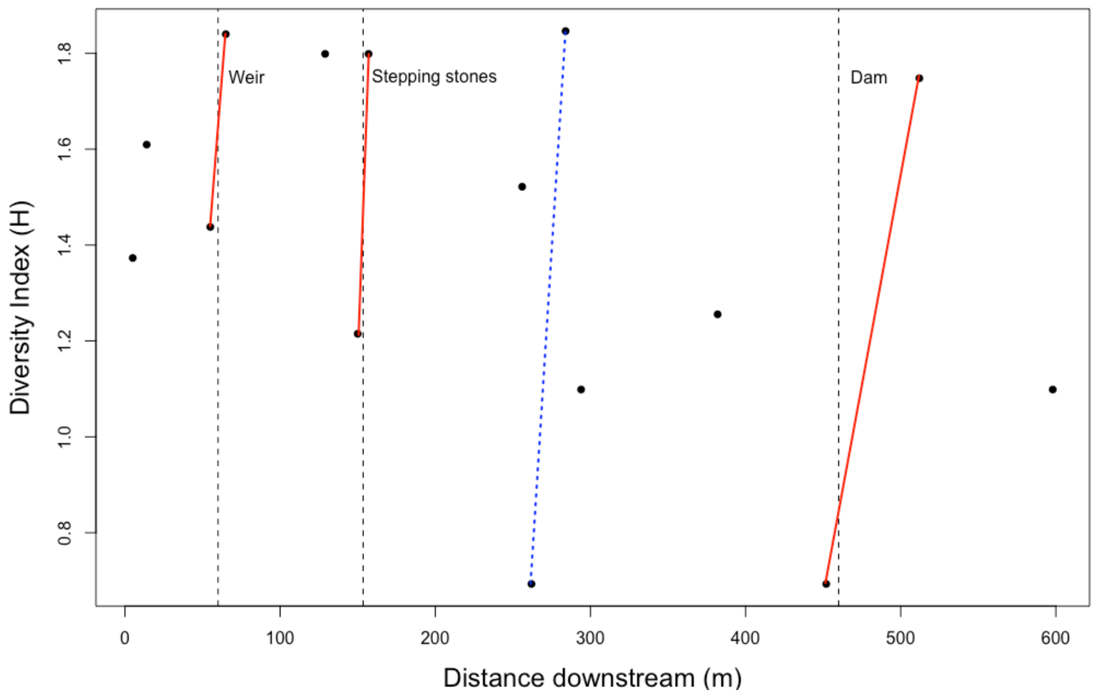

Figure 11. *Variation in the Shannon-Weiner Index of diversity downstream. The red lines indicate the species diversity increase across the stream impoundments and the blue dotted line represents an unexplained increase in species diversity across sites 9 and 10 (262-284m downstream). The vertical, grey dotted lines indicate the locations of stream impoundment.*

3.10 Geomorphology

There is an overall slight decrease in velocity downstream from 0.125 m s^{-1} at site 1 to 0.002 m s^{-1} at site 16 (Figure 12). However, there is a large increase (0.069 m s^{-1} to 0.58 m s^{-1}) in velocity from site 3 to 4 (55-65m downstream) at the location of the first weir (Figure 12). A large increase is not seen at the second impoundment, however, as the velocity decreases across the stepping-stones. A second large increase in velocity (0.021 m s^{-1} to 0.212 m s^{-1}) across the dam at sites 13 and 15 (452-512m downstream) is also visible.

No relationship was found between the width or depth of the river and distance downstream or macroinvertebrate abundance and richness (see Appendix 8.1).

