Determining the value of the Citizen Science Stream Index in assessing water quality

Madelief Smets

CARL Research Project
in collaboration with
Tracton Biodiversity Group

CARL
COMMUNITY - ACADEMIC
RESEARCH LINKS
University College Cork, Ireland

Name of student(s):	Madelief Smets
Name of civil society organisation/community group:	Tracton Biodiversity Group
Name of community group liaison person:	Mary Cunningham and Patricia O'Flaherty
Academic supervisor(s):	Dr. Simon Harrison
Name and year of course:	BSc Ecology and Environmental Biology 4
Date completed:	24/02/2023

What is Community-Academic Research Links?

Community Academic Research Links (CARL) is a community engagement initiative provided by University College Cork to support the research needs of community and voluntary groups/ Civil Society Organisations (CSOs). These groups can be grass roots groups, single issue temporary groups, but also structured community organisations. Research for the CSO is carried out free of financial cost by student researchers.

CARL seeks to:

- provide civil society with knowledge and skills through research and education;
- provide their services on an affordable basis;
- promote and support public access to and influence on science and technology;
- create equitable and supportive partnerships with civil society organisations;
- enhance understanding among policymakers and education and research institutions of the research and education needs of civil society, and
- enhance the transferrable skills and knowledge of students, community representatives and researchers (www.livingknowledge.org).

What is a CSO?

We define CSOs as groups who are non-governmental, non-profit, not representing commercial interests, and/or pursuing a common purpose in the public interest. These groups include: trade unions, NGOs, professional associations, charities, grass-roots organisations, organisations that involve citizens in local and municipal life, churches and religious committees, and so on.

Why is this report on the UCC website?

The research agreement between the CSO, student and CARL/University states that the results of the study must be made public through the publication of the final research report on the CARL (UCC) website. CARL is committed to open access, and the free and public dissemination of research results.

How do I reference this report?

Author (year) *Dissertation/Project Title*, [online], Community-Academic Research Links/University College Cork, Ireland, Available from: http://www.ucc.ie/en/scishop/completed/ [Accessed on: date].

How can I find out more about the Community-Academic Research Links and the Living Knowledge Network?

The UCC CARL website has further information on the background and operation of Community-Academic Research Links at University College Cork, Ireland.

http://carl.ucc.ie. You can follow CARL on Twitter at @UCC_CARL. All of our research reports are accessible free online here: http://www.ucc.ie/en/scishop/rr/.

CARL is part of an international network of Science Shops called the Living Knowledge Network. You can read more about this vibrant community and its activities on this website: http://www.scienceshops.org and on Twitter @ScienceShops. CARL is also a contributor to Campus Engage, which is the Irish Universities Association engagement initiative to promote community-based research, community-based learning and volunteering amongst Higher Education students and staff.

Are you a member of a community project and have an idea for a research project?

We would love to hear from you! Read the background information here http://www.ucc.ie/en/scishop/ap/c&vo/ and contact us by email at carl@ucc.ie.

Disclaimer

Notwithstanding the contributions by the University and its staff, the University gives no warranty as to the accuracy of the project report or the suitability of any material contained in it for either general or specific purposes. It will be for the Client Group, or users, to ensure that any outcome from the project meets safety and other requirements. The Client Group agrees not to hold the University responsible in respect of any use of the project results. Notwithstanding this disclaimer, it is a matter of record that many student projects have been completed to a very high standard and to the satisfaction of the Client Group.

University College Cork, Ireland
Coláiste na hOllscoile Corcaigh

Determining the value of the Citizen Science Stream Index in assessing water quality

Madelief Smets
119721175

School of Biological, Earth and Environmental Sciences,
University College Cork.

This thesis is submitted in accordance with the academic requirements of University College Cork as partial requirement for the degree of Bachelor of Science in Ecology and Environmental Biology.

Supervisor: Dr. Simon Harrison

Submitted to University College Cork on the 24/02/2023

Total Word Count: 5,647

Abstract

Freshwater ecosystems are increasingly under threat, experiencing declines in both area and quality. In response to this, there has been an increasing demand to monitor these systems. Citizen science has been an increasingly suggested method to aid in resolving this issue. Citizen science is a practice in which people from the public, who are untrained as scientists, aid in data collection for scientific research. An advantage of using citizen science is that it increases spatial and temporal coverage reaching beyond conventional, laboratory-based, monitoring programs. The Citizen Science Stream Index (CSSI) is an Irish biotic river water quality index that has been designed especially for citizen science. This study aimed to determine the validity of this index using the Minane River in County Cork, Ireland, as a study site. A kick sampling method was used to collect 22 macroinvertebrate field samples in the autumn of 2022. These samples were assigned a CSSI field score, and scores of several conventional biological water quality indices. Correlations between the CSSI and conventional indices showed significant results for a few biotic water quality indices, suggesting that the CSSI may be able to contribute towards monitoring river water quality in Ireland.

[word count: 196]

Declaration

I declare that this research is entirely my own original work and has not been submitted for any other awards at this or any other academic establishment. Where the work of others has been utilised here within, it has been fully acknowledged and referenced.

Madelief Smets

Acknowledgements

A big thank you to all the staff in the BEES department for their support throughout my degree, especially Simon Harrison for supervising and helping me with this project. Special thanks must be given to William O'Halloran (Wild Work Ireland) for organizing connections with the Tracton Biodiversity Group for this project, and to Mary Cunningham and Patricia O'Flaherty from the Tracton Biodiversity Group for their local insights in the study area and help with the project. Thanks to my friends and family for their continued support.

Table of Contents

List of Tables

List of Figures

1. Introduction

1.1 Importance of good ambient water quality

Water is one of the most important natural resources on Earth, forming an essential part of many social, economic and environmental activities (Ward and de Bruin, 2018). Freshwater ecosystems provide many ecosystem services, including provisioning services such as water for drinking (after treatment), for agricultural and industrial use, generating power; as well as regulatory services, for example maintaining water quality through natural filtration; cultural services, including recreation, tourism, and existence values; and supporting services through their role in nutrient cycling and primary production, as well as providing predator / prey relationships (Millennium Ecosystem Assessment, 2005). Though freshwaters account for less than 1% of the Earth's surface, they support close to 6% of all described species and about 9.5% of all animal species on Earth (Dudgeon et al., 2006; Dudgeon, 2019). However, freshwater ecosystems are under increasing threat, experiencing declines in both area coverage as well as biodiversity (Malmqvist and Rundle, 2002; IPBES, 2019; Kelly-Quinn et al., 2020; Vari et al., 2021). Seeing that freshwaters are under threat, various organizations and political bodies have set goals, frameworks and directives to restore and protect these ecosystems. The European Union has developed the Water Framework Directive 2000/60/EC (WFD), which aims to improve water quality across Europe as well as protect water resources, to ensure long-term and sustainable use. Under the WFD, the Member States are required to create a River Basin Management Plan (RBMP). These plans set out environmental objectives for a river basin planning cycle, which is a six-year period allowing for assessment, planning, implementation, as well as review of the environmental objectives and changes made. Similar to the EU, the United Nations recognize the threat to (fresh)water in their Sustainable Development Goals (SDGs) and the 2030 Agenda, where SDG 6 is completely devoted to "ensuring availability and sustainable management of water and sanitation for all" (United Nations, 2018). The UN also identifies that having reliable water quality monitoring data forms an essential part in restoring and protecting freshwaters, as this data provides information on status and trends, and can inform policy makers (UNEP, 2018). In the UN 2018 SDG indicator 6.3.2 progress report, the UN has identified a gap in water quality data and has suggested using citizen science, among other approaches, to fill this data gap (UNEP, 2018).

1.2 Water Quality in Ireland

Water quality in the Republic of Ireland is monitored and managed by the Irish Environmental Protection Agency (EPA). Ireland's river water quality scores well in comparison with Europe (EPA, n.d. a). However, according to the EPA the number of rivers and streams in Ireland with satisfactory ecological quality has declined by 1% since the last reporting period in 2013-2018 (EPA, 2022b). In the period 2016-2021, the EPA found that just over 50% of Irish rivers had good ecological status, and almost half of the rivers were assigned moderate or worse status with 18.5% being severely polluted and in poor or bad status (EPA, 2022b). High nutrient levels form one of the threats to river water quality, as 43% of rivers were found to have unsatisfactory nitrate concentrations (>8 mg/L NO_3) and 30% had phosphorus concentrations higher than 0.035 mg/l P, meaning they are of unsatisfactory status (EPA, 2022b). Of the sites researched by the EPA, 17% have increasing phosphorus concentrations (EPA, 2022b). The EPA identifies that these high concentrations of phosphorus are primarily caused by nutrient run-off from agriculture as well as wastewater discharge.

In 2003, the EPA was appointed as the competent authority to implement the WFD in Ireland (Barr and Thompson, 2004). In response to the WFD and the need for an RBMP, the EPA set up the EPA WFD Monitoring Programme in 2006 (EPA, 2021). The programme aims to provide a representative picture of the water quality status of rivers throughout the country, and assess the effectiveness of protection and restoration measures. Besides adhering to the requirements for the WFD, the programme also ensures other water monitoring requirements are included, such as the Nitrates Directive (Directive 91/676/EEC). A consultation report for the Irish River Basin Management Plan 2022-2027 identified several areas of improvement in order to better monitor, protect and restore rivers. One of the key areas of improvement they identified was that the current plan contains an inadequate number public participation measures (RPS, 2022). One such measure is to increase the role for citizen science programmes.

