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Comparison of the Effects of Catchment Land Use/Land Cover on Freshwater Macroinvertebrate Communities and Water Quality in Three Rivers of the Dingle Peninsula

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Comparison of the effects of catchment land use/land cover on freshwater macroinvertebrate communities and water quality in three rivers of the Dingle Peninsula

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Abstract

Comparison of the effects of catchment land use/land cover on freshwater macroinvertebrate communities and water quality in three rivers of the Dingle Peninsula

By: Brooke Chesler

The Dingle Peninsula, a dynamic coastal ecosystem in the southwest of Ireland, provides an appropriate location to study the delicate balance that exists between human activities i.e., tourism, agriculture, and forestry, and their resulting impacts on the environment. Thus, the adjacent Feohanagh, Milltown, and Owenmore catchments were analysed via three-minute kick-samples divided proportionally by substrata for macroinvertebrate community composition, in-situ physico-chemical measurements for water quality parameters, and CORINE classification of land use and land cover (LULC). The overall goal was to identify the effect of LULC on water quality using macroinvertebrates as bioindicators. The presence of sensitive or tolerant macroinvertebrates within a catchment in relation to variant environmental conditions is perhaps the most effective indicator in understanding the current health of the river. The three catchments were investigated at a catchment-scale to assess the effects of LULC on the macroinvertebrate communities. The detailed data of LULC effects could potentially be applicable to other rivers and simplify the efforts of Ireland's obligations set forth in the EU Water Framework Directive. The results of the study indicated that the variation of LULC, particularly pasture, had a significant negative effect on water quality and macroinvertebrate communities throughout the Milltown and Feohanagh catchments; and natural grassland appeared to have a positive effect throughout the Feohanagh catchment. All three catchments in the Dingle Peninsula were assigned a (Q3-4) quality rating, and therefore considered unsatisfactory, slightly polluted, and in terms of the Water Framework Directive (WFD) of 'moderate' status.

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Chapter 1: Introduction

1.1 Background

The use of macroinvertebrates to investigate the pronounced effects of land use and land cover (LULC) on the biodiversity of organisms and water quality of river channels is not a novel concept (Kelly-Quinn, Feeley and Bradley, 2020; Sarriquet, Delettre and Marmonier, 2006). In fact, it has been used in New Zealand (Boulton et al., 1997), the United States (Genito, Gburek, and Sharpley, 2002), and Finland (Heino, Muotka, and Paavola, 2003) to name a few, and is widely used by the Environmental Protection Agency (EPA) within Ireland. As described by the EPA, land use and land cover are connected due to the interaction of human activity on how the land is used (land use) with the environment and landscape (land cover). LULC are often measured as one because of their joint influence on water quality (Mello et al., 2018; Shi et al., 2016). Water quality of monitored river bodies within Ireland has decreased in recent years (O’Boyle et al., 2019; Trodd, O’Boyle, and Gurrie 2021). The decrease in water quality would be evident as changes to community structure via reduced sensitive species and increased tolerant species, the diminished function of ecological processes, and the limited ability to absorb shock from stressors (O’Boyle et al., 2019). It is important to note there have also been improvements in river water quality, though not to ‘satisfactory’ status. As such, there was a 1% net decrease of rivers with ‘satisfactory’ water quality in the most recent EPA assessment period (Trodd, O’Boyle, and Gurrie 2021). Further, the number of rivers with ‘satisfactory’ water quality has been continuously declining since the baseline assessment in 2007-2009 (O’Boyle et al., 2019). The decline, in the most recent EPA assessment period, has been attributed to pollutants entering the water system via agricultural practices and wastewater run-off, and physical damage to the aquatic environment (Trodd, O’Boyle, and Gurrie 2021).

Since 2018, there has been a 30% increase in water bodies influenced by either agriculture or hydromorphological alteration (Trodd, O’Boyle, and Gurrie 2021). Agriculture is the most prevalent land use throughout Ireland and is the greatest contributor of significant pressures to water quality (O’Boyle et al., 2019; Trodd, O’Boyle, and Gurrie 2021). The Common Agricultural Policy (CAP) aims to reduce the pressures agriculture inflicts on the surrounding water bodies and increase the national and international benefits of Irish agriculture. The policy has continually been amended since its inception, transitioning from financial support of farmers towards an environmentally sustainable approach towards agriculture (An Oifig Buiséid Pharlaiminteach, 2018). In designing CAP strategic plans, key EU laws on environmental policies, including the Nitrates Directive, the relevant components of the Water Framework Directive, and the Directive on the Sustainable Use of Pesticides will be considered (Directorate-General for Agriculture and Rural Development, 2022a). In its most recent update, the CAP was aligned with several of the objectives of the European Green Deal (Directorate-General for Agriculture and Rural Development, 2020). Presently, there is minimal information on the CAP’s direct influence on water quality within Ireland, however there is a no “back-sliding” policy, stressing the need for constant analysis and immediate improvement of all CAP measures (Directorate-General for Agriculture and Rural Development, 2022a).

Given the current situation in Ireland regarding the degradation of water quality, increased information on the effects of LULC on macroinvertebrate communities and thus water quality is vital. As a key component of the EU Water Framework Directive

(WFD), the European Union placed an emphasis on identifying catchment LULC and reducing the complementary pressures on river bodies (Water Framework Directive 2000/60/EC, 2000). This study will contribute to understanding the effect of LULC on macroinvertebrate communities in Ireland and inform the direction of future research in this area.

1.2 Bioindicators

In fulfilling the obligations set forth in the WFD, Ireland performs water quality monitoring using an array of indicators both biological and chemical (O’Boyle et al., 2019; Trodd and O’Boyle, 2020). These indicators show the current situation, recent changes, and long-term trends in environmental status and indicate the stressors causing changes (O’Boyle et al., 2019). Biological indicators, referred to simply and henceforth as bioindicators, have several beneficial properties making them advantageous to other indicator methods. For instance, bioindicators’ range of tolerances to certain biological, physical, or chemical stressors, make them useful in examining changes in environmental conditions (Stark and Maxted, 2007). In contrast to chemical and physical indicators which show the influence of stressors at the point of sampling, bioindicators have a temporal quality and reflect the environmental condition of their habitat over a substantial time period (Holt and Miller, 2011). Further, bioindicators show the accumulated influence of chemical pollutants and physical habitat changes as opposed to the analysis of a singular chemical or physical indicator (Holt and Miller, 2011). While there are several advantages to using bioindicators, it is important to note their limitations. It can be difficult to distinguish whether the displayed effects of bioindicators are due to natural environmental variability or the influence of an anthropogenic stressor (Holt and Miller, 2011; Toner et al., 2005).

1.2.1 Macroinvertebrates as Bioindicators

Macroinvertebrates are an effective bioindicator as they are relatively easy to collect and identify. In this study, freshwater macroinvertebrates were used to efficiently examine the effects that LULC can have on rivers. Macroinvertebrates are sensitive to changes in the river brought on by LULC and respond to environmental pressures in predictable ways. Analysis of the macroinvertebrate community is strongly correlated with river health (Feeley et al., 2011, Genito, Gburek and Sharpley, 2002; O'Boyle et al., 2019). Two orders of macroinvertebrates, Ephemeroptera and Plecoptera, are generally regarded as the most sensitive to pollution. Some families within those orders, as well as Odonata and close-cased Trichopterans, are less sensitive. The remaining taxa are all tolerant to degrees of pollution, though some more than others (Toner et al., 2005). A decrease in sensitive and an increase in tolerant taxa has been shown to occur in response to many anthropogenic pressures (Genito, Gburek and Sharpley, 2002; Feeley et al., 2011).

Increased habitat heterogeneity is often correlated to increased macroinvertebrate taxonomic richness (Heino, Muotka and Paavola, 2003; Kelly- Quinn, Feeley, and Bradley, 2020). Macroinvertebrate communities are influenced by physical habitat changes via channelisation, siltation, and sedimentation (Fehér et al., 2012) and pollution stressors such as excess nutrient concentration and altered water chemistry (Sarriquet, Delettre and Marmonier, 2006). Like other bioindicators, macroinvertebrate communities display the environmental condition of their habitat over a substantial period. However, temporal and spatial differences amongst macroinvertebrates from their long seasonal life cycles and preferred habitat can also be a hindrance in sampling (De Pauw, Gabriels, and Goethals, 2006).

1.3 Biotic Indices

Bioindicator taxa are sorted into groups according to their sensitivity or tolerance to an observed environmental condition, commonly pollution. Depending on the biotic index, protocols vary; generally, the abundance of taxa within each group for each sample site is observed and subsequently ranked into one of the categories defined within that biotic index (Abbasi and Abbasi, 2011). Biotic indices are regionally specific because they categorise the pollution tolerances of indigenous taxa (Abbasi and Abbasi, 2011; Stark and Maxted, 2007). An advantage to using biotic indices is the consolidation of a large set of raw macroinvertebrate community data (taxa and their corresponding abundances per site) into a singular value (Stark and Maxted, 2007). Several disadvantages of using biotic indices have been identified including the need for supplementary chemical and physical data when interpreting biotic indices, and that the index may not be sensitive enough to delineate minute pollution events (Abbasi and Abbasi, 2011).

1.3.1 The Irish Quality Rating System (Q-Value)

The Irish Quality Rating system (Q-value) is a biotic index that categorises macroinvertebrate taxa within a community into five categories, Group A-E (Appendix A). These categories represent taxa that are sensitive, less sensitive, tolerant, very tolerant, and most tolerant, respectively. The abundances of taxa, and their corresponding richness, within each of these groups are enumerated and a Q- value is assigned (Toner et al., 2005, Appendix B). Essentially, the Q-value system measures the deviation of samples from a pristine ‘reference’ condition. There are nine Q-values, ranging from Q5 to Q1. Higher Q-values indicate no or minimal pollution and as Q-values decrease the measure of pollution increases (Toner et al., 2005).

1.3.2 Current Q-Rating at the Study Sites

The EPA has reported on the three study catchments several times (Environmental Protection Agency, 2023a and 2023b). For clarity and relevance, only data collected within the last ten years is presented (Appendix C). Both sample sites at the Feohanagh River have displayed no change in ecological condition, and continuously maintain their 'high' and 'good' status (Environmental Protection Agency, 2023a; Appendix C). After Site A increased in 2016, ecological conditions at the Milltown River sample sites have remained consistent (Appendix C). Site B was satisfactory, displaying good ecological quality, Site A was assigned moderate quality, and Site C was assigned poor quality (Environmental Protection Agency, 2023b; Appendix C). Site D at the Owenmore River has always maintained satisfactory ecological condition however, the ecological quality decreased from 'high' to 'good' quality in 2021 (Environmental Protection Agency, 2023a; Appendix C).

1.4 Land Use and Land Cover

Land use and land cover (LULC), while inherently different, can have a synergistic influence on water quality. Land use is mutable, influenced by human activity, and defines the way in which land is used. Conversely, land cover is relatively constant and describes the physical surface of the land. Land cover can be analysed via satellite imagery and lends itself to classification via remote sensing (Ding et al., 2015). Though land cover is classified and quantified, both land use and land cover are often measured together because of their joint influence on water quality (Mello et al., 2018). Diminished ecological function and altered community structure are two of the many effects that certain types of LULC can have on water quality and on the biodiversity of floral and faunal species in the rivers receiving runoff from the land in the surrounding catchments (Hynes, 1975). When more rain falls than the land can absorb, the excess water ‘runs-off’ into the rivers; this water can carry nutrients, faecal coliforms, and sediment, potentially leading to nutrient enrichment and organic pollution (Hooda et al., 2000).

1.4.1 Effects of LULC on Irish Rivers

Ireland’s freshwater sources are under pressure from anthropogenic land uses and numerous rivers are influenced by more than one (O’Boyle et al. 2019). These land uses include forestry, urban run-off, and peat extraction. However, the most significant effects to Irish rivers are caused by agricultural practices and hydromorphological change (Trodd, O’Boyle, and Gurrie 2021).

Many studies have concluded that agriculture can have detrimental effects on the hyporheic (Boulton et al., 1997; Kibichii et al., 2015) and benthic zones of a river by elevating nutrients, particularly nitrate, leading to reduced taxon richness and abundance of macroinvertebrates (Sarriquet, Delettre and Marmonier, 2006), as well as increasing the possibility of eutrophication (Hooda et al., 2000). Point (livestock access) and diffuse (surface runoff) pollution introduce faecal matter into the water (Hooda et al., 2000). For example, Sarriquet, Delettre and Marmonier (2006) showed that in the Chenelais and Jumeliere Rivers in Northern Brittany, the effects of agriculture at the catchment scale were associated with increased nitrate concentration, and at the habitat scale by vegetative growth, sediment clogging, and riparian vegetation trampling by cows. Regardless of scale, intensive agriculture has been linked to decreased regional diversity of macroinvertebrate communities (Kelly-Quinn, Feeley and Bradley, 2020).

The effects of hydromorphological change can be expected to interrupt river continuities, alter sediment composition and transport, and lead to siltation, thus diminishing habitat heterogeneity (Fehér et al., 2012). These effects ultimately lead to a decrease in sensitive taxa, an increase in tolerant taxa, and homogenization of macroinvertebrate communities (Genito, Gburek, and Sharpley, 2002; Kelly-Quinn, Feeley and Bradley, 2020).

1.4.2 Additional Effects of LULC on the Study Catchments

In contrast to the other two study catchments, the Feohanagh River was classified as not at risk of significant pressures (Environmental Protection Agency, 2021a). However, in addition to agriculture and hydromorphological alteration, forestry was a significant pressure throughout both the Milltown and Owenmore catchments, in addition to urban run-off at the former and peat extraction at the latter (Environmental Protection Agency, 2021a; 2021b). Forestry, on acid-sensitive geology, is known to cause acidification in rivers leading to reduced diversity and reduction of acid-sensitive taxa, such as Ephemeroptera and Coleoptera (Kelly- Quinn et al., 2016; Tierney, Kelly-Quinn, and Bracken, 1998). County Kerry is regarded as an acid-sensitive area, where water bodies are more likely to be impacted by acidification (Environmental Protection Agency, 2019). However, as stated in Tierney, Kelly-Quinn, and Bracken (1998) and Giller and O’Halloran (2004), Ireland’s geology and low-levels of atmospheric pollution may negate this generally known effect. Further, there has been some indication that rivers in Munster, in the south of Ireland, have no obvious relationships between forest cover and stream acidity, and that macroinvertebrate communities were more likely influenced by physical factors rather than chemical (Giller and O’Halloran, 2004). Similarly, in Feeley et al., 2012, several streams in County Kerry were analysed and no forest cover effects on stream water pH were identified during base flow conditions. Thus, siltation, sedimentation, the release of excess nutrients, and altered stream flow regime are the commonly accepted impacts of forestry on water quality in Ireland (Environmental Protection Agency, 2019; O’Boyle et al., 2019).

Peat extraction can hydromorphologically alter rivers (WFD Application, 2018; 2019), and similarly to other previously mentioned pressures, cause excessive sedimentation, increased erosion rates, and siltation (O’Boyle et al., 2019). Nutrient loss to the water has also been identified as an effect of peat extraction and can cause elevated concentrations of nutrients in river bodies (Environmental Protection Agency, 2021a; O’Boyle et al., 2019). The final pressure acting on the study catchments, urban run-off, is generally regarded as indirect discharge of nutrients from misconnections and leakage of sewers (O’Boyle et al., 2019).

Both the Milltown and Owenmore Rivers were selected as Areas for Action in River Basin Management Plan (RBMP) 2018-2021. Designation as an ‘Area for Action’ ensures Local Catchment Assessments must occur to discover how and why water quality is deteriorating or not meeting its water quality target. The Milltown River was selected for many factors including its importance for tourism, its small, manageable area, and its discharge into Dingle Harbour (Environmental Protection Agency, 2021b). Whereas the Owenmore River was selected for failing protected area objectives for the Freshwater Pearl Mussel, for its importance to salmonid fisheries and tourism, and its decline in ecological condition (Environmental Protection Agency, 2021a).

1.5 Water Quality Analyses of the Study Catchments

Water quality parameters were tested at the study catchments in July, six weeks prior to the present study. Sampling occurred at an upper and lower stretch of each of the three rivers. At both Feohanagh and Milltown, the lower study sites generally had higher values of each of the water quality parameters than their respective upper sites (Appendix D). Also, there were elevated concentrations of nitrate and total coliforms at both sites of Milltown and lower Feohanagh, and elevated *Escherichia coli* at both respective lower sites (Appendix D). These water values displayed differences in water quality within and between the study rivers. This information further necessitates this present study to identify what LULC may be influencing the water quality of the three catchments using macroinvertebrate communities as bioindicators.