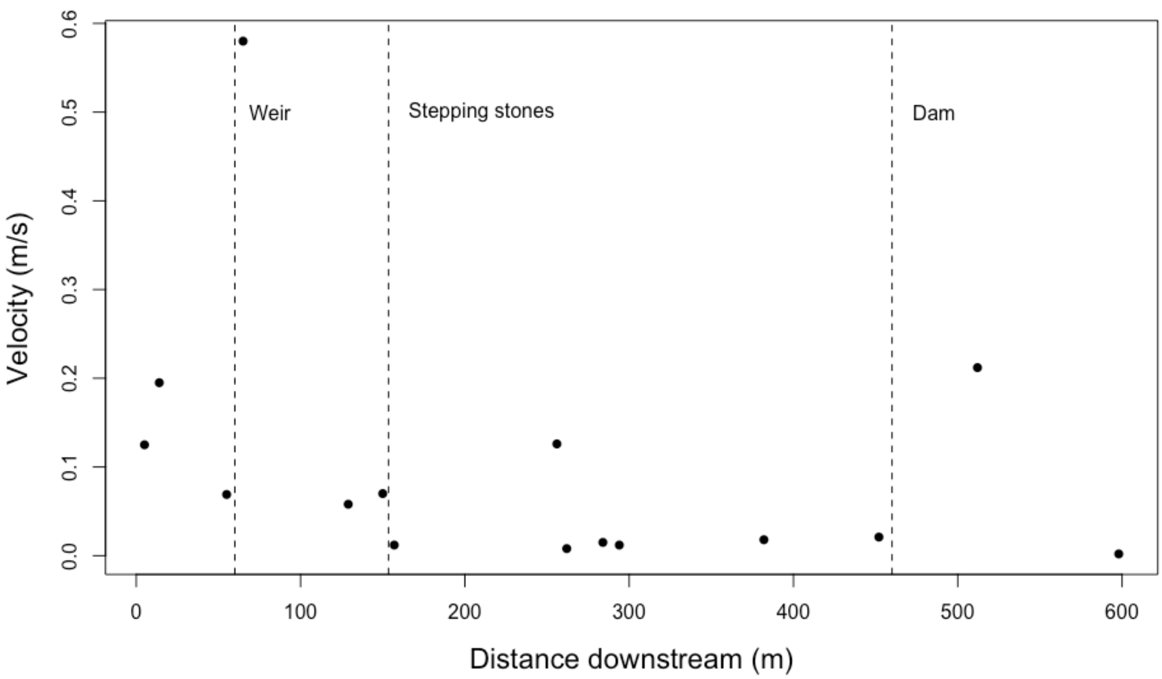

Figure 12. *The variation in velocity downstream. The vertical, grey dotted lines indicate the locations of stream impoundments.*

4. Discussion

4. 1 Grainsize Distribution

4.1.1 Macroinvertebrate Taxa and Grainsize

Coarse substrate is a characteristic of greater heterogeneity; whilst finer substrate tends to be more homogenous (Duan, et al., 2008). Further, homogenous substrate consisting of silts, sands and clays tend to be dominated by one or two species (Biesel, et al., 2000), with species distribution and response to grain size being taxa-specific (Blöcher, et al., 2020). As a result, more sediment-tolerant species are expected at more homogenous sites. During the final section of the stream where richness is consistently lower, and fine and very fine substrate is highest, the taxa consist of more pollution-tolerant and burrowing species such as *Leeches*, *Oligochaeta, Glyceridae* and *Talitridae*. Therefore, size fraction of grain size is an important control in determining bed characteristics which subsequently influence macroinvertebrate distribution.

Different taxa perform specific roles in the food chain such as filtering of organic matter or scraping of macrophyte assemblages from rocks (Wallace & Webster, 1996). Macroinvertebrates are intermediaries in the lotic ecosystem, affected by both top-down and bottom-up controls, and are an important food source for other heterotrophs, meaning a decrease in diversity has implications for the transfer of energy between low and high trophic levels, impacting the biodiversity of areas beyond the aquatic environment (Wallace & Eggert, 2010). As a result, diversity of macroinvertebrates is essential for a healthy river ecosystem. At sites characterised by a homogenous fine fraction (sites 10, 12 and 13), the dominance of these burrowing macroinvertebrates decreases the likelihood of colonisation by other taxa, further propelling a decrease in diversity (Wagenhoff, et al., 2012).

4.1.2 Very Fine Sediment

Accumulation of very fine substrate results in reduced interstitial spaces, limiting habitat and reproductive opportunities for benthic macroinvertebrates (Duan, et al., 2008). In addition, predominantly sandy substrate exhibits high vulnerability to diurnal flow variation that decreases the stability of the substrate, another key factor in reducing species richness (Ward & Stanford, 1979). However, flow rate also remained relatively stable throughout The Malago (Figure 12) meaning that any effect of grainsize is likely independent of impacts caused by flow variation. Given this relationship, species richness should operate inversely to the proportion of very fine substrate, and this relationship is partially reflected in the data, challenged by a notable anomaly at site 10. Visual comparison of the two trends demonstrates an inverse relationship that becomes more variable moving downstream (Figure 3). Rises in species richness correspond with both steep and weak declines in very fine substrate and *vice versa*, yet with little proportionality in the magnitude observed, suggesting that interaction with other grainsizes is important in a wider explanation of the relationship. Therefore, the variation in the trend of very fine substrate (< 2mm) shown in Figure 3 is likely due to the variability in geomorphology, fining processes and presence of anthropic stream influences that are known to influence streambed substrate size (Surian, 2002).

4.1.3 Fine Gravel

The cohesive nature of very fine sediment may incur a greater resistance to flow-driven tractive forces, whereas slightly coarser sediment is more prone to saltation resulting in scouring of the bed and catastrophic drift for macroinvertebrates (Culp, et al., 1986). Gravel classed as fine substrate (2 – 5.6mm) demonstrates a trend inverse to species richness that is greater in magnitude than substrate below 2mm (Figure 4). Steep rises in richness at Sites 4, 7 and 14 correspond with similarly steep falls in fine gravel proportion. Similarly, this is consistent with the literature stating that species richness should decrease as the proportion of finer sediment rises. The clearer trend in fine gravel suggests that macroinvertebrates have a more marked negative response to fine grained sediment than very fine (< 2mm).