1.3 Water quality parameters

Water quality is often measured by looking at multiple parameters that fall in three broad categories, namely biological, physical, and chemical (Swamee and Tyagi, 2007). Examples of physicochemical parameters are temperature, electrical conductivity, pH, dissolved oxygen, phosphate concentrations, and nitrate concentrations among others (Chapman, 1996). Physical and chemical monitoring reflect the conditions of the water at the time the sample was taken, while biological parameters can provide information about past as well as current conditions (Muralidharan et al., 2010). Biological monitoring is based on the idea that different species will have varying tolerances to pollution, meaning that changes in water quality, for example because of pollution, are reflected in the species composition of resident biota (Rosenberg and Resh, 1993; Harding et al., 1999; Muralidharan et al., 2010). Aquatic macroinvertebrates are often used as bioindicators of water quality, as they have varying tolerances to pollution, and integrate as well as reflect the effects of stress (Mason, 2002; Masese et al., 2009; Muralidharan et al., 2010). Species known to be tolerant to pollution indicate bad water quality, whereas species sensitive to pollution indicate good water quality. These species are adapted to specific environmental conditions, and changes in these conditions such as through pollution, will result in some species disappearing (intolerant) and be replaced by others (tolerant) (Benetti et al., 2012). Therefore, the community composition of macroinvertebrates is a good indicator of water quality over extended periods of time. In order to present this data in a consolidated and easily understandable manner, water quality indices have been created. These indices are created based on combinations of selected water quality parameters, resulting in a single dimensionless score that indicates the water quality (Mason, 2002; Rosenberg and Resh, 1993; Sutadian et al., 2016). They make it easy to compare water quality across time and space, find trends, as well as provide easy to understand information to authorities allowing for better river management (Sutadian et al., 2016). Many different indices have been created, often specific to a particular country or region (Sutadian et al., 2016). An example of a water quality index in Ireland is the Q-Value which was created by the EPA to score rivers for the WFD (Toner et al., 2005). Many indices are also taken and adapted to fit a specific country or region, such as the Biological Monitoring Working Party index, which was initially created for Britain, but now contains many variations to fit other areas, such as the Andean Biotic Index for the Andes, or the BMWP-CR score for Costa Rica (Hawkes, 1998; Díaz et al., 2012; Ríos-Touma et al., 2014)

1.4 Citizen Science

In response to the declining ambient water quality in Ireland, the involvement of citizen science in water quality monitoring has grown (Weiner et al., 2022). Citizen science refers to individuals, who are untrained as scientists, participating in scientific projects (Silvertown, 2009; Bonney et al., 2014; Quinlivan et al., 2020). Despite the vast amount of data and information that is acquired through citizen science, citizen science is still not a universally accepted method for collecting scientific data (Bonney et al., 2014). Scientists publishing research papers which present citizen science data might experience difficulties getting peer reviewed (Bonney et al., 2014). However, citizen science can provide many benefits, both in terms of research and in society. Firstly, citizen science allows for obtaining scientific data at larger spatial or temporal scales and resolutions than would be possible by individual researchers, for example due to time or financial constraints (Dickinson et al., 2012; Bonney et al., 2014; McKinley et al., 2017; Turrini et al., 2018). Besides generating new knowledge, citizen science provides an opportunity for in-depth learning about science and the environment for non-scientists (Turrini et al., 2018). In turn, this raises awareness about environmental issues, as well as provide an opportunity for civic participation in science, decision- and policy-making (Turrini et al., 2018).

1.5 Citizen Science Stream Index

An example of a water quality index that has been developed to engage citizens in ambient water quality monitoring is the Citizen Science Stream Index (CSSI). The CSSI was developed by Dr Simon Harrison, University College Cork, and is supported by the Local Authority Waters Programme (LAWPRO) and the EPA (LAWPRO, n.d.) (Appendix 1). The aim of this index is to provide a simple way of determining stream and river quality, which can be used for citizen science research and monitoring. The index is based on the presence or absence of six water quality indicator taxa. Three of these taxa are sensitive to pollution, namely stoneflies (Plecoptera), flattened mayflies (Heptageniidae), and green caddisflies (Rhyacophilidae). The other three taxa in the index are tolerant to pollution and are thus indicators of bad water quality, which include leeches (Hirudinea), snails (Gastropoda), and waterlouse (Asellidae). To calculate the CSSI score for the stream quality, citizen scientists take three separate kick samples, which are then analysed for the presence or absence of these six taxa. The presence of each pollution sensitive indicator species results in +1, and a pollution tolerant indicator species in -1. For three samples, this then results in a score of -9 to +9, where a score of -9 to -5 indicates bad water quality, -4 to +4 moderate quality, and +5 to +9 indicates good water quality.

1.6 Aims of the project

This study aimed to determine the stream water quality of the Minane River, which is located in the southeast of County Cork, Ireland. Furthermore, the study explored whether the Citizen Science Stream Index (CSSI) can reliably be used to indicate water quality in Irish streams and rivers. The validity of the CSSI was evaluated through comparison with conventional water quality indices, including the Q-value, Biological Monitoring Working Party index (BMWP), the Average Score Per Taxon (ASPT), and the Small Stream Risk Score (SSRS). Furthermore, the project aimed to identify whether the CSSI would be a good indicator for phosphorus and conductivity levels in watercourses. Therefore, both biological and physicochemical analyses of the stream water quality were performed. Additionally, alternative methods to the CSSI for citizens to determine and monitor water quality were explored, specifically conductivity, temperature, and phosphorus measurements. This was done by exploring correlations between these parameters and conventional water quality indices (Q-Value, BMWP, ASPT, SSRS, CSSI).

[Word count: 1,767]

2. Materials & Methods

2.1 Site description

The study site is a river, called the Minane River, which forms a part of a sub-catchment located between Carrigaline and Kinsale in County Cork, Ireland (51°45’39.8”N and 8°23’38.4”W) (Figure 1). The total area of the sub-catchment is approximately 163 km^2, while the site studied is roughly 17 km^2. The Minane River feeds into the Celtic Sea and has six main tributaries that feed into the river as well as numerous smaller stream tributaries. Some of these smaller tributaries are seasonal, while others are present year-round. The river also passes a dam before entering the sea, which functions as a flood relief measure. The study area also contains a ‘Groundwater Drinking Protection Area’, which means that this area is protected from contamination for groundwater abstraction (Figure 1) (Kelly & Wright, 2002). The area also contains many boreholes as well as springs and wells (Geological Survey Ireland, n.d.). The long term average temperature is 9.9°C and the long term average annual rainfall is 1228.0 mm (MetEireann, 2022). The land use in the Minane catchment predominantly consists of agriculture (approximately 97%) (Figure 2). The landscape contains elevation differences ranging from 100m to 50m above sea level at the start of the river and 2m above sea level at the bottom of the valley. These elevation differences between the start and bottom of the river could result in high oxygenation of the streams and rivers.

Figure 1. Map showing the Minane catchment and location in Ireland, with sample sites and CSSI scores (EPA, 2020).

The watercourses and sample sites were initially identified from preliminary desk studies using aerial photographs from the EPA and Ordnance Survey Ireland (EPA, 2020a; Government of Ireland and OSI, 2022). This resulted in a total of 36 sites being identified for assessment. Macroinvertebrate samples were only taken when sites were found to be accessible with a firm, gravelly river bed, had a shallow depth, and were present year-round. Physicochemical samples were taken from all sites selected for biological analysis, as well as sites that were deemed unsuitable for biological analysis due to an unsuitable river bed, or high river depths. Out of the 36 locations initially identified, only 22 were sampled for biological analysis and 27 for physicochemical analysis (8 were inaccessible, 4 were deemed too deep, and 2 had unsuitable river beds) (Figure 1). During sample collection in the field, two physicochemical samples were added. One stream potentially being farmyard runoff, and one being a potential field runoff input into the stream.

Figure 2. Map of Minane catchment, County Cork, Ireland, showing Corine Landcover types (EPA, 2018). The map indicates that the landcover of the catchment is predominantly agriculture based (Corine types: 211, 231, 242, 243).

2.2 Field Procedure

Macroinvertebrate samples for the biological water quality analysis were collected using a standard hand net with a metal frame and conical net. The net head width was 200 mm with a mesh size of 1mm. To collect the macroinvertebrate samples, a kick sampling method was used. During this procedure the gravel on the riverbed in front of the net is kicked up and what is disturbed is then collected in the net. The kick sampling was done in the fastest flowing part of the stream, as these are the areas least likely to dry up during dry periods. Each kick sample lasted for 30 seconds while moving upstream with the net. Large stones and leaves caught in the net were washed in the net to ensure that all macroinvertebrates were collected. For each site, this process was done three times. Every sample was taken in a different part of the stream site. Each of the samples was poured into a white tray with 1 cm of water and analyzed on the riverbank for a minimum of 5 minutes. The CSSI score was determined for each of the samples and the total CSSI score for the site calculated, following the methodology outlined on the CSSI leaflet provided to citizens (Appendix 1). Two of the three samples were conserved in a plastic bag with 70% ethanol, resulting in a one-minute kick-sample for further lab analysis. In total, 22 sites were sampled for biological water quality. The samples were collected from October to November, 2022.

For the physicochemical analysis of the water quality, a 500 mL water sample was collected. These samples were frozen within 12 hours of collection to ensure preservation. Conductivity and temperature of each of the sites were measured in situ using a portable conductivity meter (Cond 3110), ensuring the meter had been calibrated on the same day to follow good practice guidelines and ensure instrument reliability. These samples were collected in January 2023, after a three day period with little to no rain to avoid dilution. In total, 29 sites were sampled for physicochemical analysis.

2.3 Lab Procedure

The macroinvertebrate samples were washed and filtered using a sieve with an aperture of 500μm. The sample was placed in a white tray (30 cm by 21 cm) with 1 cm water. Using forceps and a stereoscopic dissection microscope the organisms were systematically sorted out of the tray and placed in small flasks (25 mL). These were also preserved using 70% ethanol. After sorting, the macroinvertebrates were identified to a family level using a stereoscopic dissection microscope and identification keys for macroinvertebrates in Irish streams and rivers.

The 500 mL water samples were defrosted and analyzed within 24 hours of leaving the freezer. Ensuring that all glassware used for the measurements has been acid washed to avoid invalid readings, phosphate (PO_4^{3-}) levels were measured using a spectrophotometer (Hach Lange DR2800 VIS Spectrophotometer using the 490 P React. PV program). These phosphate levels were converted to phosphorus levels to allow for comparison to Irish standards.