1.6 Legislation and Policy

There are several environmental legislations currently in effect, working to not only protect the environment's intrinsic value but aimed to improve it. These legislations include but are not limited to the Water Framework Directive (WFD), the Common Agricultural Policy (CAP), and the European Green Deal. The WFD sets direct policy on the health and management of European waterways. Whilst the CAP and EU Green Deal target agricultural productivity and climate neutrality respectively, they simultaneously influence water quality in their efforts to maintain rural areas and sustainable management of natural resources (An Oifig Buiséid Pharlaiminteach, 2018; Communication 2019/640/EC, 2019).

1.6.1 Water Framework Directive

The WFD is a key piece of environmental legislation agreed upon in 2000, by all European Union States, and was implemented into Irish law in 2003. The WFD was generated in response to the growing concern for environmental sustainability and aims to evaluate and mitigate potential threats to biodiversity and water quality while preventing future pressures from arising (Daly et al., 2017; Kristensen et al., 2018; Vörösmarty et al., 2010; Water Framework Directive 2000/60/EC, 2000). The primary goal of the WFD was for surface water and groundwater in all member states to achieve ‘good,’ or better, water quality status by 2015 and to maintain that status (Water

Framework Directive 2000/60/EC, 2000). The characterisation of ecological status is based on the overall ecological condition of surface waters, or more relevant to this study, a river's biological, hydromorphological, and physicochemical deviation from its original, undisturbed condition. The undisturbed (reference) condition was established in the first cycle of the River Basin Management Plan (RBMP) (Water Framework Directive 2000/60/EC, 2000). Annex V, of the document, describes the ecological classification categories as ‘high,’ ‘good,’ ‘moderate,’ ‘poor,’ or ‘bad,’ where the deviations from undisturbed are none or few, low, moderate, major, or severe, respectively (Water Framework Directive 2000/60/EC, 2000).

One of the main benefits of the WFD was the creation of a more succinct, uniform legislation for all member states. Albeit the combination of pressures affecting each EU state is unique to that area, the WFD encourages each member state to use methods attuned to local conditions to succeed in achieving ecological quality (Kristensen et al., 2018; Water Framework Directive 2000/60/EC, 2000). Within Ireland, not all rivers and other surface water bodies were able to achieve ‘good’ water quality status by 2015. The second cycle RBMP, which ran from 2018 to 2021, attributed this failure to multiple river basin districts (RBDs), where arranging and implementing plans was ineffective; unsuccessful governing structure; and goals set which were too ambitious and not evidence based (Department of Housing, Local Government, and Heritage (DHLGH), 2018). Therefore, in the second cycle RBMP the “Irish River Basin District” was established unifying Ireland into one river basin; coordination between the national, regional, and local structures was increased; and goals were designed with evidence-based successes that are ‘ambitious but achievable’ (DHLGH, 2018). While improving water quality is a major goal of the WFD, so is the maintenance of already high-status waters; thus, the Blue Dot Catchment Programme was created.

The third cycle RBMP recently concluded its consultation phase and is set to run from 2022-2027. The draft currently highlights 'the right measure in the right place' by using the most up to date scientific information, increasing ambition; collaboration; and catchment planning (Department of Housing, Local Government, and Heritage (DHLGH), 2021).

1.6.2 Common Agricultural Policy

The Common Agricultural Policy (CAP) was established in 1962 as a shared policy for all European countries. The primary goals of this policy are widespread and cover reasonable living wages for farmers, a steady supply of affordable food, sustainable management of natural resources and rural areas, assistance in targeting climate for Agriculture and Rural Development, 2022). It is the inherent struggle of farmers to find the sustainable balance between food production and protection of nature and biodiversity, that necessitates such an all-encompassing policy. It is especially pertinent in Ireland, where agriculture affects 53% of water bodies (O'Boyle et al., 2019). This challenge has led to many updates to the CAP, most recently in December of 2021, with the 'New CAP' commencing in January 2023. The goals of the policy specifically targeting the environment are environmental protection, preservation of landscapes and biodiversity, and climate change action (An Oifig Buiséid Pharlaiminteach, 2018). Targets of the new CAP were developed to achieve the goals set forth in the European Green Deal (Directorate-General for Agriculture and Rural Development, 2020).

1.6.3 European Green Deal

The Green Deal details a sustainable and environmentally driven initiative across multiple sectors of daily life including construction, economics, mobility, and food supply and production (Communication 2019/640/EC, 2019). This legislation is ambitious, extensive, and designed to preserve and improve the environment. Nutrient management is a key component of this policy and is addressed via eco- schemes and the ‘Farm to Fork’ strategy. Farmers are financially incentivised to improve their environmental practices, in part, by improving nutrient management and reducing emissions (Communication 2019/640/EC, 2019). ‘Farm to Fork’ is described as the global standard of sustainability. It identifies pollution to water bodies as a result of food production, as a contributor to the loss of biodiversity and concludes that implementation of this strategy will reduce pollution from excess nutrients and restore and preserve biodiversity in rivers (Communication 2019/640/EC, 2019).

1.6.4 Nitrates Directive

The Nitrates Directive was established with the goal of reducing nitrate pollution from agricultural sources to prevent further pollution (Council Directive 91/676/EEC, 1991). This directive is especially pertinent in Ireland, as agriculture is the most prevalent land use, and nutrient pollution has the most deleterious influence on water quality (O’Boyle et al., 2019). A code of good agricultural practice was designed to reduce pollution by setting strict mandates on fertiliser application, land management, and strict regulation of storage vessels for livestock manure (Council Directive 91/676/EEC, 1991). All EU member states must draft Nitrate Action Programmes (NAP). Ireland’s NAP must be revised at least every four years and is designed to prevent pollution and protect and improve water quality (Department of Housing, Local Government, and Heritage (DHLGH), 2023). Improved water protection is described in the 2018-2021 NAP, via intercepting and breaking nutrient transport pathways and preventing sediment and nutrient losses to waters (DHPLG, 2018). Revisions to NAPs ensure improved compliance with 'Good Agricultural Practice' (DHLGH, 2018).

1.6.5 Local Policy for the Study Sites

The Dingle Peninsula attracts large numbers of tourists, and the influx of people and industry has helped the economy flourish. According to the 2016 census, the peninsula has a resident population of 14,181 (An Phríomh-Oifig Staidrimh, 2022), and tourism accounts for approximately 30% of the economy (McGookin, Caoimh and O'Hara, 2021). Tourism is so important to the region that the Dingle Peninsula Visitor Experience Development Plan (VEDP) was created to support the further development of year-round tourism across the entire peninsula, and consequently stimulate the economy (Fáilte Ireland, 2020). The increased presence has caused significant stress to the landscape via alterations to site features, heavy littering and dumping of wastes, and disturbance to wildlife (CAAS Ltd., 2020). The VEDP has also indicated a stress on wastewater and drinking water management. While the VEDP notes the increase in tourism has potential to disrupt the local environment, it also addresses the possibility of environmental enhancement through sustainable tourism (Fáilte Ireland. 2020).

Due to land use and land cover's known effects on the biological, chemical, and physical parameters of a river, an analysis of the comparable Feohanagh, Milltown, and Owenmore catchments should distinguish the LULC types imposing pressures on the rivers. The three catchments exhibit differences that may allow investigations of macroinvertebrate communities to exemplify the effect of anthropogenic pressures on freshwater quality and overall ecosystem health.

1.7 Aims and Objectives

The overall objective of the study was to identify the types of catchment-wide LULC associated with water quality values in the Feohanagh, Milltown, and Owenmore Rivers using macroinvertebrate taxa as bioindicators. In addition to macroinvertebrate community analyses, river health was assessed via the water's physico-chemical parameters. Land use and land cover in the three catchments were classified, quantified, and subsequently analysed in conjunction with the macroinvertebrate community data.

Chapter 2: Materials and Methods

2.1 Overview

Sampling was conducted in the Feohanagh, Milltown, and Owenmore Rivers in County Kerry, in the southwest region of Ireland (Figure 1). The river basins whose land area drains into each of the three study rivers, are henceforth entitled Feohanagh, Milltown, and Owenmore catchments. These catchments are particularly appropriate for this type of comparative study due to their adjacent borders, similar areas, and similar potential discharge. The Feohanagh and Owenmore catchments have similar areas of 30.42 km^2 and 29.49 km^2, maximum elevations of 936 and 943 m, with potential average annual discharges of approximately 1.19 m^3/s and 1.43 m^3/s, respectively (Rapaglia, 2019). The Milltown catchment encompasses an area of 28.75 Km2, with a maximum elevation of 680 m, and a potential average annual discharge of about 1.04 m3/s (Rapaglia, 2019).

In September of 2020, the Feohanagh, Milltown, and Owenmore catchments were studied by analysing macroinvertebrate communities, water quality parameters, and upstream land use/land cover (LULC) at fifteen sites per river (Figure 2). The aim was to investigate the catchments using the sample sites to gain a more definitive idea of the influence of environmental effects on macroinvertebrate communities and thus river health.

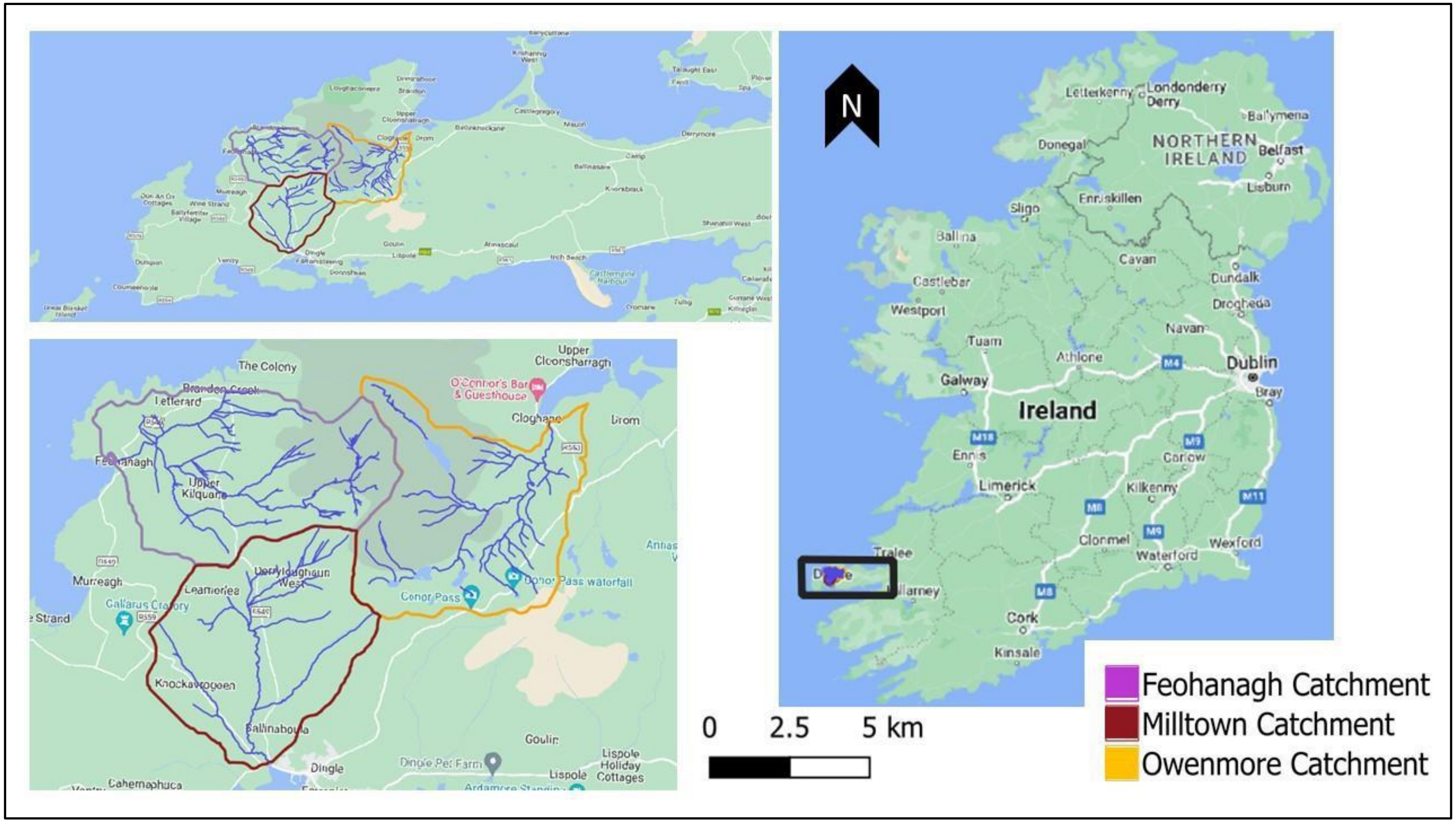


Figure 1. Feohanagh, Milltown, and Owenmore study catchments on the Dingle Peninsula, in the southwest corner of Ireland. (Generated in QGIS 3.4 Madeira). River vectors sourced from https://gis.epa.ie/GetData/Download [Accessed on Feb. 7, 2022] Displayed on Google Maps.

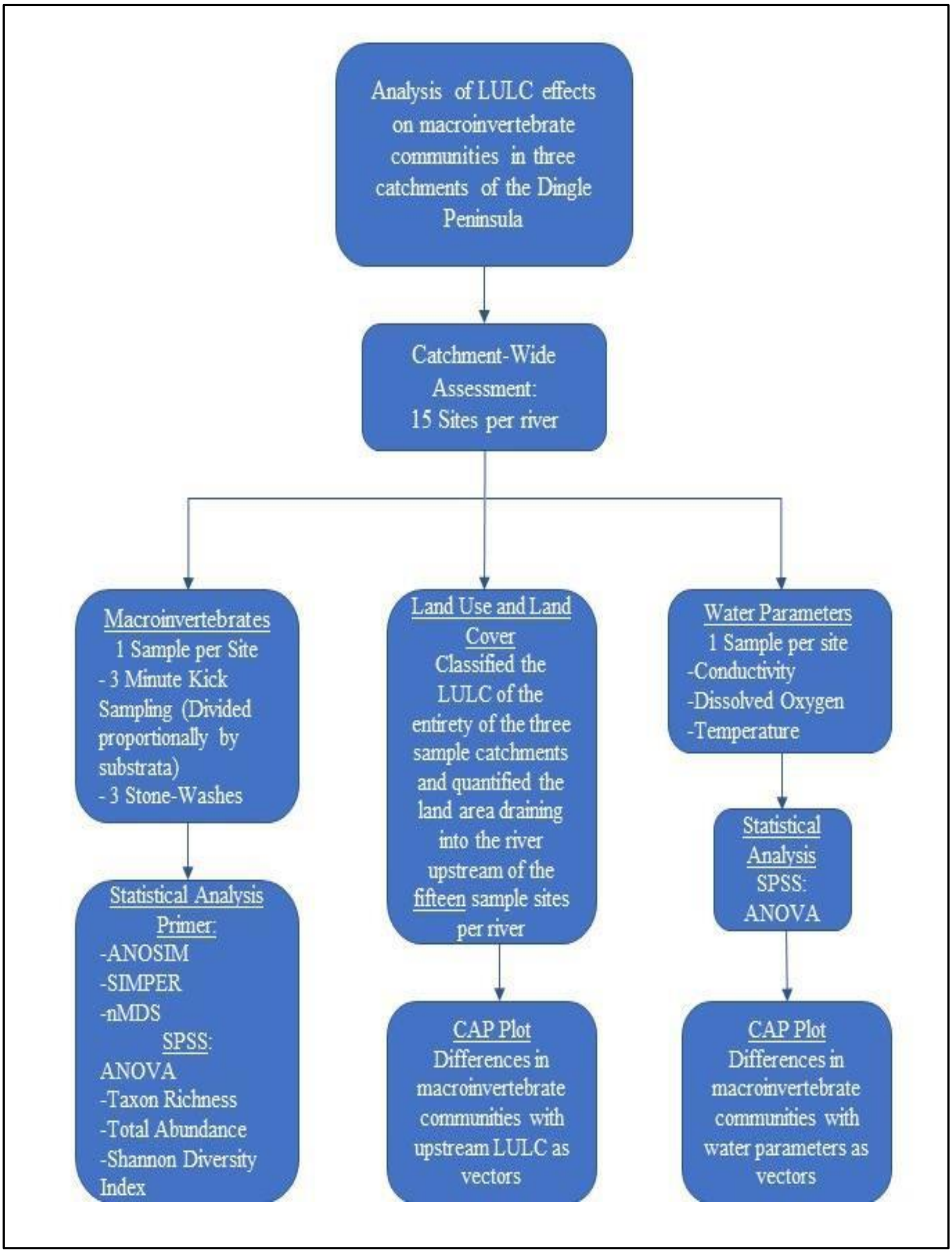


Figure 2. Schematic of the study design.