4.1.4 Medium Gravel

The greater interstitial space and heterogeneity of larger sediment size within the sediment increases opportunity for macroinvertebrate habitation and breeding (Duan, et al., 2008). Medium-classed gravel (5.6 - 16mm) presented a trend visually similar to the pattern of species richness as shown in Figure 5, suggesting that this is the threshold at which the larger grainsize becomes favourable for the macroinvertebrates. Despite a low proportion at Site 10 where richness peaks, medium gravel is a sound predictor of taxa richness down the longitudinal profile of The Malago.

4.1.5 Coarse Gravel

Coarse grainsize (16-64mm) also shows a trend similar to that of species richness, with the clearest patterns observed at sites 4, 5, and 7 (Figure 6). The coarse grainsize fraction in The Malago exhibits intra-site variability across the width of the river, meaning the inferences are somewhat limited by the number of sediment samples per site (1). This intra-site variability is likely to be resultant of the specific geomorphology of the river, yet the geomorphological variables recorded by this project are not significant in the explanation of such variation in grainsize following a multivariate regression ($p > 0.05$, $n = 15$). Despite the anomalies, the relationship between the two variables is considered to be robust as the taxa richness signal is well-matched by the coarse grainsize fraction.

4.1.6 Hypothesis 1

Grainsize exhibits a fundamental control on benthic macroinvertebrate distribution

Grainsize appears to exert a fundamental control on benthic macroinvertebrate distribution, hence the results are consistent with the hypothesis.

4.2 Stream Impoundment Effects

The effect of stream impoundment on macroinvertebrate taxa richness is subject to considerable debate amongst the literature, with disagreement characterised by reports of both increases (Maynard & Lane, 2012) and decreases (Growns & Growns, 2001) in species diversity. This is likely due to the multifaceted response of benthic macroinvertebrates to variations in flow regime, riparian vegetation and geomorphology alongside stream impoundment (Poff & Zimmerman, 2010). Data from The Malago sample area is consistent with reports of a significant increase in macroinvertebrate diversity downstream of impoundment (Petts & Greenwood, 1985), with taxa richness demonstrating a clearly visible increase immediately post-impoundment and an additional anomalous peak at Site 10 illustrated by the blue line in Figure 10. This is supported by the similar pattern shown in the Shannon-Weiner Index accounting for both the diversity and the abundance at the sampling site (Figure 11).

As discussed, substrate grainsize determines both stability and heterogeneity of the streambed, which has implications for habitat suitability. Most studies of macroinvertebrate response to altered flow regimes attribute the change in richness post-impoundment to impacts on habitat, with the key factors being an accumulation of fine sediment upstream of the obstruction, and an increase in flow rate downstream. This increases the capacity of the river to carry finer sediment downstream of the obstruction, leaving larger substrates which act as a more suitable habitat for benthic macroinvertebrates (Petts & Greenwood, 1985). Moreover, river impoundment is often associated with the regulation of the flow regime, improving the stability of flow which is one of the key determinants of macroinvertebrate distribution and abundance (Maynard & Lane, 2012).

As homogenous substrate environments are typically characterised by dominance of one or two taxa (Bunn & Arthington, 2002), heterogeneous substrate provides both greater hydraulic diversity and opportunities for habitat niches, both of which contribute to higher species richness (Biesel, et al., 2000). It is therefore highly likely that the greater proportion of medium and coarse gravel following impoundment diversifies the sediment composition, contributing to a rise in taxa richness. Therefore, the coarser substrate associated with post-impoundment environments has implications for the heterogeneity of the substrate, shown earlier to have a control on taxa richness. Further, the medium and coarse gravel boundaries extend over a wider range of substrate fractions, which may contribute to greater heterogeneity and more diverse habitation opportunities.

4.2.1 Biotic Index

The results of the Modified Family Biotic Index (FBI) shown in Table 2 are indicative of largely poor water quality in The Malago in contrast to a previous study finding that the overall health of the stream is good (Group 1, 2018). However, it is vital to account for the small sample size in these results (n = 161) that will be highly affected by the presence of a single rare species in the sample, alongside the season of sampling. The notable rise in the FBI classification downstream of the weirs and the dam aligns with the increase in substrate grain size following each impoundment, and is indicative of improved species habitation, suggesting a rise in the range of species that are less tolerant of generally unfavourable conditions. Whilst there is little intra-specific trend downstream, this additional data builds on hypothesis 2 – that impoundment has a positive effect on macroinvertebrate diversity immediately downstream of the obstruction. In addition, it poses questions about the overall quality of the stream at certain points along the profile, however that is beyond the scope of this study.