2.4 Score calculation

Macroinvertebrate data were used to derive the CSSI score in the field, while the lab data were used to derive other biological water quality scores, including the Q-value, Small Stream Risk Score (SSRS), the Biological Monitoring Working Party score (BMWP), and the Average Score Per Taxon (ASPT). These scores were selected to compare to the CSSI as they are commonly used to measure water quality in Irish streams or were specifically designed for Britain and Ireland (Hawkes, 1998; Toner et al., 2005; Ryan et al., 2015). The Q-value was determined using the guidelines outlined by the EPA (Appendix 2). The Q-value is based on the presence of specific species from varying taxa and approximate percentage frequency of occurrence of these taxa (Toner et al., 2005). The SRSS was calculated following the guidelines outlined by the EPA (Appendix 3). The SSRS is based on the presence and relative abundance of specific taxa (Ryan et al., 2015). It should be noted that the SSRS is a score that indicates whether a stream is at risk of pollution, so it does not indicate the ecological quality of a stream (Ryan et al., 2015). The BMWP score calculated using the values and guidelines of the National Water Council (1981) (Appendix 4). The BMWP score is based on the presence or absence of families that are tolerant or sensitive to pollution, where pollution-sensitive families are given a higher score than families tolerant to pollution (Hawkes, 1998). The ASPT score was also calculated as this provides a score that is less sensitive to the sampling effort and seasonal changes, as it is independent of the number of taxa in the sample (Hawkes, 1998). This score was calculated using the guidelines of Jones (1973) and Balloch et al. (1976), where the BMWP score is divided by the number of scoring taxa. The scores for all indices and their interpretations are summarized in Table 1. Lastly, ecological parameters like the total abundance, taxon richness, the Simpson's diversity index and the percentage of Ephemeroptera / Plecoptera / Trichoptera (%EPT) were calculated.

Table 1. Water Quality Indices Scores and Interpretations (Toner et al., 2005; Ryan et al., 2015; Hawkes, 1998).

CSSI		**BMWP**		**ASPT**		**SSRS**		**Q-Value**	
Score	*Interpretation*	*Score*	*Interpretation*	*Score*	*Interpretation*	*Score*	*Interpretation*	*Score*	*Interpretation*
-9 to -5	Poor	0 - 10	Very Poor	<3.9	Very poor	<6.5	Stream at risk	Q2, Q2-1, Q1	Bad
		11 - 40	Poor	4 – 4.9	Poor			Q2-3, Q3	Poor
-4 to +4	Moderate	41 - 70	Moderate	5 – 5.9	Moderate	>6.5 – 7.25	Intermediate, stream may be at risk	Q3-4	Moderate
+5 to +9	Good	71 - 100	Good	6 – 6.9	Good	>7.25	Stream probably not at risk	Q4, Q4-5	Good
		>100	Very Good	>7.0	Very Good			Q5	High

2.5 Data Analysis

Data was processed and analyzed using IBM's SPSS statistical software package, and R for non-metric multidimensional scaling ordination. Spearman Rank Correlations were performed comparing the CSSI to other conventional indices, including the SSRS, BMWP and ASPT. Furthermore, the CSSI was also compared to physicochemical indicators of water quality, including temperature, conductivity, and phosphorus levels. Lastly, the CSSI was compared to several biological scores, including Simpson's Diversity Index, total species richness, total abundance, and %EPT. Mann-Whitney U-tests were performed to determine if there were significant differences in ecological parameters between 'poor', 'moderate', and 'good' CSSI scoring sites. Significant results were accepted at 95% confidence level. Additionally, a non-metric multidimensional scaling (NMDS) ordination was performed using the Bray-Curtis distance measure to determine the similarity of the species community structure of sites with similar CSSI scores.

[Word Count: 1,389]

3. Results

3.1 Macroinvertebrates

In total, twenty-two macroinvertebrate samples were collected and analyzed, resulting in a total of 8772 individuals belonging to different 45 families being recorded in the catchment, with individual sites recording between 13 and 25 families, and an overall mean of 18 (S.D. 3.26) (Table 2). The three sites with the greatest taxon richness of 24 families, had CSSI scores of +6, 0 and -2. There was no significant difference between the taxon richness of 'good' and 'moderate' CSSI scoring sites (U = 29.0, p = .58).

Total abundance varied between sites, with individual sites recording between 32 and 1239 individuals. Figure 3 illustrates the distribution of species abundance for sites with a 'good' CSSI score and a 'moderate' score. The sites with a 'good' CSSI score (n = 4) show a more equal abundance distribution with a total of 35 species, whereas the 'moderate' scoring sites (n = 18) show unequal abundances with slightly more species (42 species). There was no significant difference between the total abundance for 'good' and 'moderate' scoring CSSI sites (U = 17.0, p = .12).

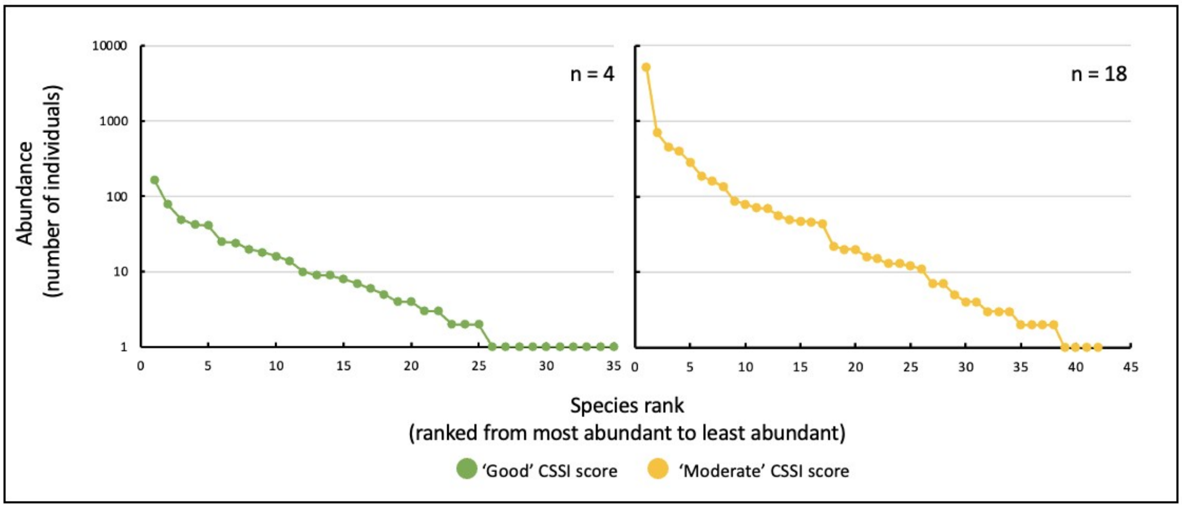


Figure 3. Differences between communities in equitability of abundances on a log scale for 'good' (n = 4) and 'moderate' (n = 18) CSSI scoring sites.

Table 2. Aquatic macroinvertebrates in the Minane River catchment (2022).

Class	Order	Family
Crustacea	Isopoda	Asellidae
	Amphipoda	Gammaridae
Hirudinea	Hirudinea	Erpobdellidae
		Glossiphoniidae
Insecta	Coleoptera	Dytiscidae
		Elmidae
		Gyrinidae
		Hydrophilidae
		Scritidae
	Diptera	Ceratopogonidae
		Chironomidae
		Dixidae
		Limoniidae
		Pediciidae
		Psychodidae
		Ptychopteridae
		Simuliidae
		Tipulidae
	Ephemeroptera	Baetidae
		Heptageniidae
	Plecoptera	Chloroperlidae
		Leuctridae
		Nemouridae
		Perlodidae
	Trichoptera	Goeridae
		Glossosomatidae
		Hydropsychidae
		Lepidostomatidae
		Limnephilidae
		Odontoceridae
		Philopotamidae
		Polycentropodidae
		Rhyacophilidae
		Sericostomatidae
Mollusca	Gastropoda	Hydrobiidae
		Lymnaeidae
		Physidae
		Planorbidae
		Planorbidae (*Ancylus* only)
	Bivalvia	Sphaeridae
Oligochaeta	Oligochaeta	Haplotaxidae
		Lumbricidae
		Other Oligochaeta
Turbellaria	Tricladida	Planariidae

The mean total abundance was 401 individuals (S.D. 363.11). Species were not evenly distributed, as 10 out of the 45 species found make up 92% of the overall abundance, see Table 3. Several families only occurred once throughout all samples. These species include, Haplotaxidae, Dytiscidae, Lymnaeidae, Physidae, Perlodidae, and Planoriidae.

Table 3. The percentage of total abundance for the 10 most abundant species in the Minane catchment.

Species	Percentage of total abundance
Hydrobiidae	60.7%
Simulidae	8.5%
Gammaridae	6.0%
Glossosomatidae	4.6%
Hydropsychidae	3.7%
Chironomidae	2.2%
Philopotamidae	2.0%
Elmidae	1.8%
Sericostomatidae	1.1%
Polycentropodidae	1.0%
Other	8.4%

Simpson's Diversity Index varied from 0.17 to 0.90 between individual sites, with a mean score of 0.64 (S.D. 0.23). The mean for 'Good' CSSI scoring sites was 0.82 (S.D. 0.03), while the mean for 'Moderate' CSSI sites was 0.60 (S.D. 0.05). There was no significant difference between the median Simpson's Diversity Index for 'good' and 'moderate' CSSI scoring sites ($U = 15.0$, $p = .081$).

Furthermore, the percentage of Ephemeroptera / Plecoptera / Trichoptera (%EPT) were calculated for each of the sites. This varied between individual sites from 20.0% to 53.8%, with a mean of 42.4% (S.D. 8.6).

3.2 Biological stream quality in the catchment

Several indices were calculated using the macroinvertebrate samples to determine the biological water quality of the sites (Table 4). Of the sites studied, 18.2% (n = 4) were given a score of 'good' in the CSSI, and 81.8% (n = 18) were given a 'moderate' score (Figure 4 & 5). No sites with 'bad' quality were found. The mean CSSI score was 1.4 (S.D. = 3.0) maximum and minimum CSSI score found within the catchment was +7 and -3, respectively.

Table 4. Water quality scores, metric scores, taxon richness, total abundance, Simpson's Diversity Index, and physicochemical parameters for each sample site and a potential input (site 26 is a stream with potential farmyard runoff, and P.I. is a potential input from field runoff feeding into site 23).