2.2 Study Site Descriptions

Fifteen sample sites were selected throughout each of the Feohanagh (Figure 3), Milltown (Figure 4), and Owenmore (Figure 5) Rivers (n=45). The Feohanagh River originates in the valley between Mount Brandon and Folach na Marbh (Ordnance Survey Ireland, 2015). The Milltown River runs towards Dingle town and empties directly into Dingle Harbour (Environmental Protection Agency, 2021b; Ordnance Survey Ireland, 2015). The Owenmore River lies in the valley between Slievenea and Mount Brandon (Ordnance Survey Ireland, 2015). The sample sites were selected to represent as many tributaries as possible, and substrata varied throughout the forty-five total sites (Appendix E).

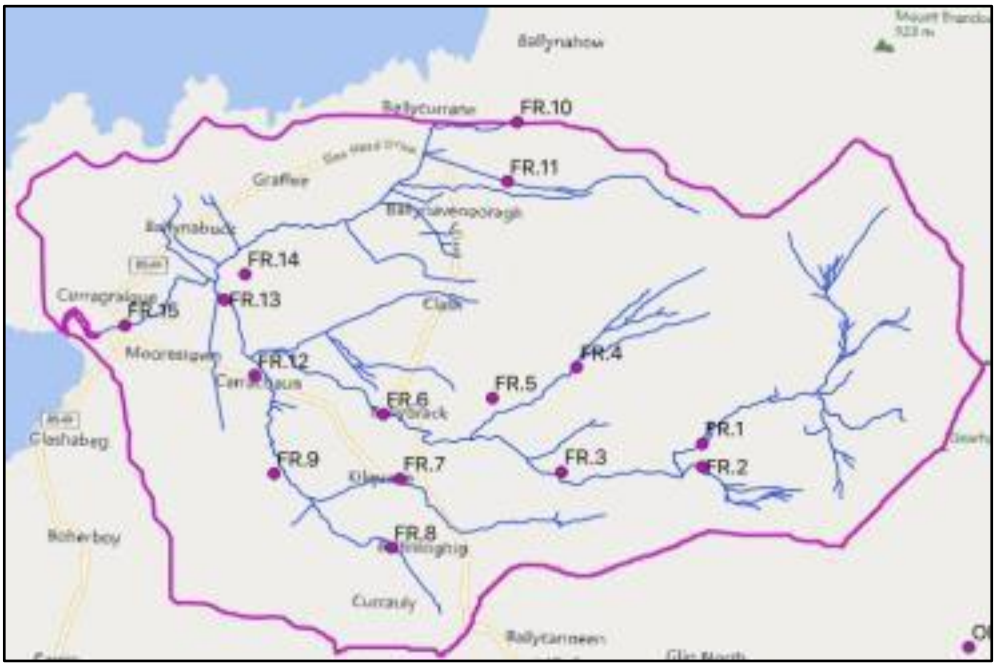


Figure 3. Fifteen sample sites of the Feohanagh River. (Generated in QGIS 3.4 Madeira). River vectors sourced from https://gis.epa.ie/GetData/Download[Accessed on Feb. 7, 2022] Displayed on 'Bing Map.'

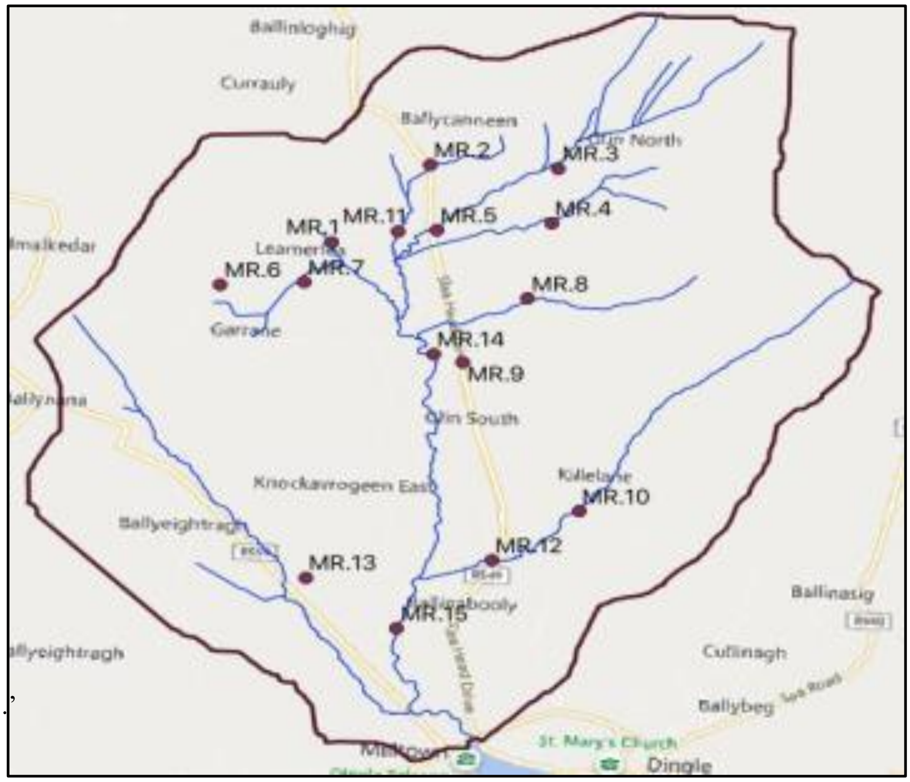


Figure 4. Fifteen sample sites of the Milltown River. (Generated in QGIS 3.4 Madeira). River vectors sourced from https://gis.epa.ie/GetData/Download [Accessed on Feb. 7, 2022] Displayed on 'Bing Map.'

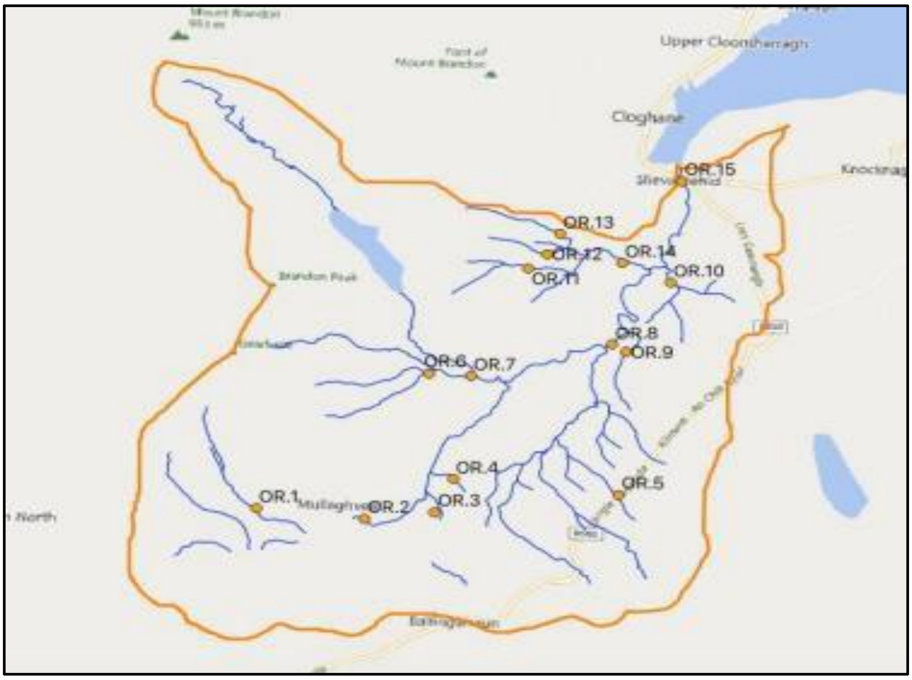


Figure 5. Fifteen sample sites of the Owenmore River. (Generated in QGIS 3.4 Madeira). River vectors sourced from https://gis.epa.ie/GetData/Download [Accessed on Feb. 7, 2022] Displayed on 'Bing Map.'

2.3 Macroinvertebrates

2.3.1 Macroinvertebrate Collection

Macroinvertebrate collection occurred within a two-week period in September 2020. While all efforts were made to minimise the length of time between samplings, the primary goal was to ensure environmental conditions were similar between sample sites and were suitable for sampler safety. Using a 500 µm mesh kick net, positioned downstream of flowing water, one sample was collected per site. Kick-samples were conducted for a total of three minutes. To capture the most diversity possible within each sample site, sampling was divided proportionally by the percentage of the varying substrata present. Where possible, sampling was conducted in riffle zones as these areas support sensitive species of macroinvertebrates (McGarrigle, 2020; Toner et al., 2005). To maximise the possibility of capturing all organisms present at the site, stone washing was conducted. Three stones, approximately 75-100mm in diameter, per sample were rinsed into the net and wiped for a total of one minute. Standard procedures for stone-washing were followed as per McGarrigle (2020), except at sample sites where a 75-100 mm stone was not present, such as the 100% bedrock of MR.2 and the 100% silt of MR.6. In cases such as these, bedrock or boulders were wiped, a smaller stone was ‘stone washed,’ or when not possible, stone washing did not occur. Organisms from the kick net and stone washing were immediately stored in a pre-labelled jar and preserved *in situ* with 70% Isopropyl Alcohol.

2.3.2 Macroinvertebrate Identification

The macroinvertebrates remained in the 70% Isopropyl Alcohol jars until they were processed. A few drops of 1g/100ml Rose Bengal were squirted into each of the sample jars to dye the organisms a distinctive pink colour and make them more easily distinguishable from other organic material (Starling, 1971). Just prior to identification the sample was drained of alcohol and replaced with clean freshwater. Samples were then analysed under the microscope in clean Petri dishes, and macroinvertebrates were separated from the organic stream material. Using keys from the Freshwater Biological Association (Dobson et al., 2012; Edington and Hildrew, 1995; Elliott, Humpesch and Macan, 1988; Hynes, 1993; Wallace, Wallace and Philipson, 2003) and *A key to the major groups of British freshwater invertebrates* (Croft, 2012), organisms were identified and segregated to the lowest practical taxonomic level. Due to time constraints, the lowest identifiable level was generally family, however, *Ecdyonurus, Amphinemura, Protonemura, Dinocras* and *Wormaldia* were identified to the genus level and *Philopotamus montanus and Chimarra marginata* were further identified to the species level. The Oligochaeta taxa were only identified to subclass. Macroinvertebrate identification was validated by project supervisors.

2.3.3 Macroinvertebrate Statistical Analysis

Catchment-wide macroinvertebrate data were culled in an adapted version of McCune and Grace (2002). Taxa displaying <3% abundance in any one sample were removed, unless that taxon was present in at least three samples within the same catchment.

Primer (ver. 7) and SPSS (ver. 25) were used for all statistical analyses. In all statistical testing, 0.05 was the accepted significance level.

2.3.3.1 Abundance and Diversity

Total macroinvertebrate abundance, taxon richness, and Shannon diversity index values (generated by Primer ver. 7) were calculated for each of the forty-five sample sites, then were compared among catchments in SPSS (ver. 25). Shapiro- Wilk tests of normality and Levene's test of homogeneity of variance were conducted to determine the most appropriate statistical test for comparison. Values analysed for all sites were normally distributed, though abundance did not meet the assumptions for homogeneity of variance. Thus, the abundance data was log(10) transformed to correct for non-homogenous variance. Three analyses of variance (ANOVAs) were conducted to compare taxon richness, Shannon diversity index, and log(10) transformed abundance among catchments. To reduce the chance of errors induced by multiple tests, when necessary, Bonferroni-corrected significance values were reported.

2.3.3.2 Multivariate Analyses

In PRIMER (ver. 7), the raw macroinvertebrate community data were transformed to the fourth-root to reduce the magnitude of influence of large differences between sample values (Clarke and Ainsworth, 1993). The macroinvertebrate community data were multivariate and were analysed as per Anderson and Willis (2003) and Clarke (1993). A resemblance matrix, measuring Bray-Curtis similarities between samples, was generated using the fourth root transformed data. Null values were replaced with a "dummy variable" with a value of 1 (Clarke and Ainsworth, 1993) to successfully conduct a one-way Analysis of Similarity (ANOSIM) test of the factor "catchment."

Similarity Percentage (SIMPER) was run on the transformed data to determine which taxa drove the differences observed in the ANOSIMs. The design of the SIMPER analysis was based on one-way Bray-Curtis Distance similarity measures, and the cut-off for low contributing taxa was set at 70%. Using the resemblance matrix, a non-metric multidimensional scale (nMDS) ordination was generated to visualise differences in the macroinvertebrate communities among sites. The 3D nMDS plot was displayed as opposed to the 2D, as the stress was lower, making it a better representation of the relationships between samples (Clarke and Ainsworth, 1993).

2.3.4 Quality Rating System

The Quality Rating system (Q-Value) was used to categorise taxa into groups (A-E), ranging from sensitive to most tolerant. While the majority of the percentages of organisms for categorisation are outlined (Toner et al., 2005), some descriptions are subjective. Thus, 'reasonable' was viewed as 1-5 organisms and 'well represented' was >5. Using these values as a guideline, Q-values were established for all sample sites, and all catchments.

As the macroinvertebrate communities were generally identified to the family level there was no distinction between *Baetis rhodani* from all other Baetidae. For the majority, the abundance of organisms in the varying groups, regardless of the Baetidae taxa, led to a clear determination of Q-value. To test the validity of this conclusion, two Q-values were established. The first assumed all Baetidae were *Baetis rhodani* and were classed in Group C, the second assumed none of the Baetidae were *Baetis rhodani* and classed them all in Group B. The Q-values only differed in 4 of the 45 samples, and in these four cases, the Q-value was selected based on those in the surrounding sample sites.

For statistical analysis, Q3-4 was input as a value of 3.5. Using SPSS, Shapiro-Wilk tests of normality and Levene's test of homogeneity of variance were run and assumptions were not met. Thus, Kruskal-Wallis tests were conducted, and where necessary, pairwise comparisons were assessed, and Bonferroni-adjusted significance values were reported. All sample sites for each catchment were averaged. These values were rounded to the nearest Q-value. Averages between 3 and 3.33 were Q3, between 3.34 and 3.66 were Q3-4, and between 3.67 and 4 were Q4.

2.4 Land Use and Land Cover Classification

2.4.1 Establishing Study Catchments

There are pre-established shapefiles of the Feohanagh, Milltown, and Owenmore catchments available through the EPA Geoportal, however for the purpose of the study, a more detailed shapefile of each of the catchments, eliminating areas flowing into the river below the sample sites, was necessary. Thus, ‘Height’ data in the form of a Digital Terrain Model (10m resolution, accuracy of elevations to ±3m) was acquired from Ordnance Survey Ireland. Using these data, and QGIS (Madeira ver. 3.4.15) a Digital Elevation Model (DEM) was generated by the following steps. The Fill Sinks (Wang and Lu, 2006) tool was used to remove surface depressions (values <0) to establish flow path directions. The Strahler order and ‘channel network and drainage basins’ functions were used to create a river channel within the catchments.

The desired Feohanagh, Milltown, and Owenmore catchments’ shapefiles were then delineated using the Upslope Areas function within QGIS (Madeira ver. 3.4.15). This function identifies the land area draining into a singular, selected pixel along the generated river channel. To establish the Feohanagh, Milltown, and Owenmore catchments, the singular pixel at the mouth of the river was selected. This process was performed three times to establish each of the catchments.

Land use and land cover (LULC) classification of the Feohanagh, Milltown, and Owenmore catchments was performed using the 2018 CORINE Land Cover database (Corine Land Cover, 2019) and QGIS (Madeira ver. 3.4.15). The CORINE database has an inventory of 44 land cover classes, downloadable as vector files. The CORINE classification database is applicable to remote sensing and this technique has been used in several studies to increase knowledge of the surrounding LULC and reduce field sampling time (Donohue, McGarrigle, and Mills, 2006; Kelly-Quinn et al., 2003). The CORINE database files were cut to the generated catchments, and the CLC legend was applied. The LULCs (km^2) of the study catchments were thus classified and enumerated. Visits to the fifteen sample sites per catchment ensured that each of the catchment's LULC was ground truthed. The LULC values from the classification were used to calculate percent cover and were summarised in Excel.

2.4.2 LULC of Upstream Areas of Sample Sites

To determine the land area draining into the river upstream of each of the sample sites, the Upslope Area function was used. In contrast to before, the selected pixel along the generated river channel was each of the individual sample sites. If successful, this process established the land area draining into the sample sites. However, the river channel file created from the DEM was not as detailed as the EPA's 'Geometric River Network' file and did not include many of the small tributaries which were sampled. In cases where the coordinate of the sample site did not line up with the river channel generated from the DEM, the Upslope Area function could not be used, and a polygon of the upslope area was created by an alternate method. These sample sites were revisited to visualise the area onsite prior to drawing a representative polygon. To draw the polygon a 5m contour was overlaid on the OSM standard (©OpenStreetMap contributors). Following the curvature of the contour overlay, the polygons were drawn from the sample site, to delineate the area indicated by the contour lines that lay within the catchment and was upslope of the sample site. The LULC of these upslope areas and those generated with the Upslope Area function were then classified from the CORINE database and percent cover was calculated. LULC assignment in the upslope areas of the sample sites was verified by both visual assessment of the upslope areas at the sample sites and examination of Ordnance Ireland Orthophotos.