4.2.2 Longitudinal Connectivity

Impoundment affects macroinvertebrates on scales larger than the immediate downstream response as it disrupts the complete longitudinal connectivity of the stream. Connectivity is essential for the survival and success of macroinvertebrates within a stream (Bunn & Arthington, 2002) as it allows them to respond to the dynamic nature of the lotic environment, with fluctuations in flow rate, temperature and water chemistry occurring both across spatial (longitudinal) and temporal (diurnal to seasonal) timescales (Vannote, et al., 1980). Despite the rise in taxa richness immediately downstream, there are significant ($p < 0.05$, $n = 15$) decreases in both species diversity and species abundance downstream (Figure 7, Figure 8). These results may be explained by the repeated obstruction of the stream in disrupting the longitudinal profile, inhibiting opportunities for natural species drift out of zones unfavourable for habitation (Bunn & Arthington, 2002). A decrease in biodiversity of macroinvertebrates has serious implications for energy transfer to higher trophic levels (Wallace & Eggert, 2010), and so the risk of knock-on effects to the wider ecosystem is a serious issue for biodiversity at wider spatial scales.

The natural longitudinal regime of the river also has implications for downstream transport of organic matter (OM), an essential food source for aquatic macroinvertebrates including grazers and filterers (Wallace & Webster, 1996). This study does not investigate the distribution of organic matter fractions with stream length, but further research may serve to illuminate the role of stream obstruction in delivery of bioavailable OM to downstream lotic ecosystems.

4.2.3 Serial Discontinuity in The Malago

The way that lotic ecosystems respond to discontinuities has been examined via the Serial Discontinuity Concept (Ward & Stanford, 1983). The concept treats the river system as a continuum in which the impacts of obstructions (i.e. impoundment) shift the river regime upstream or downstream based on the characteristics the river assumes post-impoundment. Effects of multiple discontinuities in The Malago cumulatively result in a shift downstream of the natural trend, as the ecological regime under a 'natural' flow regime are displaced further down the longitudinal profile. This may have consequences for biodiversity downstream as displacement reduces the suitability of habitats and flow for benthic macroinvertebrates that are highly sensitive to environmental stresses (Wagenhoff, et al., 2012). Given the presence of three important flow obstacles within a 600m stretch of The Malago, significant serial discontinuity may have occurred. While the immediate effect of stream impoundment has shown to be positive for macroinvertebrate diversity, there could be wider-reaching negative consequences that are beyond the scope of this study.

4.2.4 Nitrate Concentrations

Nutrient concentrations can affect the rate of primary production and organic matter decomposition (Krueger & Waters, 1983), both of which have implications for macroinvertebrate abundance. Disagreement over the direct role of nutrients in macroinvertebrate abundance and richness must be considered as the relationship is often confounded by many variables (Yuan, 2010). Previous studies of The Malago report data concerning the water chemistry of the same section of the stream as studied in this investigation, opening it up to comparison with the ecological variables identified in this study. Data from The Malago (Group 1, 2018) shown in Figure 13 demonstrates a decrease in nitrate concentrations with distance downstream, shown to correlate with macroinvertebrate abundance (Krueger & Waters, 1983). Whilst the inferences drawn from this study are inherently limited in scope and must be treated with caution, they prove a viable gateway for future work to be conducted in The Malago.