Sample Site	CSSI	BMWP	ASPT	Q-value	SSRS	%EPT	Taxon Richness	Total Abundance	Simpson's Diversity	Conductivity (µS/cm)	Phosphorus (mg/L P)	Temperature (°C)
1	4	61	5.5	Q3	7.2	33.3	14	46	0.90	280	0.08	10.0
2	2	84	5.3	Q3-4	6.4	38.1	18	671	0.49	320	0.06	9.7
3	0	50	4.5	Q3	6.4	33.3	15	81	0.43	244	0.06	9.7
4	3	83	5.9	Q4	8.0	44.4	17	55	0.89	186	0.07	9.6
5	-1	63	5.3	Q3	3.2	35.7	13	203	0.33	161	0.08	8.4
6	7	67	6.1	Q4	8.8	53.8	13	32	0.82	273	0.07	10.1
7	6	88	4.9	Q3	4.8	27.3	22	105	0.86	282	0.08	10.0
8	6	127	6.0	Q3-4	8.0	48.0	24	207	0.73	292	0.08	9.9
9	3	85	5.7	Q3	8.0	42.1	18	101	0.87	232	0.07	9.5
10	6	111	6.2	Q3-4	7.2	50.0	19	232	0.88	274	0.09	9.3
11	0	103	5.7	Q3	5.6	37.5	22	226	0.80	275	0.07	9.3
12	0	87	5.8	Q3-4	4.8	36.8	17	495	0.67	314	0.07	9.8
13	-1	106	5.6	Q3	3.2	45.5	21	967	0.35			
14	1	98	5.8	Q3	5.6	47.6	20	1239	0.72	406	0.10	10.3
15	0	117	6.2	Q3	4.8	48.0	23	585	0.59	298	0.08	9.7
16	-2	106	5.6	Q3	4.0	40.0	23	501	0.85	294	0.08	9.6
17	0	89	5.6	Q3-4	6.4	45.0	19	358	0.61	305	0.09	9.1
18	-3	72	5.1	Q3-4	4.0	29.4	16	275	0.63	305	0.08	9.7
19	-2	33	4.7	Q3	2.4	20.0	15	1176	0.17	309	0.08	10.7
20	3	84	5.6	Q3-4	6.4	47.1	17	751	0.27	423	0.05	9.7
21	-2	81	5.4	Q4	7.2	44.4	18	114	0.80	327	0.07	10.1
22	1	72	5.1	Q3	4.8	41.2	17	398	0.48	334	0.07	10.1
23										347	0.07	9.5
24										358	0.08	12.0
25										290	0.08	9.2
26										523	0.19	
27										327	0.12	
28										305	0.08	9.7
P.I. 1										561	0.29	9.1

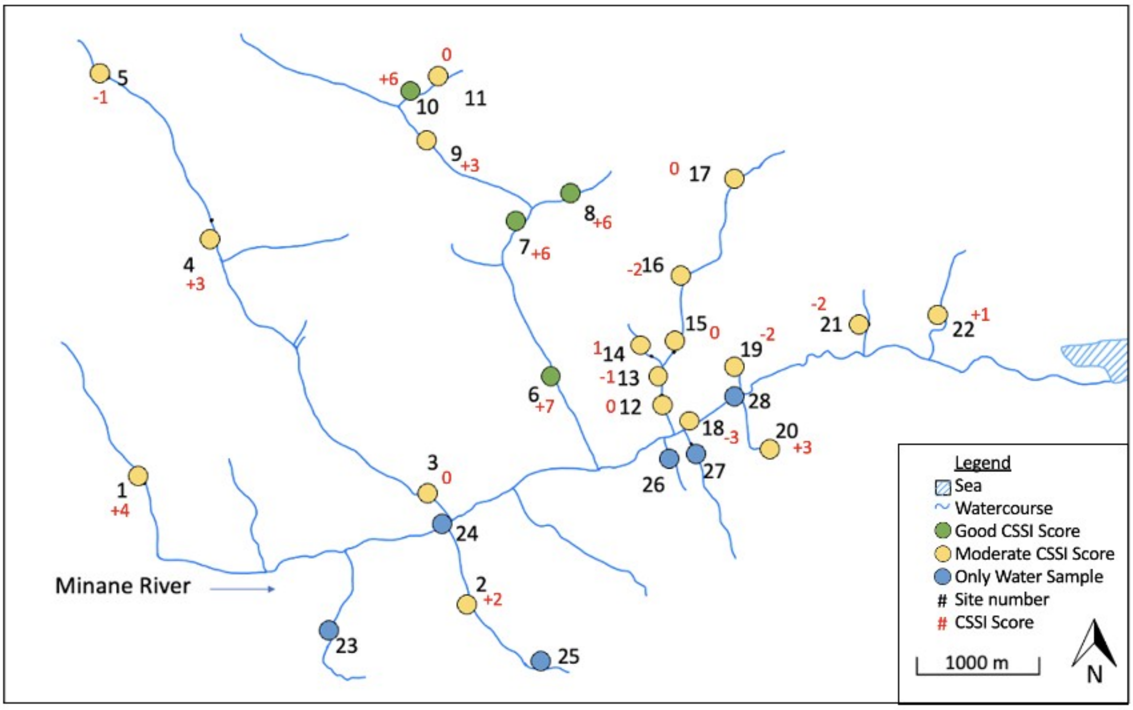


Figure 4. Map showing the Minane River catchment, and sample sites with water quality scores from the Citizen Science Stream Index.

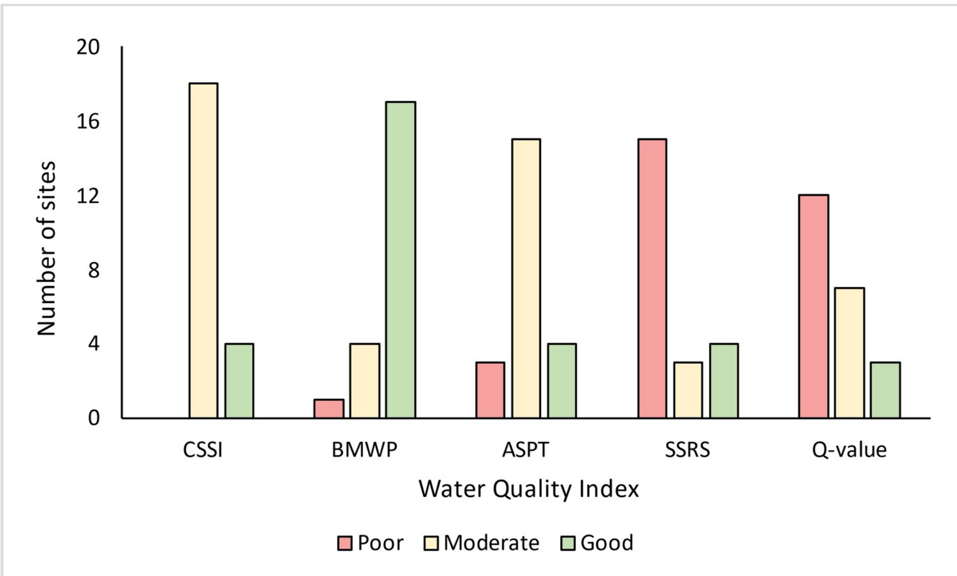


Figure 5. Interpretations of the scores of several water quality indices (CSSI, BMWP, ASPT, SSRS).

In total, 27.2% (n = 6) of sites were given a score of 'very good' in the BMWP index, 50% (n = 11) of sites were considered 'Good', 18.2% (n = 4) of sites were considered 'Moderate', and 4.5% of sites were considered 'Poor'. No sites fell into the 'Very Poor' category. The mean BMWP score was 85 (S.D. 22.4), with a minimum of 33 and a maximum of 127. In terms of the ASPT index, 13.6% (n = 3) of sites were considered 'Poor', 68.2% (n = 15) of sites scored in the 'Moderate' category, and 18.2% (n = 4) were considered 'Good'. No sites scored in the 'Very Poor' or 'Very Good' categories. The mean ASPT score was 5.5 (S.D. 0.45), with a minimum score of 4.5 and a maximum score of 6.2. In total, 68.2% (n = 15) of sites were considered 'At Risk' according to the SSRS, 13.6% (n = 3) of sites might be at risk, while 18.2% (n = 4) of sites were considered to be 'Not at risk'. The mean SSRS score was 5.8 (S.D. 1.8), with a minimum score of 2.4 and a maximum score of 8.8. As for the Q-value, 54.5% (n = 12) sites fell into the 'poor' water quality category, 31.8% (n = 7) was considered 'moderate', and 13.6% (n = 3) was considered to be of 'good' water quality. The mean Q-value was 3.3 (S.D. 0.4).

3.3 Physicochemical stream quality in the catchment

Water temperature was measured at each site (Figure 6). The mean water temperatures was found to be 9.7 °C (S.D. 0.61). The lowest water temperature was 8.4 °C and the highest was 12 °C. The mean phosphorus concentration was 0.085 mg/L (S.D. 0.04), with a minimum of 0.05 mg/L and a maximum of 0.19 mg/L. Conductivity levels varied throughout the catchment, with a minimum level of 161 µS/cm and a maximum of 523 µS/cm. The mean conductivity was 312 µS/cm (S.D. 73.8).

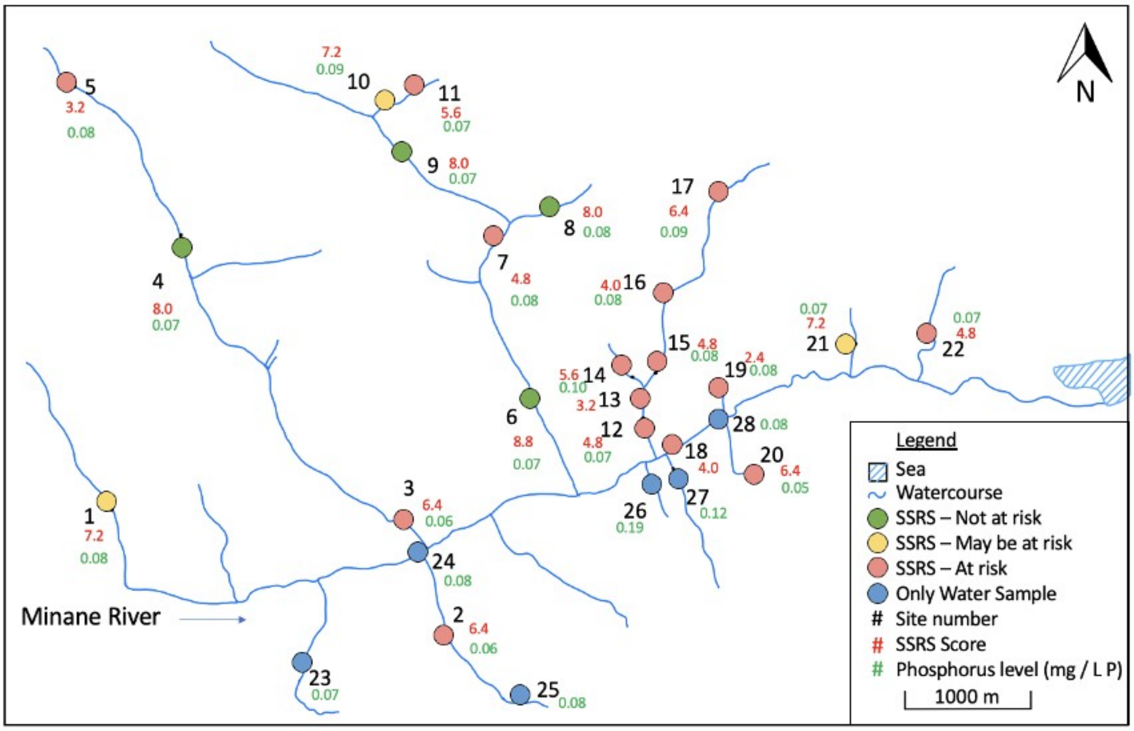


Figure 6. Map showing the Minane River catchment with risk areas identified through the Small Stream Risk Score (SSRS), and the levels of phosphorus throughout the catchment.