CORINE classifications' 'Sea and Ocean' and 'Intertidal Flats' were removed from analyses, since their percent cover was low (<0.01%) and all sample sites were upstream of these areas. Most of the CORINE LULC classification titles are reasonably self-explanatory, however some can benefit from further clarification as follows: within the Updated CLC illustrated nomenclature guidelines, "land principally occupied by agriculture, with significant areas of natural vegetation" henceforth referred to as 'Agriculture w/ Sig. Veg.' describes "land predominantly consisting of agriculture with significant patches of natural or semi- natural areas" (Kosztra et al. 2017). Likewise, 'sparsely vegetated areas' represents "areas with sparse vegetation in which herbaceous, ligneous, or semi-ligneous vegetation covers 10-50% of the surface area" (Kosztra et al. 2017).

2.4.3 Canonical Analysis of Principal Coordinates for LULC

Using PRIMER (ver. 7), a canonical analysis of principal coordinates (CAP) was performed to correlate the effect of LULC on the macroinvertebrate communities (Anderson and Willis, 2003). Similarly to the macroinvertebrate data, the percentage cover of upstream LULC data were transformed to the fourth-root. The CAP plot shows differences in macroinvertebrate communities with Pearson's correlations to upstream LULC shown as vectors. Vectors with correlation coefficients >0.2 were displayed to reduce clutter and emphasise LULC making significant contributions to differences between catchments.

2.5 Water Quality

Water analyses were performed concurrently with macroinvertebrate sampling at each of the fifteen catchment-wide sites per river. Water was tested for physical parameters, *in situ*, one value per site. Conductivity, temperature, and DO were the only physical parameters measured at these sites due to time, effort, and available equipment limitations as well as the fact that the main focus was on the LULC relationship to macroinvertebrate community composition.

2.5.1 Collection of Water Parameters

A single measurement of conductivity, dissolved oxygen (DO), and temperature were collected *in situ*, using the Hach HQd Portable Meter, HACH Conductivity CDC401, and HACH Luminescent Dissolved Oxygen LDO101 Probes (HACH Company, Loveland, CO, USA). Probes were calibrated before each use and manufacturer operating procedures were followed.

2.5.2 Water Parameters' Statistical Analysis

Water quality parameters at each of the forty-five sample sites were compared among catchments in SPSS (ver. 25). The water quality parameters: conductivity, DO, and temperature did not meet the assumptions for normality or homogeneity, so Kruskal-Wallis tests were performed. The accepted significance level was 0.05, and in the case of multiple, pairwise comparisons, SPSS-generated Bonferroni-adjusted significance values were used.

2.5.3 Canonical Analysis of Principal Coordinates for Water

The water data were also transformed to the fourth-root using PRIMER (ver.7), and again a canonical analysis of principal coordinates (CAP) was performed to correlate the effect of water quality parameters on the macroinvertebrate communities (Anderson and Willis, 2003). The CAP plot shows differences in macroinvertebrate communities with Pearson’s correlations to water quality parameters shown as vectors. As before, vectors with correlation coefficients >0.2 were displayed.

Chapter 3: Results

3.1 Macroinvertebrate Communities

Prior to data culling as per the modified version of McCune and Grace (2002), and subsequent analysis, there were 52 taxa identified (Table 1). Taxa were primarily identified to the family level, with exceptions previously stated (2.3.2).

Both the Feohanagh and Milltown catchments showed a range of total abundances at their respective sample sites. The Feohanagh catchment displayed abundances ranging from 61 to 616, and abundances from the Milltown's sample sites ranged from 35 to 932. In contrast, sample site abundances in the Owenmore catchment were more homogenous, with abundances ranging from 41 to 313 (Appendices F; G; H). The strong variation is suggestive of an influence on the macroinvertebrate communities at varied sample sites of Feohanagh and Milltown. Analysis of variance (ANOVA) was conducted to test for significant differences between the macroinvertebrate communities of the three study catchments. The one-way ANOVA indicated no significant differences in taxon richness ($F_{2,42}$= 3.038, p=0.059), overall abundance ($F_{2,42}$=2.536, p=0.091) or Shannon diversity index ($F_{2,42}$=1.910, p=0.161) between the three catchments' macroinvertebrate communities.

Table 1. Summary of the taxa observed during the study, throughout the Feohanagh, Milltown, and Owenmore catchments.

Ephemeroptera	**Plecoptera**	**Trichoptera**	**Gastropoda**
Baetidae	*Amphinemura*	Hydroptilidae	Planorbidae
Ecdyonurus	Perlodidae	Hydropsychidae	Hydrobiidae
Caenidae	Leuctridae	Leptoceridae	Lymnaeidae
Heptageniidae	*Protonemura*	Glossosomatidae	Prosobranchia
Ephemerellidae	*Dinocras*	Limnephilidae	**Bivalvia**
unidentified	unidentified	*Wormaldia*	Bivalvia
Diptera	**Coleoptera**	*Philopotamus montanus*	**Hemiptera**
Ceratopogonidae	Elmidae	*Chimarra marginata*	Veliidae
Chironomidae	Chrysomelidae	Polycentropodidae	**Oligochaeta**

Table 1. Continued.

Simuliidae	Dytiscidae	Rhyacophilidae	Oligochaete 1
Dixidae	Gyrinidae	Sericostomatidae	Oligochaete 2
Tipulidae	Dryopidae	unidentified	Oligochaete 3
Hirudinea	Scirtidae	**Lepidoptera**	Oligochaete 4
Hirudinea	**Acari**	Crambidae	Lumbricidae
Amphipoda	Acari	**Odonata**	**Isopoda**
Gammaridae		Coenagrionidae	Asellidae

3.1.1 Macroinvertebrate Community Structure

Analysis of similarities (ANOSIM) showed significant dissimilarity between macroinvertebrate community composition across the three catchments (Global r=0.152, Global p= 0.001). However, the relatively low R-value indicates there were no strong differences between the macroinvertebrate communities. The ranked dissimilarity matrix showed greater differences in community composition between the Owenmore and Feohanagh catchments (r=0.232, p= 0.001) than between the Owenmore and Milltown catchments (r=0.178, p= 0.003). The Feohanagh and Milltown catchments did not have significantly different macroinvertebrate communities. Consistent with these results, visualisation of the non-parametric data via nMDS showed how the macroinvertebrate community composition from the Owenmore differed from the Feohanagh and Milltown catchments (Figure 6).

Baetidae and Elmidae are less sensitive and tolerant to pollution, respectively, and made up the majority of the macroinvertebrate communities at the sample sites throughout the Feohanagh catchment. Baetidae dominated most of the sample sites in the upper stretches of the river, whereas Elmidae dominated sample sites in the middle and lower stretches of the river (Appendix F). Two sample sites within the Feohanagh catchment had ‘sensitive’ *Dinocras*. Other ‘sensitive’ taxa were also present in several sample sites in the upper stretches of the river (Appendix F). The presence of these taxa indicates that water quality in the upper stretches of Feohanagh was ‘high’ quality and may not be as influenced by the stressors.

Sample sites within the Milltown catchment were also dominated by Baetidae and Elmidae. The majority of the macroinvertebrate communities at the sample sites in the middle and lower stretches of the river were made up of Baetidae and Elmidae, respectively (Appendix G). Hydrobiidae, Simuliidae, Bivalvia, and Chironomidae were the other taxa that were predominant at the Milltown sample sites (Appendix G). All taxa that dominated the sample sites in the Milltown catchment were tolerant to varying levels of pollution. Asellidae, a ‘very tolerant’ taxon was also only present within this catchment. In contrast to Feohanagh, the macroinvertebrate communities of Milltown indicate reduced water quality and suggest a negative pollution influence.

Baetidae, Elmidae, and Simuliidae dominated a majority of the macroinvertebrate communities at the sample sites of the Owenmore catchment (Appendix H). Gammaridae and Hydrobiidae were each predominant at one Owenmore sample site (Appendix H). The majority of these predominant taxa are tolerant to pollution. Coenagrionidae was exclusively identified at one site in the Owenmore catchment, making up nearly 20% of the macroinvertebrate community at OR.4 (Appendix H).

Macroinvertebrate communities clearly differed between the three catchments as only Feohanagh could support the ‘sensitive’ *Dinocras* and Milltown had the only presence of the ‘very tolerant’ Asellidae. Analysis of similarity percentage (SIMPER) showed the average dissimilarity between Feohanagh and Milltown was 51%, Feohanagh and Owenmore was 53%, and Milltown and Owenmore was 52% (Appendix I). Baetidae, Elmidae, and Hydrobiidae were the three primary taxa driving the dissimilarity between the catchments (Table 2). This suggests there may be a positive influence on water quality at the Feohanagh catchment and a negative influence at Milltown. However, SIMPER also showed the average similarities of the Feohanagh, Milltown, and Owenmore catchments were 51%, 51%, and 52%, respectively (Table 2). Baetidae, Elmidae, Gammaridae, and Chironomidae had relatively high average abundance at each catchment and largely contributed to within-catchment similarity (Table 2). These taxa are all regarded as pollution tolerant taxa. The high average abundance of these taxa and their prevalence within the three catchments is suggestive of overall moderate river quality.

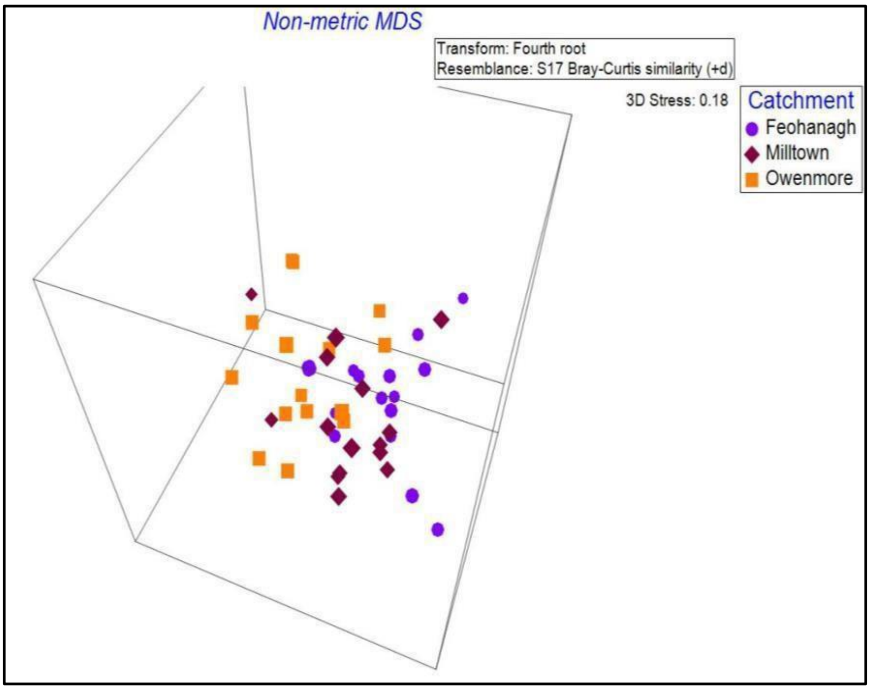


Figure 6. nMDS 3-dimensional ordination displaying the differences in macroinvertebrate communities between catchments. Greater differences occurred between sites spaced further apart.

Table 2. SIMPER results of macroinvertebrate community data, displaying average abundance, contributing %, and cumulative % for the Feohanagh, Milltown, and Owenmore catchments. Cut off was set at 70% for low contributing taxa.

CATCHMENT	TAXA	Avg. Abundance	Contributing %	Cumulative %
Feohanagh Average Similarity= 50.57	Elmidae	2.79	18.92	18.92
	Baetidae	2.31	13.43	32.36
	Chironomidae	1.53	10.25	42.60
	Hydrobiidae	1.57	7.70	50.31
	Hydropsychidae	1.33	7.62	57.92
	Oligochaete 1	0.98	5.10	63.02
	Gammaridae	1.17	5.06	68.08
	Chrysomelidae	0.91	4.79	72.88
Milltown Average Similarity= 51.29	Baetidae	2.72	15.32	15.32
	Gammaridae	1.92	10.20	25.52
	Chironomidae	1.53	9.45	34.97
	Simuliidae	1.88	8.94	43.91
	Elmidae	1.86	7.62	51.53
	Hydropsychidae	1.22	6.39	57.92
	Hydrobiidae	1.58	5.04	62.96
	Tipulidae	1.02	4.97	67.93
	Ecdyonurus	0.91	3.70	71.63
Owenmore Average Similarity= 51.83	Baetidae	2.12	14.60	14.60
	Simuliidae	1.83	13.68	28.27
	Elmidae	1.70	12.36	40.63
	Chironomidae	1.41	10.70	50.70
	Gammaridae	1.49	9.00	59.70
	Acari	1.11	8.32	68.02
	Scirtidae	0.83	4.54	72.56

3.1.2 Biotic Indices: Inference on Water Quality

Overall, the Feohanagh and Milltown catchments had the largest mean abundance of Group A and B taxa respectively (Table 3), however Owenmore had the highest relative proportions of both Groups A and B taxa. The Group A taxa with the highest average abundances at the Owenmore catchment were *Protonemura* and *Ecdyonurus* (Appendix J). Half of the sample sites had zero Group A taxa, the remaining sites had 1 or 2 taxa representing between 1 and 40 organisms (Appendix K). The Feohanagh catchment had the highest relative proportions of Groups C and E taxa, and all catchments had zero mean abundance of Group D taxa (Appendix L, Table 3).

The high average abundances of Hydrobiidae and Elmidae increased the average abundance of Group C taxa at the Feohanagh catchment (Table 3 and Appendix J). Likewise, the highest mean abundance of all Oligochaeta increased the mean abundance of Group E at the Feohanagh catchment (Appendix J and Table 3). Though the total organism abundances, taxon richness, and proportions of groups varied amongst the catchments (Appendices K; L; M), Kruskal-Wallis testing did not indicate significant differences in Q-values between the catchments (H(2)= 0.309, p=0.857). While the Owenmore and Feohanagh had higher relative proportions of Group A 'sensitive' taxa and Group E 'most tolerant' taxa, respectively, the high mean abundance of Group C 'tolerant' taxa at all three of the study catchments led to a Q3-4 water quality rating (Table 3). The Feohanagh, Milltown, and Owenmore rivers are thus considered unsatisfactory, slightly polluted, and in terms of the Water Framework Directive (WFD) of 'moderate' status.

Table 3. Summary of the mean abundance (± standard error) of taxa in the groups used for the Q- value Analysis, and mean Q-value for each of the catchments where 3.5 was used to represent Q3-4.

	Feohanagh Catchment	Milltown Catchment	Owenmore Catchment
	Mean ± SE	Mean ± SE	Mean ± SE
Group A	8 ± 2.9	7 ± 1.6	8 ± 3.3
Group B	71 ± 19.4	96 ± 18.4	53 ± 15.5
Group C	194 ± 36.1	205 ± 55.1	94 ± 18.8
Group D	0	0	0
Group E	7 ± 5.4	4 ± 2.6	1 ± 0.5
Q-Value	Q3-4	Q3-4	Q3-4

3.2 Land Use and Land Cover

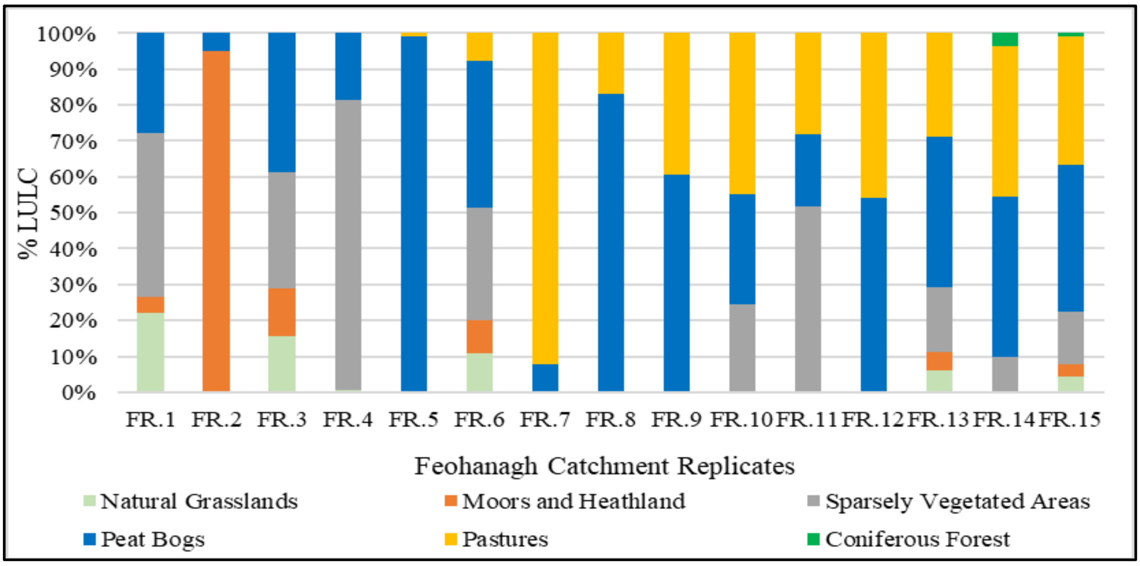
The CORINE LULC classification indicated the Feohanagh catchment had the fewest land use types upstream, followed by the Milltown and Owenmore catchments, respectively. Overall, the Feohanagh catchment was dominated by two

LULC types, peat bogs (40%) and pastures (38%). Both the Milltown and Owenmore catchments were predominantly covered by a single land use type. The majority of LULC within the Milltown catchment was pasture (55%), whereas the Owenmore catchment was dominated by peat bogs (50%). As indicated by macroinvertebrate community composition, the Owenmore catchment differed from both the Feohanagh and Milltown catchments, suggesting that LULC at the Owenmore catchment influenced a different community composition than the other two catchments, and that the 3.5% of pasture at Owenmore did not cause sufficient degradation of water quality.