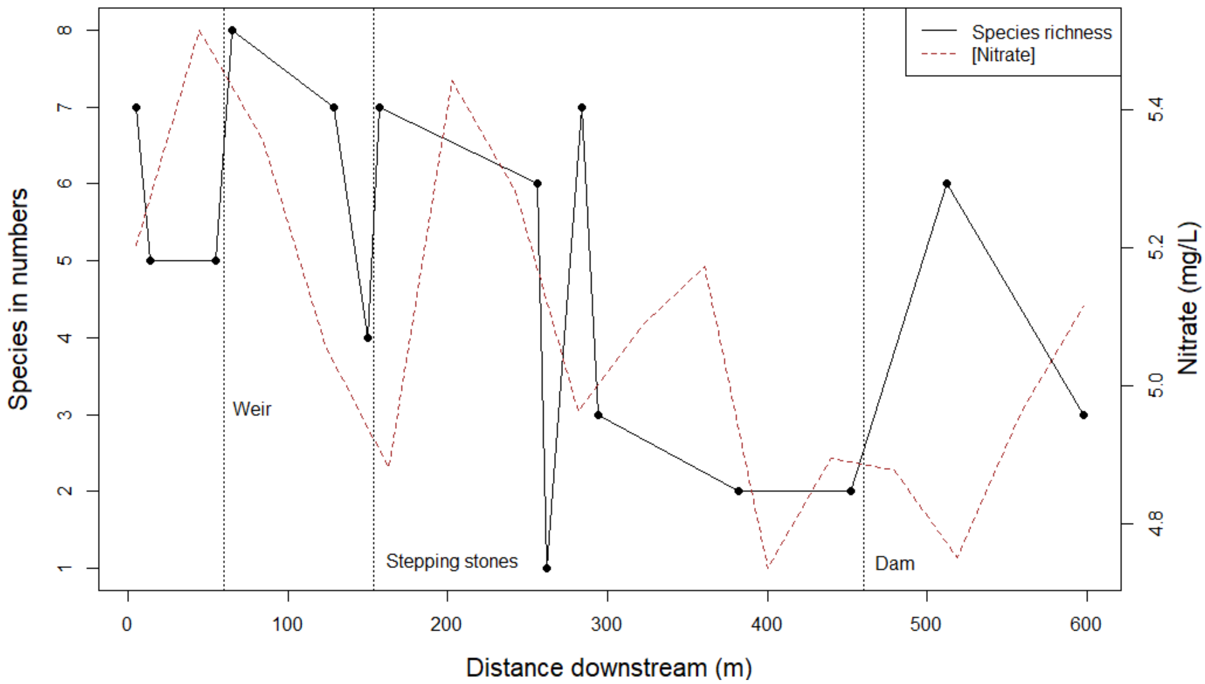

Figure 13. *Comparison between nitrate concentration recorded by past study (Group 1, 2018) and species richness recorded in this study. $NO3^{2-}$ concentrations demonstrate a significant (Linear Regression Model, $p < 0.05$) decrease downstream.*

4.2.5 - Anomalous Results

Despite the relationships observed, there are notable anomalies in the distribution that require addressing. At site 10, the proportion of very fine substrate reaches 88% of the total sample mass yet features a notably high taxa richness of seven species, strongly contradicting the relationship observed both within the results and reported across other studies (Reice, 1980). Given the relationship expected between very fine sediment and macroinvertebrate diversity, other factors must be contributing to the signal here. One explanation is that the very fine sediment at Site 10 serves to stabilise the bed substrate through the higher resistance to shear stress as discussed in section 4.1.2, however the relatively slow velocity (0.015 m s^{-1}) and lentic nature of the site makes this explanation unlikely.

4.2.6 - Hypothesis 2

Stream impoundment increases species richness of benthic macroinvertebrate downstream

From this discussion, it is apparent that the results are consistent with the hypothesis that stream impoundment increases species richness of benthic macroinvertebrates downstream.

5 Limitations and Future Research

This report has provided a niche set of data relating to macroinvertebrates and substrate composition of The Malago collected during January 2020. However, that is not to say that a complete overview has been provided.

5.1 Sample Size

A general decrease of total macroinvertebrates from 35 at site 1 to just 3 at site 16 was found downstream, albeit with high variation. This sample size is substantially below many recognised thresholds due to temporal constraints of the survey. For example, environmental departments in Australia and New Zealand recommend 200 macroinvertebrates per site, Canada recommend 300 and the United States Environmental Protection Agency, 500 (Buss, et al., 2015). Therefore, although the data collected was robust, larger samples would ensure that a more complete picture of The Malago's biodiversity is provided. Future research groups would be able to explore the importance of individual taxa found within The Malago. This is essential for exploring the health of The Malago, especially with increasing urban development and rising temperatures – both of which have an impact on river nutrients and macroinvertebrates (Burgmer, et al., 2007; Withers & Lord, 2002)**.** A more robust sample size would also enable the increased chance of discovering any rare or migratory taxa which may influence the larger food webs of The Malago; especially as the observation of an Otter (*Lutra Lutra)* has been documented – a species not commonly seen within The Malago (Loy-Hancocks, 2020, *personal communication*) revealing the area's potential for high biodiversity.

Alongside this, data was collected on a single, particularly cold, January day. As a result, a snapshot of The Malago was provided which without further research provides limited robust temporal trends. Repeat investigations during the winter period would enable the Manor Woods Valley Group to build a niche database of river macroinvertebrates for the whole season.

5.2 Spatial and Within-Stream Scales

Practical constraints meant only a small section of The Malago was sampled, and further research is needed to provide grounding for the results. Sampling up and downstream of the study site would provide a valuable context for the results which could be used to develop understanding of the increased urban coverage along The Malago's entire profile, and the implications for macroinvertebrate communities at wider spatial scales.

In addition, the research focused predominantly on a longitudinal approach – opting to explore the effect of stream impoundment on The Malago and therefore placing less focus on the highly heterogeneous lateral profile of The Malago. Further cross-profile research could compliment the data and allow for a comparison to be made at multiple spatial scales, better representing the overall heterogeneity of the river system (Culp, et al., 1983). It would be particularly worthwhile to explore the different flow rates throughout the channel depth, for example, velocity at the stream bed and the impact that this, alongside substrate, may have on macroinvertebrate spatial and population dynamics.