3.4 CSSI Comparison

The CSSI was compared to other stream indices, as well as several physicochemical values and biological metrics (Table 5, Figure 5). There was a significant correlation between the CSSI and the SSRS (ρ = .705, df = 20, p < .001), the ASPT (ρ = .438, df = 20, p = .041) as well as Simpson's Diversity Index (ρ = .490, df = 20, p = .021). However, no significant correlations were found between the CSSI and conductivity (ρ = -.256, df = 19, p = .263), temperature (ρ = .101, df = 19, p = .662), phosphorus levels (ρ = -.106, df = 19, p = .646), total abundance (ρ = -.420, df = 20, p = .052), total species richness (ρ = .011, df = 20, p = .962), %EPT (ρ = .408, df = 20, df = 20), the Q-value (ρ = .222, df = 20, p = .320), and the BMWP score (ρ = .150, df = 20, p = .505). Furthermore, all sites had at least one of the six taxa in the CSSI.

Table 5. Spearman's rho correlation values for correlations between CSSI and biological water quality indices, physicochemical water quality indicators, and biological metrics (with *. Correlation is significant at 0.05 level (2-tailed), and **. Correlation is significant at 0.01 level (2-tailed)).

	CSSI	Q-Value	BMWP	ASPT	SSRS	Taxon Richness	Total Abundance	Simpson's Diversity	Temperature	Phosphorus	Conductivity
CSSI											
Q-Value	.222										
BMWP	.150	-.025									
ASPT	.438*	.348	.626**								
SSRS	.705**	.560**	.150	.469*							
Taxon Richness	.011	-.164	.917**	.375	.011						
Total Abundance	-.420	-.232	.339	-.027	-.610**	.371					
Simpson's Diversity	.490*	.200	.233	.428*	.582**	.356	-.600**				
Temperature	.101	.004	.105	-.197	-.020	-.202	.126	-.105			
Phosphorus	-.106	-.217	.397	.167	-.303	.321	.228	.155	.001		
Conductivity	-.256	.098	.105	-.162	-.291	.173	.753**	-.445*	.233	.077	

3.5 Alternatives to the CSSI

As alternatives to the CSSI, conductivity, phosphorus levels, and temperature were considered. There were no significant correlations between conductivity and any of the indices, including the CSSI (p = .263), ASPT (p = .398), BMWP (p = .898), and the SSRS (p = .019). There were also no significant correlations between phosphorus levels and any of the biological indices (CSSI p = .646; ASPT p = .578; BMWP p = .075; SSRS p = .182). Similarly, there were no significant correlations between temperature and any of the biological indices (CSSI p = .662; ASPT p = .333; BMWP p = .180; SSRS p = .931). Even though there were no significant correlations between conductivity and phosphorus levels, the two potential pollution inputs (site 26 and P.I. 1), were both outliers of the data for both parameters (>1.5 IQR). This indicates that conductivity measurements might be able to point out potential extremes in phosphorus levels, and might therefore be taken together with the CSSI.

3.6 NMDS

A non-metric multidimensional scaling (NMDS) ordination was performed. The NMDS ordination shows that there is an overlap between the community structures of the good and moderate sites (Figure 7). The stress level for the ordination was 0.063, which is <0.1 meaning the plot provides a great representation in reduced dimensions.

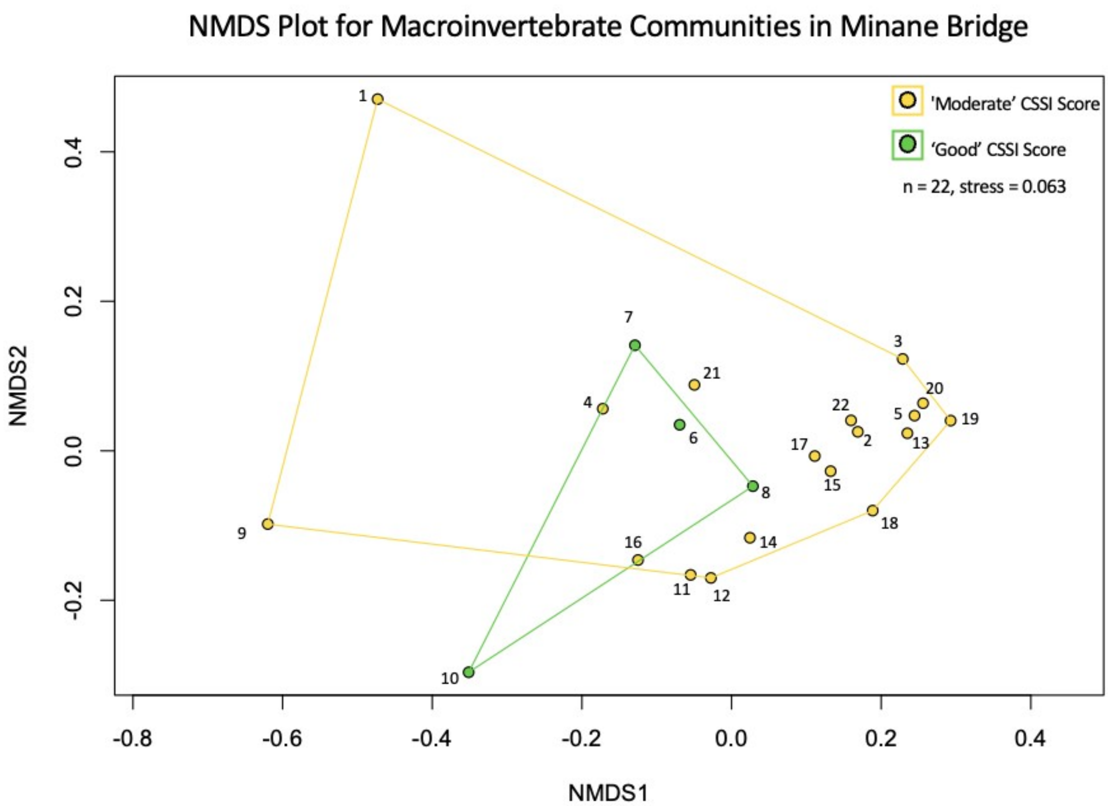


Figure 7. NMDS plot for the macroinvertebrate communities in Minane Bridge, showing the CSSI score (n = 22, stress = 0.063.

[Word Count: 1,148]

4. Discussion

4.1 Catchment water quality in agricultural areas

Agriculture accounts for 67.7% of the total land-use area in the Republic of Ireland (EPA, 2020b). Intensification of agriculture has been recognized as one of the main causes of freshwater ecosystem degradation (Malmqvist and Rundle, 2002; Collins and Anthony, 2008; Strayer and Dudgeon, 2010; Poole et al., 2013; Zhang et al., 2014; Kibichii et al., 2015; Conroy et al., 2016). This can be attributed to the close relationship that exists between lotic systems and the catchment land area, meaning that changes in land-use such as agricultural intensification directly affect these systems (Malmqvist and Rundle, 2002). A study by Harrison et al. (2019) found degraded water qualities in a catchment in the south of Ireland with a high percentage land cover of agriculture, where the majority of the headwaters were found to have elevated nutrient levels, including phosphorus. Similar conditions were found in this study catchment, where the ASPT (mean of 5.5 = moderate) and CSSI (mean of 1.4 = moderate) scores indicated moderate conditions overall. The SSRS showed that many of the streams (68.2%) are considered at risk of not meeting 'good' water quality standards (Figure 6). Furthermore, all streams exceeded the environmental quality standards of 0.035 mg/l P set by the EPA to adhere to the Phosphorus regulations (Figure 6) (EPA, n.d. b). EPA GIS maps show that the catchment has a low surface phosphate susceptibility with a few moderate and high areas, which indicates that there is an expected low chance of field run-off (EPA, 2020 a). As the study found high levels of phosphorus in the watercourses might indicate that there are point-sources of pollution. Considering the high percentage of agricultural land use in the area, farm yard drainage ditches might play a part in these elevated phosphorus levels (Harrison et al., 2019). However, in order to make definitive conclusions about elevated phosphorus levels in the catchment area, additional samples need to be taken at varying times throughout the year and at additional locations, focusing on identified risk areas including housing estates, forest felling, farm yards, and areas with high SSRS scores (Figure 6). Additional research should also focus on identifying sources of nutrient inputs in order to restore stream water quality.

4.2 Citizen Science Stream Index validity & alternatives

This study aimed to determine whether the CSSI could be used accurately to determine stream water quality. The results show a significant correlation between the CSSI and the ASPT as well as the SSRS, but no significant correlation with the BMWP or the Q-value. As the BMWP is highly dependent on the number of taxa in the sample, and thus on season as well as sample size and effort, the ASPT is found to be a more accurate representation of water quality (Hawkes, 1998). As the CSSI correlates significantly with some of the conventional indices, the index shows it has potential to contribute to river water quality monitoring. However, the catchment found no sites with a 'bad' and not many with a 'good' CSSI score. Therefore, it is uncertain whether the CSSI will give similar results to other conventional scores with 'bad' and 'good' water quality. The number of 'good' scoring sites for the CSSI was also limited to only four. As this is a small sample size, correlation results could be less accurate. Future research should therefore focus on sampling streams with a wider range of ecological stream quality to ensure the CSSI can provide good indications of water quality in all types of streams. Furthermore, the study found no significant correlations between the CSSI and phosphorus levels, conductivity or temperature, indicating that they cannot be used interchangeably and that the CSSI cannot be used to make conclusions about physical or chemical water quality. Including physicochemical measurements in citizen science together with the CSSI should therefore be considered in order to make conclusions on chemical and physical water quality. As high conductivity measurements were able to indicate extremes in phosphorus levels in two cases in this study, conductivity measurements are a potentially useful tool to indicate extremes in physicochemical water quality.