3.2.1 Land Use and Land Cover at the Sample Sites

Within each catchment, LULC upstream of the individual sample sites differed considerably (Figures 7A, 7B, 7C). For instance, the LULC of OR.3 was sparsely vegetated areas (62%), peat bogs (37%), and natural grasslands (1%), while OR.10 was pasture (84%) and transitional woodland shrub (15%) (Figure 7C). Other instances of this are apparent upon examination of Figures 7A, 7B, and 7C.

The most prominent LULCs upstream of the sample sites of the Feohanagh catchment were pasture and peat bogs, followed closely by sparsely vegetated areas. Pasture occurred at 11 of the 15 sites and ranged in cover from approximately 3-93% across sites (Figure 7A). Peat bogs occurred at all 15 sites and ranged from 5-98% (Figure 7A). Sparsely vegetated areas were upstream of 9 of the 15 sample sites and ranged in cover from 10-81% (Figure 7A). In contrast, both Milltown and Owenmore were dominated by a singular LULC. The Milltown catchment had pasture upstream of 14 of its 15 sample sites, ranging from approximately 2-96% (Figure 7B). Similarly, Owenmore had peat bogs upstream of 14 of its 15 sample sites, with cover ranging from 30-100% (Figure 7C).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Feohanagh Catchment Replicates
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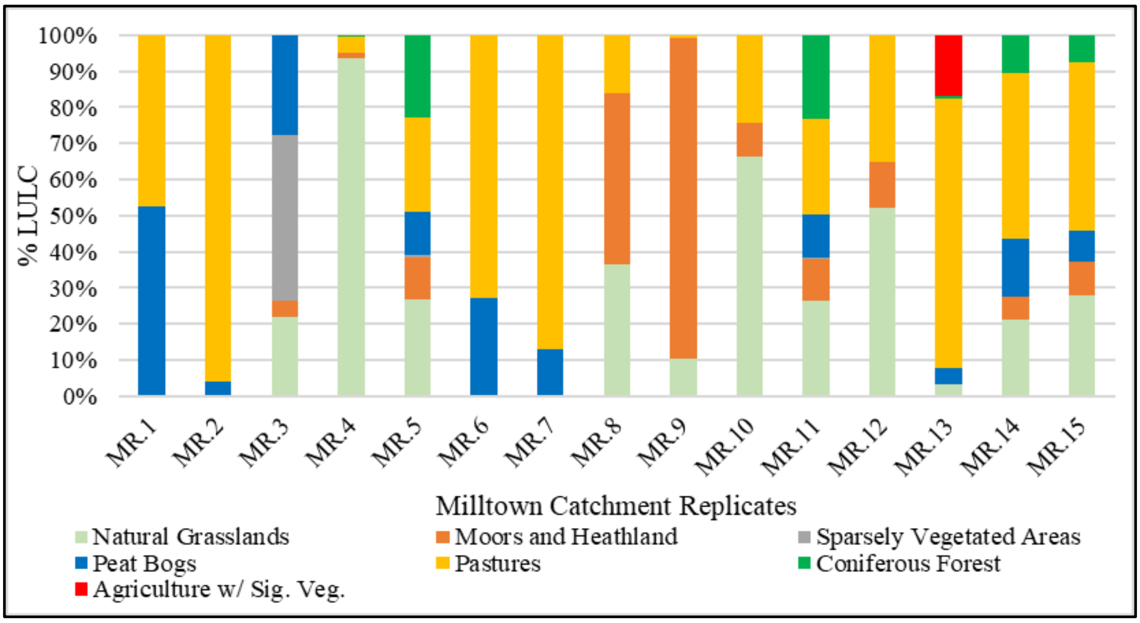
Moors and Heathland
Sparsely Vegetated Areas
Peat Bogs
Pastures
Coniferous Forest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Milltown Catchment Replicates
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Moors and Heathland
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Peat Bogs
Pastures
Coniferous Forest
Agriculture w/ Sig. Veg.

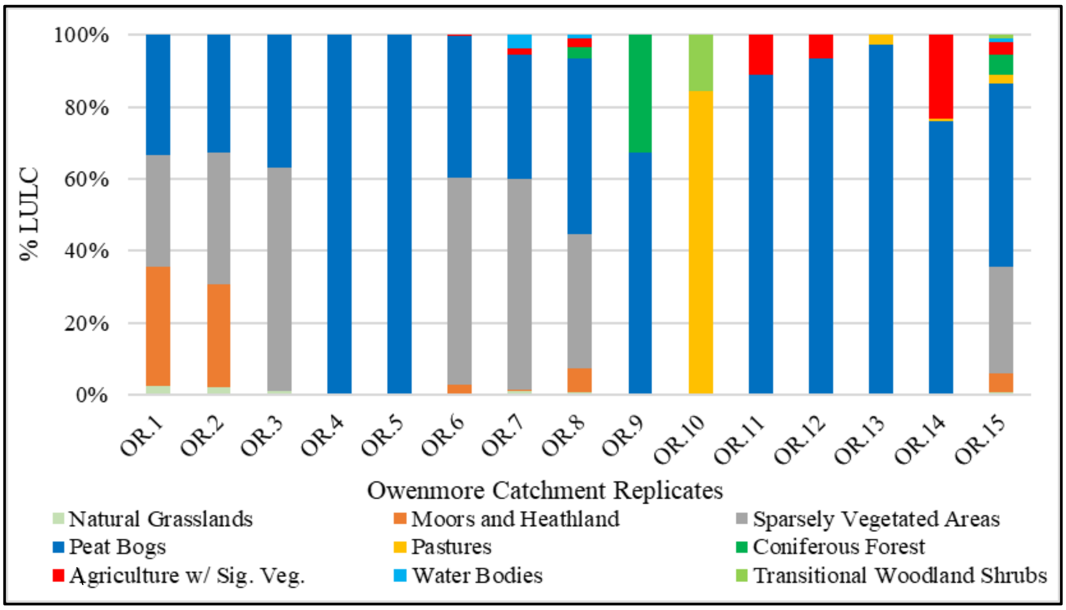

Figure 7. CORINE LULC classification percentages of the areas upstream of the sample sites within the A) Feohanagh, B) Milltown, and C) Owenmore catchments.

3.2.2 Land Use and Land Cover's Influence on Macroinvertebrate Communities

SIMPER indicated the presence of several highly abundant taxa, present at all catchments; necessitating the use of a constrained ordination figure to distinguish potentially less abundant taxa not correlated with the more-abundant taxa. Canonical analysis of principal coordinates (CAP) displayed clear differences in the LULC influencing the macroinvertebrate communities between the catchments (Figure 8). Many of the macroinvertebrate communities at the sample sites of the Feohanagh and Milltown catchments were associated with high values of pasture and were clearly distinct from those within the Owenmore catchment (Figure 8). There was an observable pattern in high mean abundances of Dipterans, Coleopterans, Oligochaetes, and Hydrobiidae in Feohanagh and Milltown (Appendix J); suggesting that the macroinvertebrate communities and water quality of the Feohanagh and Milltown were negatively influenced by high values of pasture. Several Feohanagh sample sites were also associated with high values of natural grasslands and 'sparsely vegetated areas.'

The Feohanagh catchment had the only presence of the highly sensitive *Dinocras* (Appendix J), suggesting the two LULC types had a positive influence on macroinvertebrate communities and water quality. Macroinvertebrate communities at the Owenmore catchment did not possess any strong associations to LULC, but samples grouped around the ‘agriculture with significant vegetation’ axes (Figure 8). Thus suggesting that the Owenmore sample sites differed from the macroinvertebrate communities of both the Milltown and Feohanagh, but were influenced by some unidentified local condition, rather than by LULC.

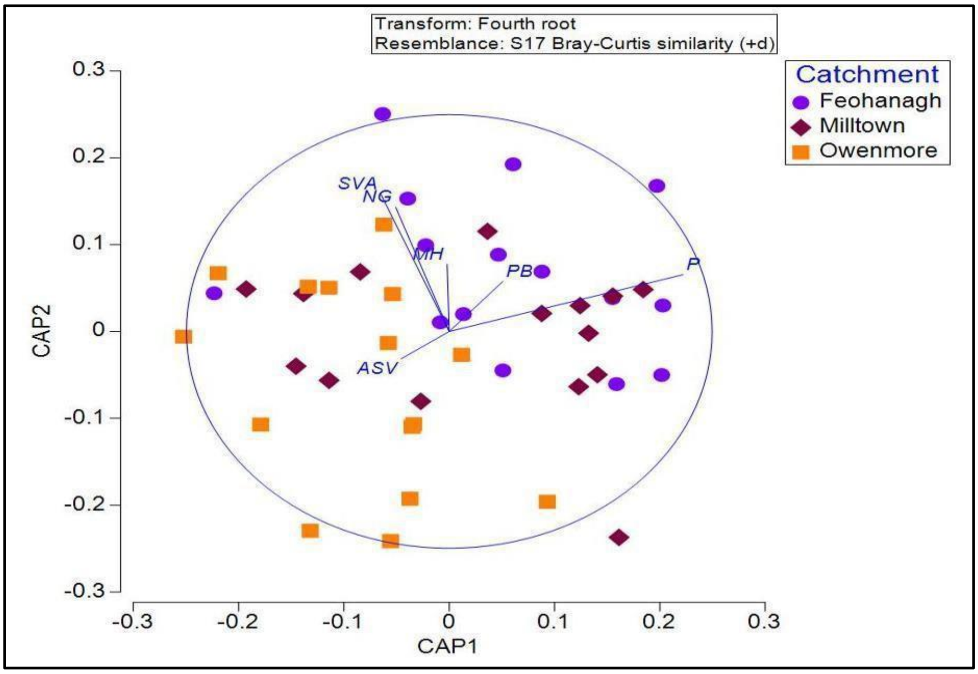

Figure 8. CAP analysis of macroinvertebrate community composition of the Feohanagh, Milltown, and Owenmore sites. Vectors represent Pearson’s correlation values for each LULC. Vectors extending to the circle would have a correlation coefficient of 1. The correlation coefficient cut-off for vector display was set at >|0.2|. Vectors entitled (SVA) sparsely vegetated areas, (NG) natural grasslands, (MH) moors and heathland, (PB) peat bogs, (P) pasture, and (ASV) agriculture with significant vegetation.

3.3 Water Quality

The Kruskal-Wallis test showed statistically significant differences in conductivity between the catchments (H(2)= 14.45, p=0.001). Pairwise comparisons indicated that only the Milltown catchment had significantly higher conductivity than the Owenmore catchment (p=0.001, Figure 9), however the Feohanagh catchment did have substantially higher conductivity than the Owenmore. There were no significant differences in dissolved oxygen (H(2)= 2.795, p=0.247, F=10.4, M= 10.2, O= 10.1) or temperature (H(2)= 0.569, p=0.752, F= 13.5, M= 13. 9, O= 13.7) between the three catchments. Elevated measures of conductivity, with no significant differences in temperature, suggest a higher input of salts or organic compounds into Milltown, followed by Feohanagh, then the Owenmore.

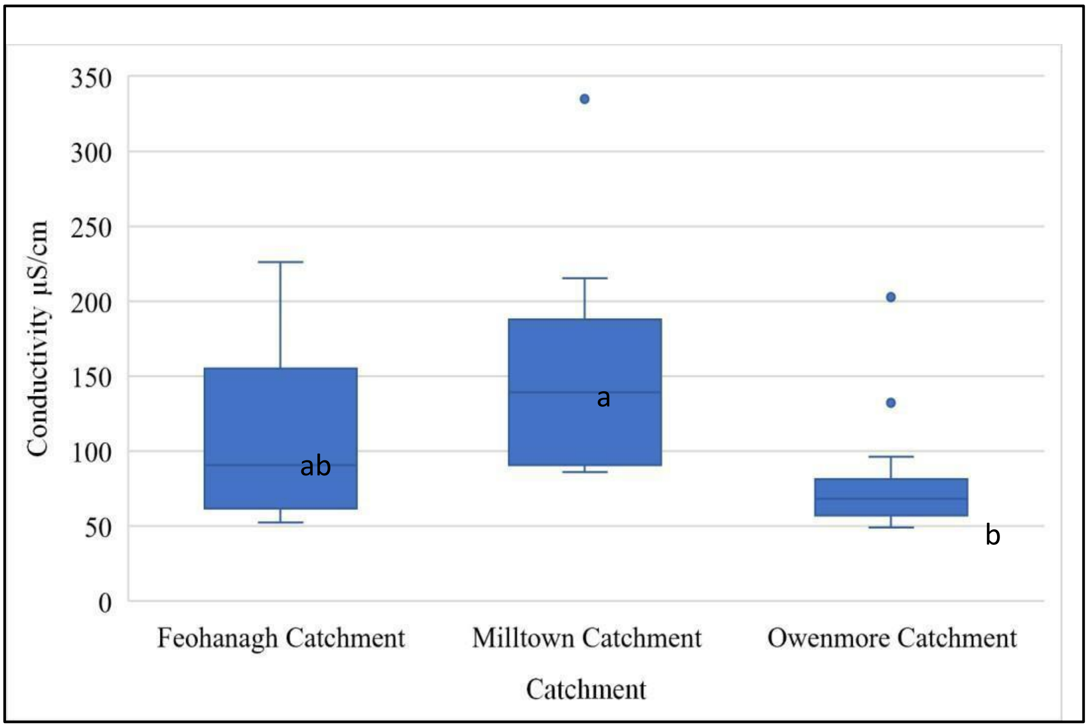

Figure 9. Median and variation of conductivity between the Feohanagh, Milltown, and Owenmore catchments, where letters display significant differences between catchments.

3.3.1 Water Parameters' Influence on Macroinvertebrate Communities

CAP of water parameters' effect on macroinvertebrate communities displayed no distinct groupings between the catchments (Figure 10). There is modest separation between the catchments that suggests Owenmore had lower values of conductivity than Milltown and Feohanagh, thus reinforcing the results of the Kruskal-Wallis. There was an observable pattern between higher values of conductivity, macroinvertebrate communities with high mean abundances of tolerant taxa: Dipterans, Coleopterans, Oligochaetes, and Hydrobiidae, and catchments (Milltown and Feohanagh) dominated by pasture.