5.3 Macroinvertebrate Drift

Macroinvertebrate drift is an important phenomenon that must be accounted for when examining spatial distribution of macroinvertebrates, as studies have reported site colonisation as a result of drift to range from 42% (Willams & Hynes, 1976) to 82% (Townsend & Hildren, 1976). The likelihood of species drift determining anomalous results in The Malago is varied as drift tends to be lowest during the Winter months, therefore the sampling month of January may negate this; yet drift is highest among pupae and larvae following hatching (Brittain & Eikeland, 1988). Given that many of the macroinvertebrates sampled were in early life stages (Figure 9) drift may be a possible determinant of taxa distribution. It is important to consider however, that species drift is a result of a wide spectrum of factors such as water chemistry, sedimentation, predation and seasonality, all notoriously difficult to differentiate (Brittain & Eikeland, 1988), and that in general, further work is needed to quantify the effects of macroinvertebrate drift on the aquatic biodiversity of The Malago.

5.4 Macroinvertebrates and Temperature Change

Macroinvertebrates have been shown to vary with temperature on diurnal to seasonal timescales (Scrine, et al., 2017) and are some of the most vulnerable freshwater organisms to climate change (Hart & Calhoun, 2010). Considering the regular seasonality of macroinvertebrates, the high number that were already in medium-advanced life stages as opposed to pupae is likely to be indicative of temperature-driven premature emergence. Whilst this is not the focus of the study in question, the data provides an opportunity for future investigation to compare the effect of seasonal temperature changes on macroinvertebrate emergence times, and the implications for wider population dynamics.

6 Conclusion

The fundamental aim of this project was to analyse the relationship between benthic macroinvertebrates and riverbed grainsize within The Malago during the winter period, whilst considering the anthropic influence of this complex aquatic ecosystem. Consistent with much of the literature (Duan et al., 2008; Reice et al., 1980), it is found that coarser grainsizes are more favourable for macroinvertebrates as heterogeneity increases along with substrate stability. The management of The Malago also impacts immediate macroinvertebrate richness as the river's flow rate is regulated, with downstream substrate showing greater heterogeneity. It has been proposed however, that the longitudinal connectivity of the stream has been negatively impacted by the presence of stream impoundment, leading to the general trend of reduced species numbers and richness downstream.

The output of this study points to the importance of investigating macroinvertebrate abundance and diversity when considering river ecosystem dynamics. The collection of macroinvertebrates in a winter month such as January not only illuminates lesser-studied aspects of macroinvertebrate seasonality, but contributes to a wider literature on macroinvertebrate population dynamics in warmer winters (Scrine, et al., 2017). The two hypotheses are interrelated in grainsize/impoundment dynamics and above all, demonstrate the ecological impacts of anthropic influences on small streams in urban environments. Negative trends in both macroinvertebrate abundance and richness are likely to affect higher trophic levels and therefore ecosystems on a wider spatial scale than the studied area (Wallace & Eggert, 2010).

7 References

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8.1 Primary Data Appendix

Table 4. Compiled table of primary data collected – Macroinvertebrates of The Malago

Site	Easting	Northing	Distance Downstream (m)	Macroinvertebrate abundance	Species Richness	Shannon – Weiner Index (H')	Biotic Rating
1	357275	169111	5	35	7	1.37	Fairly Poor
2	357279	169118	14	5	5	1.61	Fair
3	357295	169155	55	14	5	1.44	Fairly Poor
4	357296	169165	65	19	8	1.84	Fair
5	357327	169221	129	11	7	1.80	Good
6	357336	169240	150	11	4	1.21	Poor
7	357340	169246	157	11	7	1.80	Fair
8	357416	169313	256	21	6	1.52	Poor
9	357414	169318	262	4	2	0.69	Fairly Poor
10	357429	169335	284	11	7	1.85	Poor
11	357437	169340	294	3	3	1.10	Fairly Poor
12	357505	169396	382	4	2	1.26	Very Poor
13	357572	169419	452	2	2	0.69	Fairly Poor
14	357588	169148	468	2	2	0.69	Excellent
14*			486	2	2	0.69	Excellent
15	357631	169429	512	7	6	1.75	Good
16	357686	169495	598	3	3	1.10	Fairly Poor

Table 5. Compiled table of primary data collected – Physical Parameters of The Malago