4.3 Contribution of CSSI to current monitoring

Ireland has more than 84,000 km of watercourses, but only 13,200 km (15.7%) of these are monitored for chemical and biological quality every three years (Feeley et al., 2020). This lack of monitoring, similar to trends found globally, could result in watercourses being polluted unnoticed and unresolved (UNEP, 2018). Besides the UN, the European Commission has also suggested that citizen science could increase data coverage and fill in data gaps in environmental reporting for ambient water quality, as well as other environmental priorities of the Green Deal (EC, 2018; EC, 2020). The use of citizen science allows for collecting data at higher spatial and temporal frequencies than traditional monitoring programs (Quinlivan et al., 2020; Hegarty et al., 2021). Since 1989, the Minane River catchment has been monitored by the EPA in two locations up to 2006, when monitoring was ceased in one of the two locations (Figure 2) (EPA, 2022 a). The river is sampled for biological and chemical assessments every three years, as part of the WFD monitoring programme. This study suggests that the CSSI can be used to provide an indication of water quality at resolutions greater that those carried out by agency monitoring. The CSSI was able to show differences in water quality in the various tributaries feeding into the river. Furthermore, the CSSI provides a faster indication of water quality than other conventional indices currently being employed, which often require more extensive field or laboratory analysis, such as the BMWP, ASPT and SSRS. Therefore, the CSSI shows quick results in the field, which allows tracking water quality along the river and its tributaries. This can provide earlier warnings of potential pollution, aid in finding the point sources of pollution, and ultimately restore water quality. Besides increasing data collection, citizen science can provide a major benefit to research in terms of capturing additional relevant information (Hegarty et al., 2021). Because citizens often have a long term knowledge of the area, they could be able to pinpoint sources of pollution and data gaps potentially missed by the national monitoring agencies (Hegarty et al., 2021).

4.4 Constraints & future directions

Future studies performed to validate the CSSI should focus on how well citizens are able to use this index, and whether their results are reliable and can be used to make conclusions about water quality. Furthermore, research should be done in areas with known good water quality as well as bad water quality to see if the CSSI can be used to accurately to determine water quality across a wide range of streams with varying quality. Lastly, focus should be placed on incorporating the CSSI into monitoring programs, as well as already existing citizen science indices with only physicochemical parameters to provide an indication of both ecological and chemical stream quality.

[Word Count: 1,147]

References

Balloch, D., Davies, C.E., and Jones, F.H., 1976. Biological assessment of water quality in three British rivers: the North Esk (Scotland), the Ivel (England) and the Taf (Wales).

Barr, A.G. and Thompson, E., 2004. Shannon River Basin District Project. In *Proceedings of the National Hydrology Seminar, IHS* (pp. 21-27).

Benetti, C.J., Pérez-Bilbao, A. and Garrido, J., 2012. Macroinvertebrates as indicators of water quality in running waters: 10 years of research in rivers with different degrees of anthropogenic impacts. *Ecological water quality-water treatment and reuse*, pp.23-44.

Bonney, R., Shirk, J.L., Phillips, T.B., Wiggins, A., Ballard, H.L., Miller-Rushing, A.J. and Parrish, J.K., 2014. Next steps for citizen science. *Science*, *343*(6178), pp.1436-1437.

Chapman, D.V., 1996. Water Quality Assessments: A guide to the use of biota, sediments and water in environmental monitoring. 2nd ed. CRC Press.

Collins, A.L. and Anthony, S.G., 2008. Assessing the likelihood of catchments across England and Wales meeting 'good ecological status' due to sediment contributions from agricultural sources. *environmental science & policy*, *11*(2), pp.163-170.

Conroy, E., Turner, J.N., Rymszewicz, A., O'sullivan, J.J., Bruen, M., Lawler, D., Lally, H. and Kelly-Quinn, M., 2016. The impact of cattle access on ecological water quality in streams: Examples from agricultural catchments within Ireland. *Science of the Total Environment*, *547*, pp.17-29.

Díaz, J.S., Kohlmann, B. and López, E.L., 2012. Benthic macroinvertebrates as indicators of water quality in streams of Costa Rica: using an adaptation of the BMWP score. *Transylvanian Review of Systematical and Ecological Research*, *14*, pp.177-188.

Dickinson, J.L., Shirk, J., Bonter, D., Bonney, R., Crain, R.L., Martin, J., Phillips, T. and Purcell, K., 2012. The current state of citizen science as a tool for ecological research and public engagement. *Frontiers in Ecology and the Environment*, *10*(6), pp.291-297.

Dudgeon, D., 2019. Multiple threats imperil freshwater biodiversity in the Anthropocene. *Current Biology*, *29*(19), pp.R960-R967.

Dudgeon, D., Arthington, A.H., Gessner, M.O., Kawabata, Z.I., Knowler, D.J., Lévêque, C., Naiman, R.J., Prieur-Richard, A.H., Soto, D., Stiassny, M.L. and Sullivan, C.A., 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. *Biological reviews*, *81*(2), pp.163-182.

Environmental Protection Agency (EPA), 2018. Corine Landcover 2018, Data [Online]. Available from: https://gis.epa.ie/EPAMaps/ [Accessed 20th February 2023].

Environmental Protection Agency (EPA), 2020a. Catchments.ie, EPA Maps [online]. Available from: https://gis.epa.ie/EPAMaps/Water [Accessed 18th January 2023].

Environmental Protection Agency (EPA), 2020b. Ireland's Environment 2020 – Chapter 5 – Land and Soil [Online]. Available from: https://www.epa.ie/publications/monitoring--assessment/assessment/state-of-the-environment/irelands-environment-2020----chapter-5---land-and-soil.php [Accessed 22nd February 2023].

Environmental Protection Agency (EPA), 2021. Ireland's National Water Framework Directive Monitoring Programme, 2019-2021 [Online]. Available from: https://www.epa.ie/publications/monitoring--assessment/freshwater--marine/irelands-national-water-framework-directive-monitoring-programme-2019-2021.php [Accessed 18th January 2023].

Environmental Protection Agency (EPA), 2022a. EPA River Quality Surveys: Biological. Hydrometric Area 20.

Environmental Protection Agency (EPA), 2022b. Water Quality in Ireland: 2016 – 2021 [online]. Available from: https://www.epa.ie/publications/monitoring--assessment/freshwater--marine/water-quality-in-ireland-2016--2021-.php#:~:text=The%20analysis%20is%20based%20on,over%20the%20period%202016%2D2021.&text=This%20assessment%20shows%20that%20over,%25)%20are%20in%20unsatisfactory%20condition. [Accessed 18th January 2023].

Environmental Protection Agency (EPA), n.da. National River Monitoring Programme [Online]. Available from: https://www.epa.ie/our-services/monitoring--assessment/freshwater--marine/rivers/ [Accessed 25th January 2023].

Environmental Protection Agency (EPA), n.db. River Water Quality – Phosphates [Online]. Available from: https://www.epa.ie/resources/charts--data/freshwater-and-marine/river-water-quality---phosphates.php [Accessed 25th January 2023].

European Commission (EC), 2018. Citizen Science for environmental policy: Development of an EU-wide inventory and analysis of selected practices [Online]. Available from: https://op.europa.eu/en/publication-detail/-/publication/842b73e3-fc30-11e8-a96d-01aa75ed71a1/language-en [Accessed 22nd February 2023].

European Commission (EC), 2020. Best Practices in Citizen Science for Environmental Monitoring [Online]. Available from: https://repository.oceanbestpractices.org/handle/11329/1980 [Accessed 22nd February 2023].

Feeley, H.B., Bradley, C., Free, G., Kennedy, B., Little, R., McDonnell, N., Plant, C., Trodd, W., Wynne, C. and Boyle, S.O., 2020. A national macroinvertebrate dataset collected for the biomonitoring of Ireland's river network, 2007–2018. *Scientific Data*, *7*(1), p.280.

Geological Survey Ireland, n.d. Geological Survey Ireland Spatial Resources [Online]. Available from: https://dcenr.maps.arcgis.com/apps/MapSeries/index.html?appid=a30af518e87a4c0ab2fbde2aaac3c228 [Accessed 15th February 2023].

Government of Ireland and Ordnance Survey Ireland (OSI), 2022. GeoHive main Map Viewer [Online]. Available from: https://webapps.geohive.ie/mapviewer/index.html [Accessed 18th January 2023].

Harding, J.S., Young, R.G., Hayes, J.W., Shearer, K.A. and Stark, J.D., 1999. Changes in agricultural intensity and river health along a river continuum. *Freshwater biology*, *42*(2), pp.345-357.

Harrison, S., McAree, C., Mulville, W. and Sullivan, T., 2019. The problem of agricultural 'diffuse' pollution: Getting to the point. *Science of the Total Environment*, *677*, pp.700-717.

Hawkes, H.A., 1998. Origin and development of the biological monitoring working party score system. *Water research*, *32*(3), pp.964-968.

Hegarty, S., Hayes, A., Regan, F., Bishop, I. and Clinton, R., 2021. Using citizen science to understand river water quality while filling data gaps to meet United Nations Sustainable Development Goal 6 objectives. *Science of The Total Environment*, *783*, p.146953.

IPBES, 2019. Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. *Díaz et al (eds.). IPBES secretariat, Bonn, Germany*.

Jones, F., 1973. Quantitative changes in the benthic macroinvertebrate communities of the river Taf and the relationship between plant detritus and invertebrate numbers. *Hawkes, HA (1997) Origin and development of the biological monitoring working party score system. Wat. Res*, *32*(3), pp.964-968.

Kelly-Quinn, M., Feeley, H. and Bradley, C., 2020. Status of freshwater invertebrate biodiversity in Ireland's rivers–time to take stock. In *Biology and Environment: Proceedings of the Royal Irish Academy* (Vol. 120, No. 2, pp. 65-82). Royal Irish Academy.

Kelly, D. and Wright, G., 2002. Minane Bridge Water Supply: Groundwater source protection zones. *Geological Survey of Ireland.*

Kibichii, S., Feeley, H.B., Baars, J.R. and Kelly-Quinn, M., 2015. The influence of water quality on hyporheic invertebrate communities in agricultural catchments. *Marine and Freshwater*

Research, *66*(9), pp.805-814.