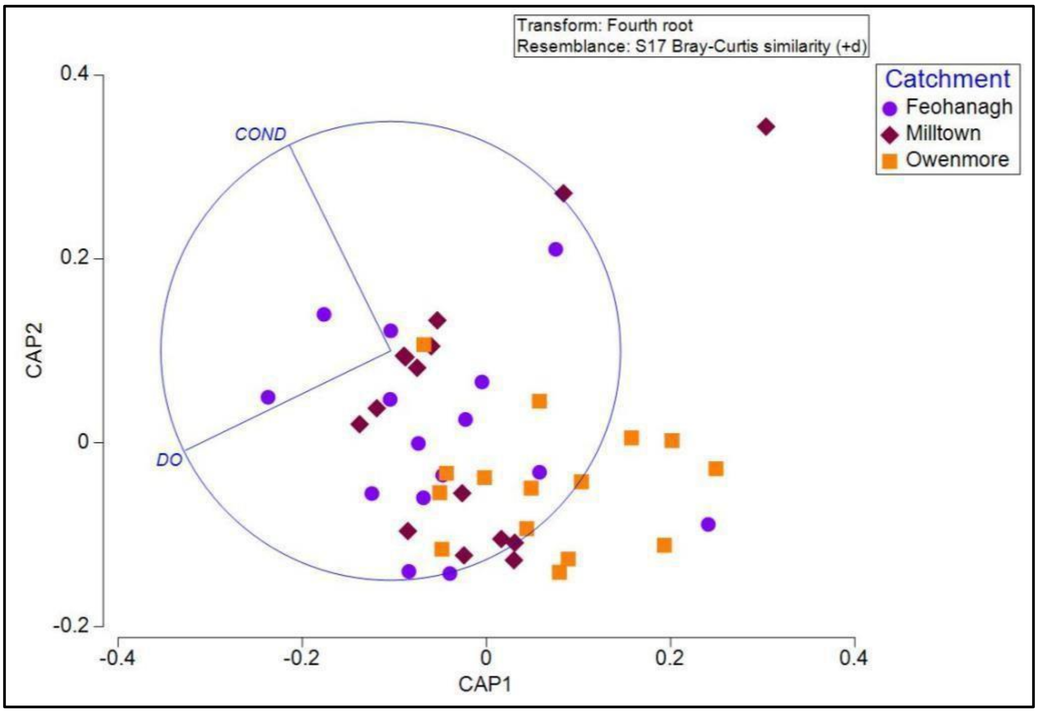

Figure 10. CAP analysis of macroinvertebrate community composition of the Feohanagh, Milltown, and Owenmore sites. Vectors represent Pearson’s correlation values for each water quality parameter. Vectors extending to the circle would have a correlation coefficient of 1. The correlation coefficient cut-off for vector display was set at >0.2. Vectors entitled (COND) conductivity and (DO) dissolved oxygen.

3.4 Summary of Results

Results of this study indicated significant differences in macroinvertebrate community composition between the three catchments. ANOSIM and SIMPER analyses and nMDS ordination showed greater similarities in community composition between the Feohanagh and Milltown catchments than either did with the Owenmore catchment. Pastureland was associated with the differences between macroinvertebrate communities and was evident in the greater presence of tolerant taxa and the elevated conductivity and DO concentrations at the Feohanagh and Milltown catchments. There is some indication that natural grasslands and sparsely vegetated areas had a positive influence on macroinvertebrate communities and water quality within the Feohanagh catchment as it could support sensitive taxa such as *Dinocras*. However, there were no significant differences in the taxon richness, total organism abundance, or mean Q- values for the three catchments, suggesting that while the LULC influencing the catchments differs, the Feohanagh, Milltown, and Owenmore catchments all had similar degradation of water quality.

Chapter 4: Discussion

4.1 Overview

Increased emphasis in the ‘the right measure, in the right place’ highlighted in the third River Basin Management Plan (RBMP) draft, stresses the need for additional, detailed data on the effects of land use and land cover on freshwater quality (DHLGH, 2021). There have been many studies on the effects of LULC at upstream and downstream sample sites along river channels (Conroy et al., 2016; Madden et al., 2011). However, catchment-scale assessments, as presented in this study, are vital in attempting to reduce confounding influences and identify LULC effects. The primary intent of the study presented was to investigate the effects of LULC on the macroinvertebrate communities of rivers at a catchment-scale in an area where conjoined river catchments of similar size offer a reasonable basis for comparison.

The results of this study show that there are differences in macroinvertebrate communities between the three catchments investigated and suggest that the differences are influenced by differences in land use and land cover.

4.2 Effect of Pasture on Macroinvertebrate Communities

The results of the study indicate that macroinvertebrate communities were negatively affected at study sites adjacent to and downstream of pasture. The Milltown catchment had the greatest percent cover of pasture and generally supported tolerant taxa. Exclusively identified in this catchment was Asellidae, a ‘Group D: very tolerant taxon’ (Toner et al., 2005). At least three of the Milltown sample sites had evidence of cattle access and faeces in the riparian zone (personal observation). Studies have shown the negative effects of pasture, particularly cattle access points, on macroinvertebrate communities within Ireland (Conroy et al.,2016; Madden et al., 2011). Similarly, in New Zealand, sample sites drained into by pasture throughout the Waipa River had macroinvertebrate communities composed of tolerant taxa and sensitive taxa were rare or absent (Quinn et al., 1997).

The Owenmore catchment had low percent cover of pasture and high relative proportions of sensitive taxa. Exclusive to the Owenmore catchment were Coenagrionidae and 'Group C: tolerant taxa,' *Chimarra marginata* and Dryopidae. Coenagrionidae, while categorised as 'Group B: less sensitive', were collected in only one sample site that stemmed from a small lake in the upper stretches of the Owenmore. As lakes, fens, and ephemeral water are known habitats for Coenagrionidae (Nelson, Ronayne and Thompson, 2011), it is likely due to location more so than differences in water quality.

The Feohanagh catchment had equal proportions of pasture and peat bog upstream of its sample sites. Both LULC types had lower percent cover at the Feohanagh catchment than the Milltown and Owenmore, respectively. *Dinocras,* classified as 'Group A: sensitive,' were only identified within the Feohanagh catchment. While the catchment was supportive of highly sensitive taxa, it also had high relative abundances of tolerant taxa. This suggests that upper reaches of the Feohanagh had higher water quality, whereas lower reaches had worse water quality and were more similar to the sample sites in the Milltown catchment. Due to the nature of the study design, it is impossible to determine the precise location where pasture effects begin to diminish the quality of the Feohanagh River. This study can only suggest that the effects are beginning in the mid-reaches of the river's course and occur within and downstream of pasture starting around sites FR.6, FR.7, and FR.8. Further analyses with replication of samples would be required to precisely identify the initial input of run-off leading to degraded water quality.

4.2.1 Effect of Pasture on Water Quality Parameters

An exclusively chemical or biological study is not cost-effective nor capable of indicating the specific effect of effluents, respectively (Toner et al., 2005). Therefore, in conjunction with macroinvertebrate community analyses, the effect of LULC on water quality was measured using conductivity, DO, and temperature. Conductivity had strong associations with community composition and measured high across the Milltown catchment, low across the Owenmore, and variable across the Feohanagh. This finding is in agreement with the community composition findings because conductivity is often inversely correlated to water quality (United States Environmental Protection Agency, 2022).

Previous analysis of water quality parameters at select sites along the Milltown and Feohanagh Rivers showed elevated concentrations of nutrients, faecal coliforms, and other coliforms (Appendix D). In New Zealand, the Waipa River had higher nitrate in rivers drained into by pasture. Elevated nitrate was attributed in part to nitrate leaching of pasture animals' urine and faeces (Quinn et al., 1997). As the nutrient and coliform parameters were not collected simultaneously with the macroinvertebrate community data of the present study, this must be taken with caution. However, these nutrient and coliform values, similarly to the conductivity values, measured high across the Milltown catchment, low across the Owenmore, and variably across the Feohanagh, thus displaying the same pattern of water quality degradation by pastureland.

While remaining cautious not to overinterpret the response of community composition to LULC, the resulting macroinvertebrate assemblages corroborated the water quality parameters analysed throughout the study. Therefore, based on macroinvertebrate assemblages and water quality parameters, the Owenmore catchment had the highest water quality and could support sensitive taxa. The Milltown catchment had the lowest water quality and supported tolerant taxa. The Feohanagh catchment had water quality measuring at a level in between.

4.3 Additional Land Use and Land Cover Effects

There was evidence that suggests ‘natural grassland’ had a positive effect on water quality within the Feohanagh catchment. While 38% of the Feohanagh catchment is made up of pasture, the presence of the sensitive taxa *Dinocras*, exclusively found in this catchment, suggests higher water quality than catchments predominantly influenced by pasture. As such, the Feohanagh showed lower values of all analysed water quality parameters than the Milltown catchment.

In contrast to the results of the present study, Roberts et al. (2016) predicted grassland throughout the Republic of Ireland had a negative impact on the likelihood of sites to remain at high ecological status. The incongruity between the results of the present study identifying a positive influence of grassland on water quality, may be due to the fact that in Roberts et al. (2016), grassland was also referred to as ‘grassland agriculture.’ Also, the negative effects of grassland were attributed to hydromorphological alterations and fertiliser and pesticide use. However, grassland managed by the application of pesticides and fertilisers are not included in the ‘natural grassland’ category within the CORINE classification guidelines (Kozstra et al., 2016). Similarly, in Conroy et al. (2016) the effect of cattle grazing on ‘calcareous grassland’ was studied. Again, CORINE classification separately categorised grassland on calcareous soils from other pasture and agricultural land (Kozstra et al, 2017).

Therefore, the positive influence of grassland on water quality within the present study may not be comparable to other existing studies.

A greater percentage of coniferous forest occurred throughout the Milltown and Owenmore catchments, than at Feohanagh. In previous water quality testing, the Owenmore had the highest pH, followed by the Feohanagh, then the Milltown (Appendix D). In County Cork in the Douglas River system, there was a general increase in pH with increased levels of afforestation (Cleneghan et al., 1998). Generally, forestry is known to decrease pH, however Cleneghan et al., (1998) attributed the elevated pH at a sample site in the Douglas River to the underlying geology and the low atmospheric pollution in south-west Ireland. As in Cleneghan et al., (1998), the underlying geology of the three study catchments is made up of Old Red Sandstone (Geological Survey of Ireland, 2004). Neither the Milltown nor Owenmore catchments displayed significantly reduced diversity or abundance of acid-sensitive taxa due to forestry upstream as in Kelly-Quinn et al. (2016) and Tierney, Kelly-Quinn, and Bracken (1998). Several streams in a known acid-sensitive region in County Kerry were examined over a period of fourteen months, and no forest cover effects on stream water pH were identified (Feeley et al., 2012). As mentioned, rivers in Munster have shown no apparent relation between forestry and acidity, and it is more likely that some unidentified local physical factor is raising the pH throughout the Owenmore as in Giller and O'Halloran (2004). Along with acidification, the effects of forestry on streams in Ireland are sedimentation, nutrient loss, siltation, and stream flow regime modification (Environmental Protection Agency, 2019). However, the Owenmore catchment did not have strong associations with LULC, therefore additional investigation would be required to determine what conditions are influencing macroinvertebrate communities and water quality in the Owenmore catchment.

4.4 Comparison of Results with EPA Assessment

The LULC influencing the Feohanagh, Milltown, and Owenmore catchments do not align with the pressures outlined in the EPA assessment. As previously mentioned, the EPA listed agriculture as a significant pressure of the Owenmore River, by its analysis of Site D and assigned the site good (Q4) quality (Environmental Protection Agency, 2023a; WFD Application, 2019; Appendix C). This same sample site was used in the study as OR.15. A particular caveat must be made as the CORINE classification has two distinct categories for ‘agriculture with significant vegetation’ and pasture (Kozstra et al., 2017), however the EPA categorises the two together. Therefore, the LULC upstream of this sample site was a combined 8% agricultural land. There were no strong associations between agricultural land and community composition at the Owenmore, thus results from this present study make it impossible to distinguish if the low percentages of agricultural land are a significant pressure on this site.

The EPA also listed urban run-off at Milltown, peat bogs at Owenmore, and forestry at both as significant pressures on these catchments. Within this study, none of these LULC pressures were associated with differences in the macroinvertebrate communities. It is possible that the catchment-wide nature of this study enabled climatic, geographical, and historical large-scale effects to mask local scale influences on water quality (Clenaghan et al., 1998). All three catchments were designated as Q3-4, or slightly polluted. Based on the macroinvertebrate community compositions, water quality parameters, and varied LULC between the three catchments, more variability was expected between the catchments’ Q-values. While the Milltown and Owenmore catchments had macroinvertebrate communities, water quality parameters, and LULC results expected of degraded or fair water quality, respectively, the Feohanagh catchment showed far more variability in all resulting parameters, similarly to the River Raisin in Michigan, from Roth, Allan, and Erickson (1996). Both the Feohanagh and the River Raisin had a range of sites with varied water quality, a wide range of LULC types influencing the river, and ultimately measure, on average, at an intermediary state of water quality degradation. Without further investigation it is impossible to delineate if Q-values, in this study, are not a good representation or qualifier of water quality, or if the catchments had low water quality and pasture upstream did not cause additional measurable deterioration as in Madden et al. (2011).

Rapid sampling, as performed by the EPA, is vital in assessing water quality in due regard for the WFD. However, considering the decline in river quality within Ireland, it seems pertinent that rivers be conservatively examined. Unfortunately, the time and labour required to have multiple sampling stations across all the river channels in Ireland, is not feasible. Not only can this study provide data to increase the knowledge of macroinvertebrate response to LULC at a fine scale, but perhaps it can indicate the need for a more thorough sampling design in particular watersheds.

4.5 Limitations and Recommendations

One of the major goals of this investigation was to develop a more detailed data set of macroinvertebrates' responses to anthropogenic pressures. This goal was partially set in the hopes of informing efforts to meet Ireland's obligations as set forth in the Water Framework Directive. This was accomplished to an extent, but more replication would be required to determine where along the river channel pollution events were occurring. A study combining the multiple sample sites throughout the river as conducted in this study, with replication at each sample site, would suggest where pollution events begin and increase downstream; and would further the understanding of LULC's effect on macroinvertebrates and water quality. However, it is important to note that this is an extensive, and time-consuming amount of work, which was unfortunately not feasible in the context of this study. As mentioned, time and individual labour were limiting factors and ensuring that field collection and macroinvertebrate identification were completed with due regard for salmon spawning, weather, and Covid-19 restrictions was difficult. In moving forward with this research, it is also suggested to assess temporal differences as in Kelly, Feeley and Bradley (2020), to detect more subtle fluctuations in biodiversity and homogenisation of the community.

To develop a more complete explanation of LULCs' effects on macroinvertebrate communities, it would be beneficial to conduct a finer-scale analysis of LULC. Though within the present study the LULC was ground-truthed to ensure validity, the classification is only as detailed as the CORINE 2018 database. This new analysis would include a more precise classification generated from analysis of high resolution orthophotos and direct measurements, as opposed to using the course scale CORINE database based on LANDSAT imagery. This will give a more definitive image of the land use types surrounding the rivers and ultimately could lead to a more thorough understanding of the effects of LULC on water quality.

4.6 Conclusions

Based on the results, pasture upstream of several of the sample sites had a negative impact on the macroinvertebrate communities and is likely responsible for degrading water quality and eliminating, or reducing sensitive taxa. Runoff from fields and point source faecal matter from cows and sheep is likely responsible for the reduced water quality. In contrast, natural grasslands had a positive effect on the macroinvertebrate communities and water quality within the Feohanagh. However, all three study catchments, on average, had moderate, slightly polluted water quality (Q3-4).