Site	Width (m)	Mean depth (m)	Flow Rate (m s^{-1})	% very fine	% fine	% medium	% coarse
1	7.73	0.062	0.125	0.8	9.29	81.5	8.59
2	4.8	0.097	0.195	4.14	39.56	17.91	38.22
3	4.84	0.24	0.069	7.6	31.5	17.52	43.19
4	3.5	0.16	0.58	3.86	18.45	31.27	46.57
5	2.9	0.16	0.058	9.05	48.92	18.38	23.64
6	7.13	0.3	0.07	29.01	33.81	3.17	32.86
7	5.19	0.15	0.012	0.02	1.77	27.58	70.77
8	6.2	0.077	0.126	0.01	2.21	31.62	66.23
9	4.79	0.21	0.008	37.74	46.16	9.41	6.65
10	4.5	0.4	0.015	88.53	11.35	0	0
11	3.5	0.61	0.012	20.19	2.22	0	76.73
12	7.95	0.23	0.018	63.1	36.6	0	0
13	5.15	0.49	0.021	93.28	6.13	0	0
14	4	0.14	0.184	3.85	0.86	23.64	71..62
14*	4	0.14	0.184				
15	3.1	0.1	0.212	0.2	1.65	29.83	68.44
16	3.45	0.44	0.002	6.52	25.63	60.37	7.48

8.2 Secondary Data Appendix

Table 6. Lompart and McCowan, 2013. Unpublished. Data table of collected results over 15 years in London.

	Site Name and corresponding number of Taxa								Mean (x̄) per year
Year	Old Victoria	Highbury	Green Valley	Green Lane	White Oak	Wonderland	Colonel Talbot	Lambeth	
1999	9	5	4	7	9	0	0	8	7.2
2000	9	14	4	4	7	0	0	5	7
2001	8	8	7	8	5	0	0	6	97
2002	13	9	10	10	10	0	0	7	9.8
2003	10	7	8	8	10	0	0	6	8.1
2004	9	9	9	6	9	5	7	6	7.5
2005	9	8	5	6	9	12	6	13	8.5
2006	11	14	12	5	16	18	7	14	12.1
2007	8	9	14	14	14	12	17	14	12.8
2008	10	17	15	15	17	21	14	15	15.5
2009	11	16	18	14	12	21	16	18	15.8
2010	20	21	20	16	14	19	17	17	18
2011	11	23	20	23	18	21	23	25	20.5
2012	9	12	0	13	13	15	18	19	14.1
2013	7	17	0	12	14	17	12	13	13.1
(x̄) of 15									11.8

Table 7. Fletcher, R. 1992. Unpublished. Total macroinvertebrates over 25 sites sampled during the summer season.

Total number and Mean ($\bar{x}$) value	**Site Number**	**Number of taxa**
	1	6
	2	5
	3	10
	4	8
	5	19
	6	11
	7	6
	8	3
	9	4
	10	4
	11	11
	12	10
	13	18
	14	19
	15	9
	16	15
	17	5
	18	8
	19	13
	20	3
	21	22
	22	9
	23	13
	24	13
	25	17
Total number of taxa		261
Mean ($\bar{x}$)		**10.44**

8.3 Ethics Appendix

University of BRISTOL

SCHOOL OF GEOGRAPHICAL SCIENCES

RESEARCH ETHICS MONITORING FORM, 2019-20

D: UNDERGRADUATE COURSEWORK

Research by all academic and related Staff and Students in the School of Geographical Sciences is subject to the standards set out in the Code of Practice on Research Ethics.

It is a requirement that prior to the commencement of all funded and non-funded research that this form be completed and submitted to the School's Research Ethics Committee (REC). The REC will be responsible for issuing certification that the research meets acceptable ethical standards and will, if necessary, require changes to the research methodology or reporting strategy.

A copy of the research proposal which details methods and reporting strategies must be attached. *Submissions without a copy of the research proposal will not be considered*.

The REC seeks to establish from the form that researchers have (i) thought purposefully about potential ethical issues raised by their proposed research; and (ii) identified appropriate responses to those issues.

Name: JAMES SMITH, ROSIE MCGAHAN, GRACE RICKMAN, MORGAN HARPER, LOUIE BELL
Email: KX18023@BRISTOL.AC.UK
Title of dissertation: MAPPING THE SUBSTRATES OF THE MALAGO AND ITS IMPACT ON THE ECOLOGY

				External/lay scrutiny required?
		YES	NO	Action
1.	Does your research involve living human subjects?		X	If NO, go to Q.3, 12, 13, & '*Declaration*'
2.	Does your research involve ONLY the analysis of large, secondary and anonymised datasets?			If YES, go to Q.3, 12, 13, & '*Declaration*'
3.	Do others hold copyright or other rights over the information you will use, or will they do so over information you collect?	X		If YES please provide further details below
4.	Will you give your informants a written and/or verbal summary of your research and its uses?			If NO, please provide further details below.