Local Authority Waters Programme (LAWPRO), n.d. Citizen science in freshwater rivers [Online]. Available from: https://lawaters.ie/citizen-science/ [Accessed 5th December 2022].

Malmqvist, B. and Rundle, S., 2002. Threats to the running water ecosystems of the world. *Environmental conservation*, *29*(2), pp.134-153.

Masese, F.O., Muchiri, M. and Raburu, P.O., 2009. Macroinvertebrate assemblages as biological indicators of water quality in the Moiben River, Kenya. *African Journal of Aquatic Science*, *34*(1), pp.15-26.

Mason, C.F., 2002. *Biology of freshwater pollution*. 4th ed. Pearson Education.

McKinley, D.C., Miller-Rushing, A.J., Ballard, H.L., Bonney, R., Brown, H., Cook-Patton, S.C., Evans, D.M., French, R.A., Parrish, J.K., Phillips, T.B. and Ryan, S.F., 2017. Citizen science can improve conservation science, natural resource management, and environmental protection. *Biological Conservation*, *208*, pp.15-28.

MetEireann, n.d. 30 Year Averages 1981 – 2010 – Cork Airport [Online]. Available from: https://www.met.ie/climate-ireland/1981-2010/cork.html [Accessed 5th December 2022].

Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-Being: Wetlands and Water Synthesis. *World Resources Institute, Washington, DC.*

Muralidharan, M., Selvakumar, C., Sundar, S. and Raja, M., 2010. Macroinvertebrates as potential indicators of environmental quality. *Ind. J. Biotechnol*, *1*, pp.23-28.

National Water Council, 1981. *River quality: the 1980 survey and future outlook*. National Water Council.

Poole, A.E., Bradley, D., Salazar, R. and Macdonald, D.W., 2013. Optimizing agri-environment schemes to improve river health and conservation value. *Agriculture, ecosystems & environment*, *181*, pp.157-168.

Quinlivan, L., Chapman, D.V. and Sullivan, T., 2020. Validating citizen science monitoring of ambient water quality for the United Nations sustainable development goals. *Science of the Total Environment*, *699*, p.134255.

Ríos-Touma, B., Acosta, R. and Prat, N., 2014. The Andean Biotic Index (ABI): revised tolerance to pollution values for macroinvertebrate families and index performance evaluation. *Revista de biologia tropical*, *62*, pp.249-273.

Rosenberg, D.M. and Resh, V.H., 1993. *Freshwater biomonitoring and benthic macroinvertebrates*. Chapman and Hall.

RPS, 2022. Third cycle draft river basin management plan 2022 – 2027: Consultation Report.

Ryan A., Reynolds, K, Ó Súilleabháin, L., and Kennedy, B., 2015. Guidance on Application and Use of the SSRS in Enforcement of Urban Waste Water Discharge Authorisations in Ireland. EPA Ireland.

Silvertown, J., 2009. A new dawn for citizen science. *Trends in ecology & evolution*, *24*(9), pp.467-471.

Strayer, D.L. and Dudgeon, D., 2010. Freshwater biodiversity conservation: recent progress and future challenges. *Journal of the North American Benthological Society*, *29*(1), pp.344-358.

Sutadian, A.D., Muttil, N., Yilmaz, A.G. and Perera, B.J.C., 2016. Development of river water quality indices—a review. *Environmental monitoring and assessment*, *188*, pp.1-29.

Swamee, P.K. and Tyagi, A., 2007. Improved method for aggregation of water quality subindices. *Journal of environmental engineering*, *133*(2), pp.220-225.

Toner, P., Bowman, J., Clabby, K., Lucey, J., McGarrigle, M., Concannon, C., Clenaghan, C., Cunningham, P., Delaney, J., O'Boyle, S. and MacGarthaigh, M., 2005. Water quality in Ireland. *Environmental Protection Agency, Co. Wexford, Ireland*.

Turrini, T., Dörler, D., Richter, A., Heigl, F. and Bonn, A., 2018. The threefold potential of environmental citizen science-Generating knowledge, creating learning opportunities and enabling civic participation. *Biological Conservation*, *225*, pp.176-186.

UNEP, 2018. Progress on Ambient Water Quality. Piloting the Monitoring Methodology and Initial Findings for SDG Indicator 6.3. 2.

United Nations, 2018. Sustainable Development Goal 6 Synthesis Report on Water and Sanitation 2018. United Nations, New York, New York.

Vári, Á., Podschun, S.A., Erős, T., Hein, T., Pataki, B., Iojă, I.C., Adamescu, C.M., Gerhardt, A., Gruber, T., Dedić, A. and Ćirić, M., 2022. Freshwater systems and ecosystem services: Challenges and chances for cross-fertilization of disciplines. *Ambio*, *51*(1), pp.135-151.

Ward, P. and de Bruin, S., 2018. The geography of future water challenges. The Hague: PBL Netherlands Environmental Assessment Agency.

Weiner, D., Bloomer, J., Conchúir, R.Ó. and Dalton, C., 2022. The Role of Volunteers and Citizen Scientists in Addressing Declining Water Quality in Irish River Catchments. *Citizen Science: Theory and Practice*, *7*(1).

Zhang, Y., Collins, A.L., Murdoch, N., Lee, D. and Naden, P.S., 2014. Cross sector contributions to river pollution in England and Wales: Updating waterbody scale information to support policy delivery for the Water Framework Directive. *Environmental Science & Policy*, *42*, pp.16-32.

Appendix 1 – Citizen Science Stream Index (LAWPRO, n.d.)

Calculating the Citizen Science Stream Index

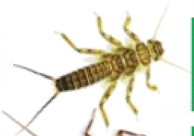
Recorder name:	**Stream name:**
Date:	**GPS/location:**

The Citizen Science Stream Index (CSSI) is based on the presence or absence of six key aquatic invertebrates. Three pollution-sensitive invertebrates ('good guys') are commonly found in clean streams and three pollution-tolerant invertebrates ('bad guys') are commonly found in polluted streams.

Citizens use a pond net to take three 30-second kick-samples (the three samples should be a few metres apart) from a shallow (<20cm), gravelly, fast-flowing part of the stream. The invertebrates captured in each sample are examined in a white tray on the bankside. The six key invertebrates are easily spotted amongst the many other species in the tray, by their characteristic shape, colour or movement.

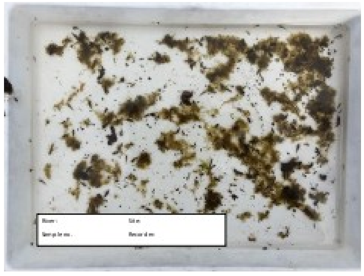
The citizen will score each sample depending on which, if any, of the six key invertebrates occur in the tray. The three **'good guys' have a score of +1** each and the three **'bad guys' have a score of -1 each**.

The score for each kick-sample can range from +3 (all three good guys and no bad guys) to -3 (all three bad guys and no good guys). When the scores from all three samples are added together, the CSSI ranges from +9 to -9.

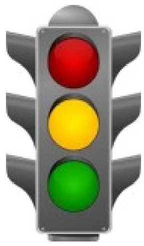
		Sample 1	Sample 2	Sample 3
Stonefly (+1)				
Flattened mayfly (+1)				
Green caddisfly (+1)				
Snail (-1)				
Leech (-1)				
Waterlouse (-1)				
		Sum of scores 1	Sum of scores 2	Sum of scores 3

Total score for the 3 samples = CSSI Score

Citizens should also take a good, clear photo of one of the 3 samples, including a label in the tray, with information on the date, stream name, location and recorder.



CSSI Scores can be a 'traffic light' for water quality



CSSI score -9 to -5
Poor

CSSI Score -4 to +4
Moderate

CSSI Score +5 to +9
Good

Any observations (eg. excessive algae or fine sediment, cattle access nearby, surface foam, presence of trout/salmon etc):

The 'good guys'

Stonefly
2 thin filamentous tails at end of abdomen

Flattened mayfly
3 thin filamentous tails, wide head with large eyes on top and <u>flattened</u> body

Green caddisfly
Green caterpillar-like larva. Gills along abdomen give it a 'spiky' appearance

The 'bad guys'

Leech
Suckers at both ends & moves by stretching out body

Snail
Hard pointed or coiled shell covering body

Waterlouse
Looks like a woodlouse, crawls slowly along bottom

These invertebrates are found in most streams and are <u>NOT</u> scored for the CSSI

Freshwater shrimp

Swimming mayfly

Blackfly larva

Brown caddisfly

Pink caddisfly

Appendix 2 – EPA Q-value (Toner et al., 2005)

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.

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		

Observations on Q Determination Scheme

Q5 assigned if :-

a) Group A at least *common**: Typically with ***either*** one or more Heptageniidae spp or *Ephemera* sp. plus three or more Plecoptera spp ***or else*** four or more Plecoptera species present
b) Group B ranging from scarce/absent to numerous
c) Group C not more than *common** but *B. rhodani* may be dominant*
d) Groups D and E *scarce** or absent.
e) Macrophytes, if present, diverse and not excessive in development.
f) Filamentous algae if present not excessive
g) *Cladophora*, sewage 'fungus' and other slime growths/complexes absent.
h) substrata clean and unsilted.
i) DO close to 100% at all times.

* As defined below.

Q4 assigned if :-

a) At least ***one*** Group A taxon present in, at least, *fair numbers**
b) Group B taxa may be *common**, *scarce** or absent
c) *B. rhodani* usually *dominant** Other Group C taxa never *excessive**
d) Groups D and E may be present in *small numbers** or absent
e) Macrophyte & algal growths not excessive
f) *Cladophora,* if present, not excessive
g) Sewage 'fungus' and other slime growths absent
h) Substrata may be lightly silted
i) DO ranging from 80 to 120%

Q3-4 assigned if :-

a) At least ***one*** Group A taxon present in, at least *small numbers**.
b) Group B *common**, *scarce** or absent
c) Group C *numerous**, *dominant* or excessive**.
d) Group D *common**, *scarce** or absent
e) Group E *scarce** or absent.
f) Macrophytes and algal growths usually luxuriant, often excessive.
g) *Cladophora*, usually excessive.
h) Sewage 'fungus' and other slime growths sometimes present in small amounts.
i) Substrata may be considerably silted.
j) DO ranging from < 80 to >120%.