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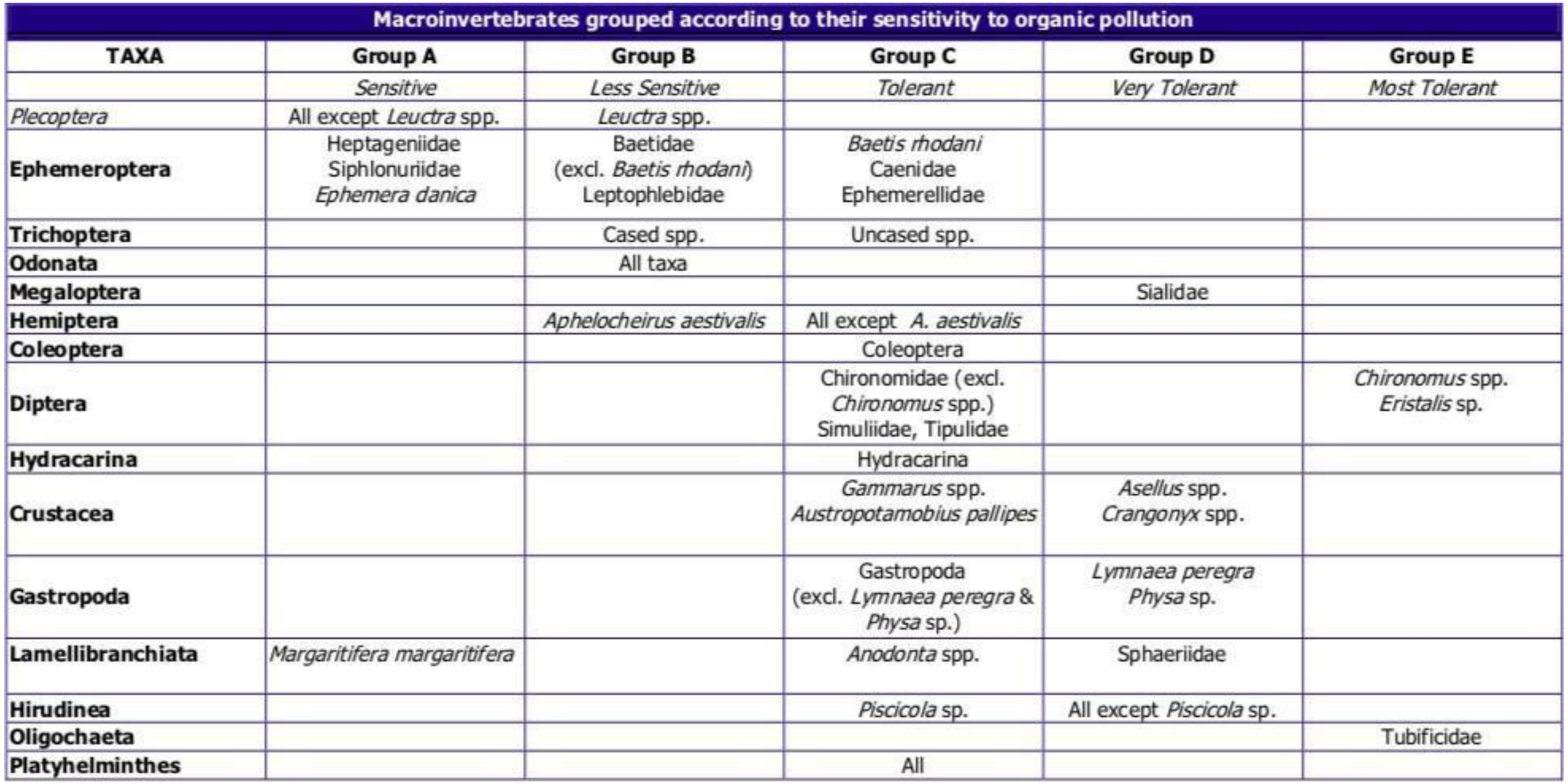
Appendix

Appendix A. Macroinvertebrate groupings based on sensitivity to organic pollution.

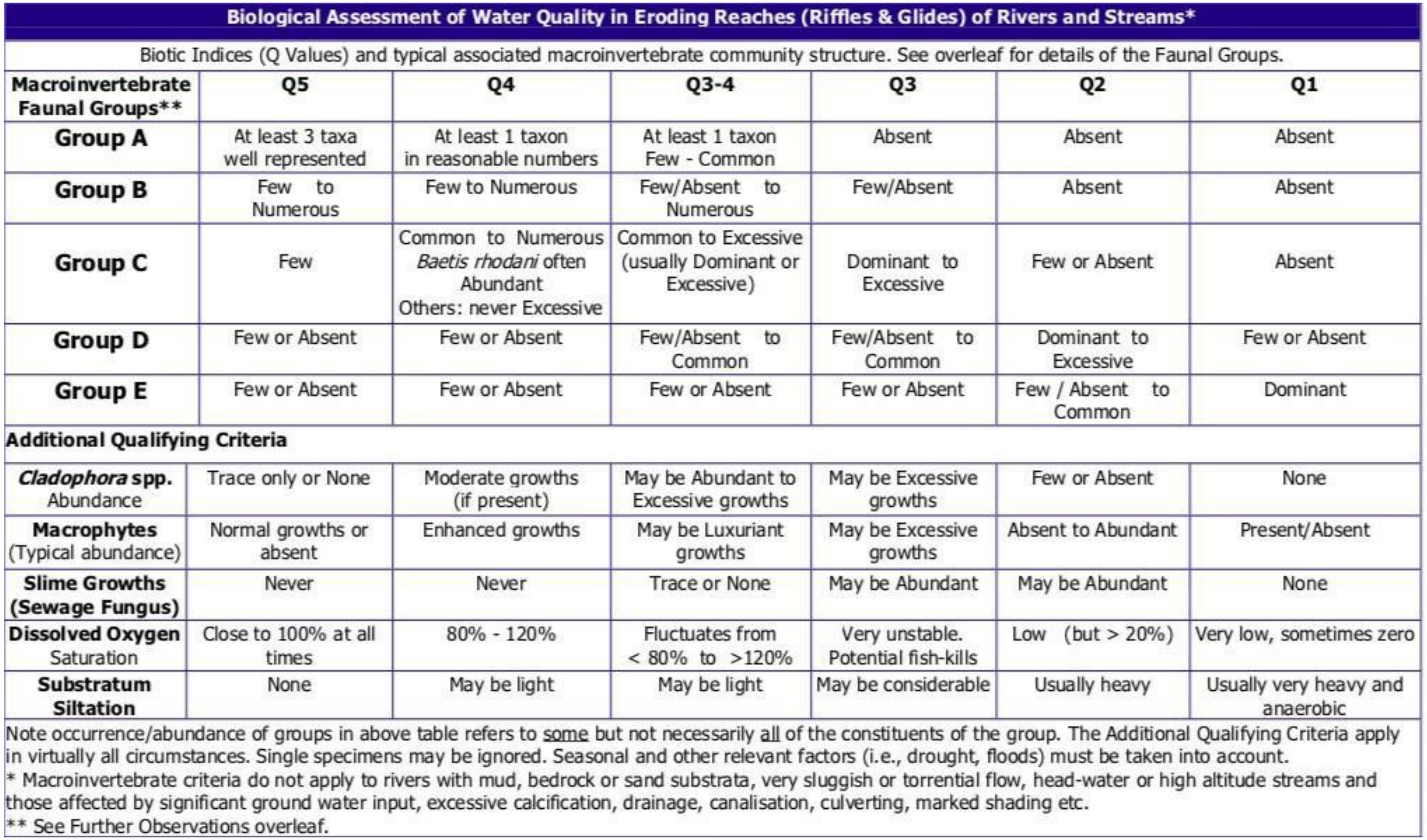


Macroinvertebrates grouped according to their sensitivity to organic pollution

TAXA	**Group A**	**Group B**	**Group C**	**Group D**	**Group E**
	Sensitive	*Less Sensitive*	*Tolerant*	*Very Tolerant*	*Most Tolerant*
Plecoptera	All except *Leuctra* spp.	*Leuctra* spp.			
Ephemeroptera	Heptageniidae Siphlonuriidae *Ephemera danica*	Baetidae (excl. *Baetis rhodani*) Leptophlebidae	*Baetis rhodani* Caenidae Ephemerellidae		
Trichoptera		Cased spp.	Uncased spp.		
Odonata		All taxa			
Megaloptera				Sialidae	
Hemiptera		*Aphelocheirus aestivalis*	All except *A. aestivalis*		
Coleoptera			Coleoptera		
Diptera			Chironomidae (excl. *Chironomus* spp.) Simuliidae, Tipulidae		*Chironomus* spp. *Eristalis* sp.
Hydracarina			Hydracarina		
Crustacea			*Gammarus* spp. *Austropotamobius pallipes*	*Asellus* spp. *Crangonyx* spp.	
Gastropoda			Gastropoda (excl. *Lymnaea peregra* & *Physa* sp.)	*Lymnaea peregra* *Physa* sp.	
Lamellibranchiata	*Margaritifera margaritifera*		*Anodonta* spp.	Sphaeriidae	
Hirudinea			*Piscicola* sp.	All except *Piscicola* sp.	
Oligochaeta					Tubificidae
Platyhelminthes			All		

Toner et al. 2005, Appendix I

Appendix B. Biological Assessment of Water Quality in Eroding Reaches (Riffle & Glides) of Rivers and Streams.



Biological Assessment of Water Quality in Eroding Reaches (Riffles & Glides) of Rivers and Streams*

Biotic Indices (Q Values) and typical associated macroinvertebrate community structure. See overleaf for details of the Faunal Groups.

Macroinvertebrate Faunal Groups**	**Q5**	**Q4**	**Q3-4**	**Q3**	**Q2**	**Q1**
Group A	At least 3 taxa well represented	At least 1 taxon in reasonable numbers	At least 1 taxon Few - Common	Absent	Absent	Absent
Group B	Few to Numerous	Few to Numerous	Few/Absent to Numerous	Few/Absent	Absent	Absent
Group C	Few	Common to Numerous *Baetis rhodani* often Abundant Others: never Excessive	Common to Excessive (usually Dominant or Excessive)	Dominant to Excessive	Few or Absent	Absent
Group D	Few or Absent	Few or Absent	Few/Absent to Common	Few/Absent to Common	Dominant to Excessive	Few or Absent
Group E	Few or Absent	Few or Absent	Few or Absent	Few or Absent	Few / Absent to Common	Dominant
Additional Qualifying Criteria						
***Cladophora* spp.** Abundance	Trace only or None	Moderate growths (if present)	May be Abundant to Excessive growths	May be Excessive growths	Few or Absent	None
Macrophytes (Typical abundance)	Normal growths or absent	Enhanced growths	May be Luxuriant growths	May be Excessive growths	Absent to Abundant	Present/Absent
Slime Growths (Sewage Fungus)	Never	Never	Trace or None	May be Abundant	May be Abundant	None
Dissolved Oxygen Saturation	Close to 100% at all times	80% - 120%	Fluctuates from < 80% to >120%	Very unstable. Potential fish-kills	Low (but > 20%)	Very low, sometimes zero
Substratum Siltation	None	May be light	May be light	May be considerable	Usually heavy	Usually very heavy and anaerobic

Note occurrence/abundance of groups in above table refers to some but not necessarily all of the constituents of the group. The Additional Qualifying Criteria apply in virtually all circumstances. Single specimens may be ignored. Seasonal and other relevant factors (i.e., drought, floods) must be taken into account.

* Macroinvertebrate criteria do not apply to rivers with mud, bedrock or sand substrata, very sluggish or torrential flow, head-water or high altitude streams and those affected by significant ground water input, excessive calcification, drainage, canalisation, culverting, marked shading etc.

** See Further Observations overleaf.

Toner et al. 2005, Appendix I

Appendix C. Q-Value ratings from the EPA assessment of the Feohanagh, Milltown, and Owenmore Rivers in the last ten years.

River	EPA Sample Site	2013	2014	2016	2017	2018	2019	2020	2021	2022
Feohanagh	Site E		4-5		4-5			4-5	4-5	
	Site F		4 Brackish		4			4		
Milltown	Site B	4		4			4		4	4
	Site A	2-3		3-4			3-4		3-4	3-4
	Site C	3		3			3		3	3
Owenmore	Site D									

EPA, 2023a and 2023b.

Appendix D. Water quality parameters collected at two sample sites of the three study catchments, measured six weeks prior to the study. Conductivity µS/cm, DO mg/L, temperature C°, and pH were collected one value per site, *in situ*. Average values ± standard error of the six replicates of nitrates, phosphates, total coliforms, and *Escherichia coli*.

	Upper Feohanagh	Lower Feohanagh	Upper Milltown	Lower Milltown	Upper Owenmore	Lower Owenmore
Conductivity µS/cm	97.4	154.9	114.2	170.4	85.9	91.9
DO mg/L	10.2	10.7	10.1	10.4	10.5	10.2
Temperature C°	12.5	13.5	12.5	13	13.7	14.9
pH	7.1	7.2	6.1	6.6	8.1	7.7
Nitrate	0.3 ± 0.1	0.2 ± 0	0.4 ± 0.1	0.7 ± 0.1	0.3 ± 0.1	0.2 ± 0
Phosphate	0	0	0	0	0.1 ± 0	0
Total Coliforms	19.2 ± 2.9	142.3 ± 6.9	100.3 ± 7.9	302.3 ± 36.3	16.8 ± 1.7	11.2 ± 2.2
Escherichia coli	18.8 ± 2.7	98.3 ± 7.8	26.3 ± 3.4	291.2 ± 37.3	16.3 ± 1.5	10 ± 2.0

Appendix E. Varied substrate from the fifteen sample sites each at the Feohanagh, Milltown, and Owenmore catchments.

Sample	Bedrock	Boulder	Cobble	Gravel	Fine-Gravel	Sand	Silt
FR.1		🟪	🟪	🟪			
FR.2		🟪	🟪				
FR.3			🟪	🟪	🟪	🟪	
FR.4		🟪	🟪				
FR.5			🟪	🟪			
FR.6		🟪					
FR.7		🟪	🟪	🟪	🟪		
FR.8		🟪	🟪				
FR.9			🟪	🟪	🟪		
FR.10		🟪	🟪				🟪
FR.11		🟪	🟪	🟪			
FR.12			🟪	🟪	🟪	🟪	
FR.13			🟪	🟪	🟪	🟪	
FR.14		🟪		🟪	🟪	🟪	
FR.15		🟪	🟪				
MR.1		🟥	🟥	🟥	🟥	🟥	
MR.2	🟥	🟥	🟥				
MR.3		🟥					
MR.4		🟥					
MR.5			🟥	🟥	🟥		
MR.6							🟥
MR.7			🟥	🟥	🟥		
MR.8			🟥				
MR.9		🟥	🟥			🟥	

Appendix E. Continued

MR.10		■	■				
MR.11			■	■		■	
MR.12		■	■				
MR.13			■				■
MR.14			■	■	■		
MR.15			■			■	
OR.1		■			■		
OR.2		■	■		■		
OR.3		■					
OR.4			■		■		
OR.5		■					
OR.6		■	■				
OR.7		■	■				
OR.8		■	■			■	
OR.9				■	■	■	
OR.10		■			■	■	
OR.11		■		■			
OR.12		■		■			
OR.13		■					
OR.14		■			■		■
OR.15			■	■			

Appendix F. Total abundance, taxon richness, and distribution of taxa making up the macroinvertebrate community from the Feohanagh catchment.

Taxa	Site	FR.1	FR.2	FR.3	FR.4	FR.5	FR.6	FR.7	FR.8	FR.9	FR.10	FR.11	FR.12	FR.13	FR.14	FR.15
	Total Abundance	304	121	177	76	61	123	537	535	377	616	366	163	176	354	214
	Taxon Richness	16	17	17	10	15	15	12	19	12	21	16	16	10	17	4
Ephemeroptera	Baetidae	44	36	16	49	36	62	43	28	17	0	50	4	0	5	0
	Ecdyonurus	6	12	6	16	0	1	0	0	0	0	3	0	0	1	0
	Ephmerellidae	1	0	2	1	0	0	3	3	0	0	1	0	3	1	0
Plecoptera	*Dinocras*	0	0	5	0	0	0	0	0	0	0	2	0	0	0	0
	Leuctridae	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0
	Protonemura	0	2	0	0	0	0	1	1	0	0	7	0	0	1	0
Trichoptera	Hydroptilidae	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0
	Hydropsychidae	2	2	3	4	15	5	1	4	0	8	2	0	2	2	0
	Glossomatidae	1	1	1	0	5	2	2	0	0	0	2	0	0	0	0
	Limnephilidae	0	2	0	0	0	1	1	0	0	0	1	0	0	0	0
	Wormaldia	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	Philopotamus montanus	0	0	2	0	7	0	0	1	0	0	1	1	0	0	0
	Polycentropodidae	1	0	1	4	0	0	0	0	0	0	0	0	0	0	0
	Rhyacophilidae	0	0	0	5	2	0	1	0	0	0	1	0	0	0	0
	Sericosotomatidae	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0
	unidentified	0	0	1	0	2	0	0	0	1	0	0	1	0	0	0
Oligochaeta	Oligochaete 1	0	2	1	3	0	1	0	0	1	9	0	2	2	0	0
	Oligochaete 2	0	0	0	0	0	0	0	0	0	5	0	0	0	1	0
Diptera	Ceratopogonidae	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	Chironomidae	2	7	2	14	2	5	0	1	3	10	0	18	10	1	0
	Simuliidae	0	17	0	3	3	7	0	1	1	1	0	24	0	2	0
	Tipuliidae	0	0	0	0	0	0	0	1	0	0	0	2	0	1	0
Coleoptera	Elmidae	34	5	54	0	11	8	48	30	45	8	27	37	78	78	54
	Chrysomelidae	0	1	3	0	2	1	0	2	1	0	1	2	1	1	0

Appendix F. Continued

	Dytiscidae	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	Scirtidae	0	1	0	1	2	0	1	2	0	2	1	2	1	0	0
Bivalvia	Bivalvia	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Gastropoda	Hydrobiidae	1	2	3	0	2	2	0	9	27	45	0	4	1	2	39
Hemiptera	Veliidae	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Hirudinea	Hirudinea	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Acari	Acari	0	0	1	0	3	2	0	0	0	0	0	1	1	0	7
Amphipoda	Gammaridae	4	5	0	0	7	3	0	16	5	1	0	1	3	5	0

Appendix G. Total abundance, taxon richness, and distribution of taxa making up the macroinvertebrate community from the Milltown catchment.