5.	Does your research involve covert surveillance (for example, participant observation)?			If YES, please provide further details.
6.	Will your informants *automatically* be anonymised in your research?			If NO, please provide further details below.
7.	Will you explicitly give *all* your informants the right to remain anonymous?			If NO, please provide further details below.
8.	Will monitoring devices be used openly and only with the permission of informants?			If NO, why not? – give details below.
9.	Have you considered the implications of your research intervention on informants?			Please provide details below.
10.	Will data/information be encrypted/secured, and stored separately from identification material to maintain confidentiality??			If NO, why not?
11.	Will your informants be provided with a summary of your research findings?			If NO, please provide further details.
12.	Will there be restrictions on your research being available through the university data archive (e.g. by the sponsoring authorities or from participants)?		X	Please provide details below
13.	What other potential ethical issues arising from this research have you identified?	X		Please state below how they will be taken into consideration.

Further details:

Group 9 – James Smith, Rosie McGahan, Grace Rickman, Morgan Harper, Louie Bell
Supervisor – Dr Max Stockdale

3: The research site is a public park owned by Bristol City Council and managed by Manor Woods Valley Group. Manor Woods Valley Group have organised this project and have given us permission to perform the tests we require to produce our report. Neither the reseachers, Manor Woods Valley Group or Bristol City Council have any conflict of interests surrounding The Malago and its Substrate or Ecology; this is merely an exploritative research activity aiming to indicate specific areas for further research rather than to solve a problem.
3: Research used to create our methodology will be properly cited and referenced along with secondary data which is included as a table or graph which will also be fully referenced and ensured that it has been in the public domain. This will include previous studies undertaken by University groups on The Malago site which have already been put onto the Manor Woods Valley Group website.
3: To construct our report, it is likely that we will be using previously captured environmental data for both our river and other similar rivers. While this is likely to be published and in the public domain, any unpublished data which we believe could be useful could be requested. Upon our request, we would explain the purpose and use of the data to ensure that the rights holder is comfortable with it being used in our publically available report and executive summary.

12: Manor Woods Valley Group have previously worked with the University of Bristol in a 2nd year research capacity. They are aware of the University policy of storing the data in the University Data Archive and have given us consent to allow this to happen once again. Our report and executive summary will also be uploaded to their website in the public domain. There are no other outside parties directly involved with the project.

13: As we are not using chemicals during our fieldwork, water quality downstream of our site is unlikely to be impacted and the samples we are taking are only a very small proportion of the substrate and ecology in the river, limiting our ecological impact as much as possible.
13: Data collected in the project will be used in the results and discussion section of the report and executive summary unless there is a good reason for it to be excluded such as an improperly executed method (invertebrate sampling not done for the correct amount of time or grainsize not repeated at a site). A sudden but extended downpour would lead us to discard our geomorphological results as the river changes depth and flow rate rapidly in response to rainfall. In order to keep reliability in our results, geomorphology must be measured on one day without changeable conditions as unexplained changes in geomorphological results halfway through our data could be a cause for major concern for future management. This process will ensure that our results are as conclusive as possible and not misleading.
13: Any potential implications from our research are very unlikely to impact the public in a negative way, likely positively if any, as the Manor Woods Valley Group are aiming to conserve the natural area surrounding the river with any future management work.
13: Our method includes geomorphological measurements of the river, including its depth, flow rate and width. As these measurements are variable temporally, it is important that we make this clear. If this isn't made clear, future management plans could be designed around results found only during low flow, rendering them useless, and possibly dangerous, during periods of spate.
13 : The lab analysis will be conducted in a thorough and safe manner according to the instructions set out in the Teaching and Laboratory Methods Handbook provided by the School. Any divergence from these methods will be recorded and justified in the methodology section of the report so our method can be repeated in any future investigation regarding substrate size and ecology of river environments. Any safety implications we come to find in the lab or the field will be reported in order to reduce the chances of them occurring and endangering any students in future studies.
13: Data analysis will be carried out using the appropriate statistical software that will be credited in the report along with the current and, at the time of analysis, most up-to-date version of the software. All of the data will be subject to analysis, and if any is excluded in the case of poor results this will be explicitly mentioned in the report. Anomalous results will individually be criticised within a holistic approach to all of the data and will be identified within the analysis. Due to the typically 'noisy' nature of environmental data, we are prepared to exclude results on the basis of their being 'random' noise, but this will be done in a careful manner in order to reduce the chance of future river management being affected by overly-transformed or misleading data. Any conclusions reached will incorporate a recognition of the statistical error in our sampling/analysis method and reccomendations for the future will be adjusted appropriately.

Continuation sheet NO (delete as applicable)

Declaration

I have read the School's Code of Practice on Research Ethics and believe that my research complies fully with its precepts.

I will not deviate from the methodology or reporting strategy without further permission from the School's Research Ethics Committee.

Student
Signed JAMES SMITH Date 17/01/20

Project advisor
Signed ……………………………………………………. Date ………….

Progress:

(please leave blank)