Q3 assigned if :-

a) Group A absent.
b) Group B *fair numbers**, *scarce** or absent
c) Group C usually *excessive** (*Gammarus, Hydropsyche* etc. may be fungus infested).
a) Groups D (excl. *Asellus) common**, *scarce** or absent
e) Group E *scarce** or absent
f) Macrophytes, if present often silted and/or infested with epiphytic algae.
g) *Cladophora* usually excessive.
h) Sewage 'fungus' and other slime growths/complexes may be considerable.
i) Substrata may be heavily silted.
j) DO ranging from <80 to >120%.

Q2 assigned if :-

a) Groups A and B absent.
b) Group C *scarce** or absent.
c) *Asellus sp.* c*ommon** *to excessive**. Other Group D taxa may be c*ommon**, *numerous** or *excessive**.
d) Group E may be *common**.

Appendix 3 – Small Stream Risk Score (Ryan et al., 2015)

River:	Code:	Date:	Time:
Station no.	Location:	Grid (6 figure):	
	Stream Order:	Stream flow: Riffle / Riffle/Glide / Slow flow	

Field Chemistry	
DO%	
DO mg/l	
Temp (°C)	
Conductivity	
pH	
Bank width (cm)	
Wet width (cm)	
Avg Depth (cm)	
Staff gauge	

Velocity	Colour
Torrential	None
Fast	Slight
Moderate	Moderate
Slow	High
Very slow	

Clarity	Discharge
Very clear	Flood
Clear	Normal
Slightly turbid	Low
Highly turbid	Very Low
	Dry
	Recent Flood

Modifications: Y/N Canalised-widened-bank erosion-arterial drainage

Dominant Types:
Bedrock
Boulder (>128mm)
Cobble (32-128mm)
Gravel (8-32mm)
Fine Gravel (2-8mm)
Sand (0.25-2mm)
Silt (<0.25mm)

Slope: Low – Medium – High – Very High

Geology: Calcareous-Siliceous-Mixed

Substratum Condition: Calcareous-Compacted-Loose - Normal

Substratum: Stoney bottom-Muddy bottom-Mud over stones

Degree of siltation: Clean-Slight-Moderate-Heavy

Depth of mud: None: <1cm: 1-5cm: 5-10cm: >10cm

Litter: None – Present – Moderate - Abundant

Filamentous Algae: None – Present – Moderate - Abundant

Main land use u/s: Pasture, Bog, Forestry, Urban, Tillage, Other

Sample retained: Y / N

Shading: High – Moderate – Low - None

Cattle access Y: upstream – downstream or N

Photo: Y / N

Sewage Fungus: None – Present – Moderate - Abundant

Sampled in Minutes:
Pond net x
Stone wash x
Weed sweep x

General Comments:

Macroinvertebrate Composition

The macroinvertebrates are divided into the following 5 specific groups:

- Group 1 = Ephemeroptera (3-tails) – note that tails may be damaged during sampling
- Group 2 = Plecoptera (2-tails) - note that tails may be damaged during sampling
- Group 3 = Trichoptera
- Group 4 = G.OL.D (Gastropoda, Oligochaeta and Diptera)
- Group 5 = *Asellus*
- Calculate the total number of taxa and relative abundance of each macroinvertebrate group below: (Abundance – Ab)

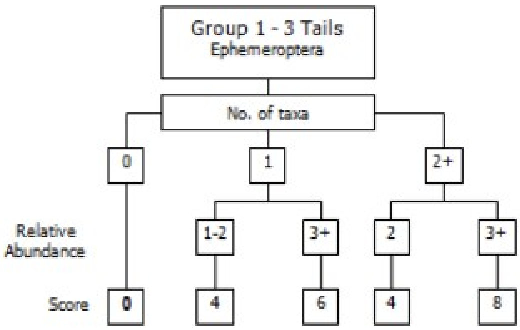
Relative Abundance	
1-5	1
6-20	2
21-50	3
51-100	4
101+	5

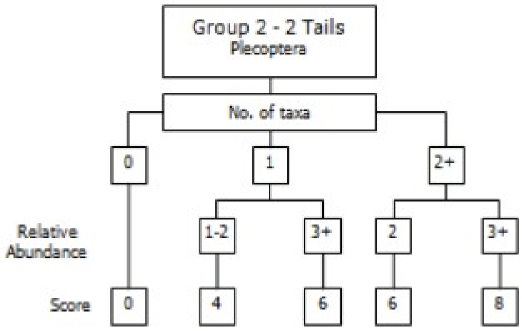
Ephemeroptera:		Plecoptera:	
Ecdyonurus Ab		*Leuctra* Ab	
Rhithrogena Ab		*Isoperla* Ab	
Heptagenia Ab		*Protonemura* Ab	
Ephemerella Ab		*Amphinemura* Ab	
Caenis Ab		*Perla* Ab	
Paraleptophlebia Ab		*Dinocras* Ab	
Ephemera danica Ab		Other Plecop Ab	
Other Ephem Ab		Other Plecop Ab	
Total no. of taxa	Total Relative Abundance	Total no. of Taxa	Total Relative Abundance

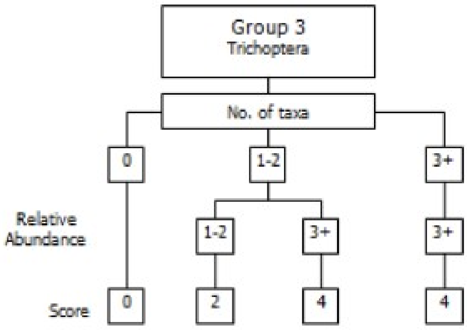
Trichoptera:		G.OL.D:				*Asellus*:
Hydropsychidae Ab		*Lymnaea* (G) Ab		Chironomidae (D) Ab		Absent
Polycentropodidae Ab		*Potamopyrgus* (G) Ab		*Chironomus* (D) Ab		Few (1-20)
Rhyacophila Ab		*Planorbis* (G) Ab		Simuliidae (D) Ab		Common (>20)
Philopotamidae Ab		*Ancylus* (G) Ab		*Dicranota* (D) Ab		
Limnephilidae Ab		*Physa* (G) Ab		Tipulidae (D) Ab		
Sericostomatidae Ab		*Lumbriculus* (Ol) Ab		Ceratopogonidae (D) Ab		NOTE: *Asellus* must be recorded as absent if none are found
Glossosomatidae Ab		*Eiseniella* (Ol) Ab		Other GOLD Ab		
Lepidostomatidae Ab		Tubificidae (Ol) Ab				
Other Trichoptera Ab						
Total no. of Taxa	Total Relative Abundance	Total no. of Taxa		Total Relative Abundance		

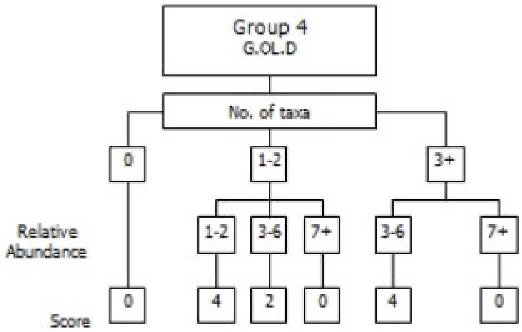
NOTE *Baetis* is an Ephemeropteran and is the most commonly occurring invertebrate genus in streams in Ireland. It is vital that *Baetis* is not counted in SSRS. See Appendix B for more details on how to identify *Baetis*.

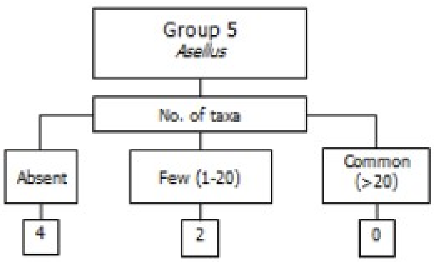
Step 1. Calculate the Index Score by circling the appropriate box representing the total number of taxa and the total abundance calculated from ***each macroinvertebrate group*** calculated from page 1 of the recording sheet and enter in to the boxes in Step 2.











Step 2

a) Index Score Group 1 [ ]
b) Index Score Group 2 [ ]
c) Index Score Group 3 [ ]
d) Index Score Group 4 [ ]
e) Index Score Group 5 [ ]

Step 3. Calculate the Total Index Score, the Average Index Score and the SSR Score using the boxes below

Total Index Score (TIS) sum (a+b+c+d+e) [ ]   Average Index Score (AIS) TIS/5 (5 for 5 groups) [ ]   **SSR Score** (AIS x 2) [ ]

Step 4. Assess the stream by comparing the final SSR score with the categories below and tick the appropriate box

> 7.25 Probably not at risk [ ]   > 6.5 – 7.25 Indeterminate Stream may be at risk [ ]   <6.5 Stream at risk [ ]

Surveyor (signed): ________________ Name (print): ________________ Date: _____/_____/______

Appendix 4 – Biological Monitoring Working Party (National Water Council, 1981)

Taxa	
Families ex. *Oligochaeta*	Score
Siphlonuridae, Heptageniidae, Leptophlebiidae, Ephemerellidae, Potamanthidae, Ephemeridae, Taeniopterygidae, Leuctridae, Capniidae, Perlodidae, Perlidae, Chloroperlidae, Aphelocheiridae, Phryganeidae, Molannidae, Beraeidae, Odontoceridae, Leptoceridae, Goeridae, Lepidostomatidae, Brachycentridae, Sericostomatidae	10
Astacidae, Lestidae, Agriidae, Gomphidae, Cordulegasteridae, Aeshnidae, Corduliidae, Libellulidae, Psychomyiidae, Philopotamidae	8
Caenidae, Nemouridae, Rhyacophilidae, Polycentropodidae, Limnephilidae	7
Neritidae, Viviparidae, Ancylidae, Hydroptilidae, Unionidae, Corophiidae, Gammaridae, Platycnemididae, Coenagriidae	6
Mesovelidae, Hydrometridae, Gerridae, Nepidae, Naucoridae, Notonectidae, Pleidae, Corixidae, Haliplidae, Hygrobiidae, Dytiscidae, Gyrinidae, Hydrophilidae, Clambidae, Helodidae, Dryopidae, Elminthidae, Chrysomelidae, Curculionidae, Hydropsychidae, Tipulidae, Simuliidae, Planariidae, Dendrocoelidae	5
Baetidae, Sialidae, Piscicolidae	4
Valvatidae, Hydrobiidae, Lymnaeidae, Physidae, Planorbidae, Sphaeriidae, Glossiphoniidae, Hirudidae, Erpobdellidae Asellidae	3
Chironomidae	2
Oligochaeta	1