Taxa	Site	MR.1	MR.2	MR.3	MR.4	MR.5	MR.6	MR.7	MR.8	MR.9	MR.10	MR.11	MR.12	MR.13	MR.14	MR.15
	Total Abundance	616	383	35	211	148	111	163	102	379	273	354	68	304	595	932
	Taxon Richness	20	20	12	13	17	7	14	16	18	20	21	14	16	20	20
Ephemeroptera	Baetidae	29	12	14	73	47	0	23	27	53	70	19	12	29	23	13
	Ecdyonurus	0	0	6	6	3	0	0	14	1	1	1	15	0	1	0
	Ephmerellidae	0	1	3	0	9	0	0	0	1	0	0	0	7	2	1
Plecoptera	Leuctridae	0	0	0	0	7	0	0	1	3	1	8	1	1	2	0
	Protonemura	1	0	3	3	0	0	0	0	1	0	1	0	0	1	2
Trichoptera	Hydropsychidae	1	3	3	1	1	0	0	3	2	0	3	3	0	2	1
	Glossomatidae	0	0	0	0	1	0	0	0	0	0	2	1	1	0	0
	Limnephilidae	0	1	0	0	0	0	4	0	0	0	0	0	0	0	0
	Wormaldia	0	0	0	0	0	0	0	0	1	0	3	0	0	0	0
	Philopotamus montanus	0	1	0	0	0	0	0	5	6	1	0	4	0	0	1
	Polycentropodidae	0	0	9	0	1	0	1	5	0	1	0	0	0	0	0
	Rhyacophilidae	0	1	0	0	0	0	0	0	2	0	0	0	0	0	0
	Sericosotomatidae	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	unidentified	0	0	6	2	1	0	0	0	0	0	0	1	0	0	0
Oligochaeta	Lumbricidae	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	Oligochaete 1	0	0	0	0	0	5	6	1	0	0	1	4	0	0	0
	Oligochaete 2	0	0	0	0	0	30	1	0	0	0	0	0	0	0	0
Diptera	Ceratopogonidae	0	0	0	0	0	10	1	0	0	0	0	0	0	0	0
	Chironomidae	2	1	23	1	2	15	6	1	0	2	1	7	3	3	4
	Simuliidae	8	38	0	7	1	1	13	22	20	3	5	1	11	0	20
	Tipuliidae	1	1	3	0	3	2	12	0	0	0	0	0	0	0	1
Coleoptera	Elmidae	2	2	17	3	11	0	0	11	1	4	20	0	35	49	35
	Chrysomelidae	1	0	0	1	2	0	0	1	0	5	1	0	0	2	1
	Dytiscidae	0	0	0	0	0	0	6	1	0	0	0	0	1	0	0

Appendix G. Continued

	Scirtidae	0	0	0	0	0	0	8	3	1	1	1	0	0	0	1
Isopoda	Asellidae	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Bivalvia	Bivalvia	0	1	0	0	0	37	0	0	0	0	1	1	0	0	0
Gastropoda	Hydrobiidae	49	14	0	0	1	0	8	0	0	0	12	44	6	7	15
Hemiptera	Veliidae	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
Acari	Acari	0	0	3	0	5	0	0	2	0	1	0	0	0	1	0
Amphipoda	Gammaridae	5	23	11	1	6	0	9	3	10	7	20	1	4	6	6

Appendix H. Total abundance, taxon richness, and distribution of taxa making up the macroinvertebrate community from the Owenmore catchment.

Taxa	Site	OR.1	OR.2	OR.3	OR.4	OR.5	OR.6	OR.7	OR.8	OR.9	OR.10	OR.11	OR.12	OR.13	OR.14	OR.15
	Total Abundance	223	304	206	119	194	104	87	313	175	180	55	44	123	41	172
	Taxon Richness	11	18	14	12	14	11	14	16	13	15	10	13	17	13	14
Ephemeroptera	Baetidae	82	8	1	0	55	38	52	53	35	15	4	20	22	10	1
	Ecdyonurus	6	0	0	0	4	30	0	0	0	0	0	0	4	2	0
	Ephmerellidae	2	2	4	1	0	1	5	4	1	0	0	0	0	0	1
Plecoptera	Leuctridae	0	2	0	0	0	0	2	5	1	0	15	2	2	2	7
	Protonemura	0	0	0	0	4	0	0	0	23	0	5	0	7	0	0
Trichoptera	Hydroptilidae	0	0	1	1	0	2	0	0	0	0	2	0	1	0	0
	Hydropsychidae	0	6	0	0	0	0	0	3	0	0	0	0	0	2	2
	Glossomatidae	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
	Limnephilidae	0	0	0	0	1	0	3	1	1	2	0	5	0	2	0
	Philopotamus montanus	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1
	Chimarra marginata	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
	Polycentropodidae	0	0	3	9	0	1	0	0	0	1	9	11	0	0	1
	Rhyacophilidae	0	0	0	0	1	0	0	1	0	0	0	2	1	0	1
	Sericosotomatidae	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
	unidentified	0	0	0	0	1	0	0	0	0	0	0	2	0	0	0
Oligochaeta	Oligochaete 1	0	1	0	6	0	0	0	0	0	0	0	0	0	2	0
Diptera	Ceratopogonidae	0	0	0	0	2	1	0	0	0	0	0	5	0	0	0
	Chironomidae	1	5	7	8	7	2	3	3	0	2	13	16	2	0	14
	Simuliidae	2	16	51	14	18	2	1	4	13	4	24	14	26	2	1
	Tipuliidae	0	0	0	0	0	0	2	0	0	1	0	0	1	0	0
Coleoptera	Elmidae	1	7	2	19	2	4	2	15	3	5	20	0	5	46	60
	Chrysomelidae	0	1	0	0	0	0	7	3	0	0	0	0	10	5	6
	Dytiscidae	0	0	0	0	0	0	0	0	1	1	0	0	0	7	0
	Dryopidae	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0

Appendix H. Continued

	Scirtidae	0	0	0	0	1	0	11	0	1	2	7	7	2	5	0
Odonata	Coenagrionidae	0	0	0	18	0	0	0	0	0	0	0	0	0	0	0
Bivalvia	Bivalvia	0	2	24	2	0	0	0	0	0	0	0	0	0	0	0
Gastropoda	Hydrobiidae	0	0	0	0	0	0	0	0	0	55	0	0	2	5	1
Hemiptera	Veliidae	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Acari	Acari	0	1	1	3	0	7	2	1	1	1	2	5	3	7	3
Amphipoda	Gammaridae	4	49	0	13	4	13	6	6	21	2	0	7	6	0	2

Appendix I. SIMPER results of macroinvertebrate community data displaying average dissimilarity, average abundance, contributing %, and cumulative % between the Feohanagh, Milltown, and Owenmore catchments. Cut off was set at 50% for low contributing taxa.

Taxa	**Average Abundance**		**Contribution %**	**Cumulative %**
Av. Dissim= 51.85	**Milltown**	**Owenmore**		
Hydrobiidae	1.58	0.44	6.03	6.03
Baetidae	2.72	2.12	5.34	11.36
Elmidae	1.86	1.7	4.82	16.19
Gammaridae	1.92	1.49	4.26	20.45
Simuliidae	1.88	1.83	4.22	24.67
Hydropsychidae	1.22	0.48	4.14	28.81
Ecdyonurus	0.91	0.63	3.97	32.78
Tipuliidae	1.02	0.21	3.77	36.55
Leuctra	0.82	0.9	3.64	40.19
Protonemura	0.82	0.48	3.63	43.82
Acari	0.51	1.11	33.53	47.35
Chrysomeldiae	0.85	0.62	3.51	50.86
Av. Dissim= 50.60	**Feohanagh**	**Milltown**		
Elmidae	2.79	1.86	6.91	6.91
Hydrobiidae	1.57	1.58	6.04	12.95
Baetidae	2.31	2.72	5.42	18.38
Simuliidae	1.03	1.88	5.24	23.62
Gammaridae	1.17	1.92	4.76	28.37
Ecdyonurus	0.79	0.91	3.87	32.24
Tipuliidae	0.33	1.02	3.63	35.87
Ephemerellidae	0.8	0.95	3.61	39.49
Oligochaete 1	0.98	0.54	3.46	42.95
Leuctra	0.31	0.82	3.28	46.22
Protonemura	0.57	0.82	3.26	49.48
Scirtidae	0.79	0.65	3.19	52.67
Av. Dissim= 53.01	**Feohanagh**	**Owenmore**		
Elmidae	2.79	1.7	6.59	6.59
Hydrobiidae	1.57	0.44	6.45	13.04
Baetidae	2.31	2.12	5.72	18.76
Hydropsychidae	1.33	0.48	4.85	23.61
Simuliidae	1.03	1.83	4.82	28.43
Gammarus	1.17	1.49	4.66	33.09
Ecdyonurus	0.79	0.63	4.07	37.16
Oligochaete 1	0.98	0.32	3.81	40.97

Appendix J. Mean ± standard error of the macroinvertebrates' lowest taxonomic groupings from the Feohanagh,Milltown, and Owenmore catchments of catchment-wide assessment.

Taxa	Lowest Taxonomic Grouping	Feohanagh River	Milltown River	Owenmore River
Ephemeroptera	Baetidae	66 ± 18.9	89 ± 18.4	46 ± 15.3
	Ecdyonurus	5 ± 1.7	4 ± 1.2	4 ± 2.2
	Ephemerellidae	4 ± 1.4	4 ± 1.7	3 ± 1.0
Plecoptera	*Dinocras*	1 ± 0.7	0	0
	Leuctridae	1 ± 0.4	5 ± 2.1	3 ± 1.3
	Protonemura	2 ± 1.6	3 ± 1.2	4 ± 2.7
Trichoptera	Hydroptilidae	1 ± 0.5	<1 ± 0.1	1 ± 0.2
	Hydropsychidae	8 ± 3.1	5 ± 1.1	2 ± 1.3
	Glossosomatidae	2 ± 0.8	1 ± 0.5	<1 ± 0.2
	Limnephilidae	1 ± 0.3	1 ± 0.5	1 ± 0.3
	Wormaldia	<1 ± 0.1	1 ± 0.6	0
	Philopotamus montanus	1 ± 0.5	3 ± 1.5	<1 ± 0.1
	Chimarra marginata	0	0	<1 ± 0.2
	Polycentropodidae	1 ± 0.3	1 ± 0.4	2 ± 0.8
	Rhyacophilidae	1 ± 0.4	1 ± 0.4	1 ± 0.3
	Sericostomatidae	1 ± 0.4	<1 ± 0.2	<1 ± 0.1
	unidentified	<1 ± 0.3	1 ± 0.3	<1 ± 0.1
Diptera	Ceratopogonidae	<1 ± 0.1	1 ± 0.7	<1 ± 0.3
	Chironomidae	11 ± 4.1	9 ± 2.4	8 ± 1.7
	Simuliidae	6 ± 2.7	38 ± 14.3	21 ± 7.2
	Tipulidae	1 ± 0.3	3 ± 1.3	<1 ± 0.2
Bivalvia	Planorbidae	3 ± 2.7	1 ± 0.4	2 ± 1.1
	Sphaeriidae	1 ± 0.7	3 ± 2.7	4 ± 3.3
Gastropoda	Hydrobiidae	36 ± 19.1	43 ± 20.7	7 ± 6.6
Hemiptera	Veliidae	<1 ± 0.3	<1 ± 0.2	<1 ± 0.1
Hirudinea	Hirudinea	<1 ± 0.2	<1 ± 0.1	<1 ± 0.1
Acari	Acari	2 ± 1.0	1 ± 0.7	3 ± 0.5
Oligochaeta	Oligochaete 1	5 ± 3.5	2 ± 0.8	1 ± 0.5
	Oligochaete 2	2 ± 2.1	2 ± 2.2	0
	Lumbricidae	<1 ± 0.1	<1 ± 0.1	0
Amphipoda	Gammaridae	11 ± 5.5	26 ± 7.0	18 ± 9.6
Isopoda	Asellidae	0	<1 ± 0.1	0
Coleoptera	Elmidae	103 ± 22.5	57 ± 27.3	18 ± 6.9
	Chrysomelidae	2 ± 0.7	3 ± 1.1	3 ± 1.1
	Dytiscidae	<1 ± 0.1	1 ± 0.6	<1 ± 0.2
	Dryopidae	0	0	<1 ± 0.4
	Scirtidae	3 ± 1.2	2 ± 0.9	2 ± 0.7
Odonata	Coenagrionidae	0	0	1.5 ± 1.5

Appendix K. Total organism abundance, percentage, and number of taxa within each Q-value group from the Owenmore catchment's sample sites.

Q-Value Grouping	OR.1	OR.2	OR.3	OR.4	OR.5	OR.6	OR.7	OR.8	OR.9	OR.10	OR.11	OR.12	OR.13	OR.14	OR.15
Total Organism Abundance															
Group A	13	1	0	0	15	31	0	0	40	0	3	0	14	1	0
Group B	184	29	7	23	108	42	51	187	64	30	11	12	30	6	14
Group C	26	271	198	89	71	31	36	126	70	148	41	30	78	33	158
Group D	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Group E	0	2	1	7	0	0	0	0	0	0	0	0	0	1	0
Percentage															
Group A	6	0	0	0	8	30	0	0	23	0	5	0	11	2	0
Group B	83	10	3	19	56	40	59	60	37	17	20	29	25	15	8
Group C	12	89	96	75	37	30	41	40	40	83	75	71	64	80	92
Group D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Group E	0	1	0	6	0	0	0	0	0	0	0	0	0	2	0
Number of Taxa															
Group A	1	1	0	0	2	1	0	0	1	0	1	0	2	1	0
Group B	2	3	4	2	2	2	4	4	3	2	3	3	3	3	2
Group C	8	12	9	9	10	8	10	12	8	12	6	9	11	8	12

Appendix L. Total organism abundance, percentage, and number of taxa within each Q-value group from the Feohanagh catchment's sample sites.

Q-Value	FR.1	FR.2	FR.3	FR.4	FR.5	FR.6	FR.7	FR.8	FR.9	FR.10	FR.11	FR.12	FR.13	FR.14	FR.15
Total Organism Abundance															
Group A	20	18	18	12	0	1	3	3	0	2	41	0	0	5	0
Group B	143	49	34	37	25	79	244	151	65	7	201	6	0	17	0
Group C	141	51	123	25	34	41	287	377	309	521	124	152	173	329	214
Group D	0	0	0	0	0	0	1	1	0	0	0	2	0	0	0
Group E	0	3	2	2	0	1	2	3	3	85	0	3	3	3	0
Percentage															
Group A	7	15	10	16	0	1	1	1	0	0	11	0	0	1	0
Group B	47	40	19	49	42	65	45	28	17	1	55	4	0	5	0
Group C	46	42	69	33	58	34	53	70	82	85	34	93	98	93	100
Group D	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Group E	0	2	1	3	0	1	0	1	1	14	0	2	2	1	0
Number of Taxa															
Group A	2	2	2	1	0	1	1	1	0	1	3	0	0	2	0
Group B	3	4	4	1	2	3	3	3	3	3	5	1	0	2	0
Group C	11	10	10	7	12	9	6	12	8	14	8	13	9	11	4
Group D	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0
Group E	0	1	1	1	0	1	1	2	1	2	0	1	1	2	0

Appendix M. Total organism abundance, percentage, and number of taxa within each Q-value group from the Milltown catchment's sample sites.

Q-Value Grouping	MR.1	MR.2	MR.3	MR.4	MR.5	MR.6	MR.7	MR.8	MR.9	MR.10	MR.11	MR.12	MR.13	MR.14	MR.15
Total Organism Abundance															
Group A	4	1	3	19	5	0	0	14	6	4	8	10	0	9	17
Group B	181	54	5	154	81	0	44	29	210	195	103	10	95	151	124
Group C	430	327	27	36	62	72	107	57	163	73	236	44	209	435	790
Group D	0	0	0	2	0	0	0	1	0	1	1	0	0	0	0
Group E	0	1	0	0	0	39	12	1	0	0	6	4	0	0	1
Percentage															
Group A	1	0	9	9	3	0	0	14	2	1	2	15	0	2	2
Group B	29	14	14	73	55	0	27	28	55	71	29	15	31	25	13
Group C	70	85	77	17	42	65	66	56	43	27	67	65	69	73	85
Group D	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0
Group E	0	0	0	0	0	35	7	1	0	0	2	6	0	0	0
Number of Taxa															
Group A	1	1	2	2	1	0	0	1	2	2	2	1	0	2	1
Group B	3	4	1	1	3	0	2	2	2	2	4	3	3	4	4
Group C	15	14	9	8	13	5	10	11	14	15	12	8	13	14	14
Group D	0	0	0	2	0	0	0	1	0	1	1	0	0	0	0
Group E	0	1	0	0	0	2	2	1	0	0	2	2	0	0	1