Macroinvertebrate Biodiversity and Ecosystem Health: Insights from Species Distribution and Abundance Patterns

Author: Owhonda C. Ihunwo

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# Abstract

This study investigated the ecological significance of headwater streams by examining macroinvertebrate communities in three high-status rivers in Ireland: Silver River, Camcor River, and Faurawn River. A total of 54 species were identified, primarily from Ephemeroptera, Plecoptera, and Trichoptera orders. The study employed a refined kick sampling method to collect macroinvertebrates at three points along each river, capturing spatial variation. Data analysis, including heatmaps, bar plots, scatter plots, and UpSet plots, revealed patterns in species abundance and distribution. The dominance of sensitive taxa like *Serratella ignita* and *Baetis rhodani* indicated favorable environmental conditions. However, the presence of rare species suggested potential localized stressors or habitat fragmentation. This research highlights the importance of macroinvertebrates as bioindicators and underscores the need for conservation efforts to protect these vital ecosystems. By understanding the relationships between macroinvertebrate communities and environmental factors, we can develop effective strategies to maintain the ecological integrity of headwater streams.

# Introduction

Headwater streams, defined as the uppermost reaches of a river network, are crucial for maintaining the ecological integrity and overall health of freshwater ecosystems. Despite their relatively small size, headwater streams perform several vital ecosystem functions, including nutrient cycling, organic matter processing, sediment transport, and habitat provision for diverse aquatic and terrestrial species (Benda et al., 2005; Gomi et al., 2002). These streams often act as ecological sentinels, reflecting the impacts of land use changes, climate variability, and other anthropogenic disturbances on larger downstream systems (Lowe & Likens, 2005). Therefore, understanding the role of headwater streams in broader watershed dynamics is imperative for informed management and conservation strategies.

Macroinvertebrates are a diverse group of organisms, including insects, crustaceans, and mollusks, which inhabit stream substrates. They are widely recognized as reliable bioindicators for assessing water quality and stream health due to their varying sensitivities to pollutants, specific habitat preferences, and relatively sedentary lifestyles (Ollis et al., 2006; Resh et al., 1995). The presence, absence, and abundance of certain taxa can reflect cumulative environmental conditions over time, providing insights into the impacts of nutrient loading, sedimentation, hydrological changes, and contaminants.

Particularly in headwater streams, macroinvertebrates play an integral role in organic matter decomposition, nutrient cycling, and energy transfer to higher trophic levels (Wallace & Webster, 1996). The functional diversity of macroinvertebrate communities is directly linked to stream ecosystem processes, and their composition is often used to infer ecological conditions (Vannote et al., 1980). Quantitative indices such as the Biotic Index and Functional Feeding Groups (FFGs) have been developed to categorize streams based on macroinvertebrate community structure and functional contributions (Kondratieff, 2009). These tools are especially useful in evaluating headwater streams, which may be disproportionately influenced by local environmental variables compared to larger systems (Dodds & Oakes, 2006).

Sampling macroinvertebrates from headwater streams involves a combination of quantitative and qualitative methods, ranging from kick-net sampling to artificial substrate colonization. Each method offers insights into different aspects of stream health, such as habitat complexity, substrate stability, and pollution impacts. Standardized protocols, such as those outlined by Water (1999) , ensure consistency and reliability in macroinvertebrate-based assessments, enabling comparisons across spatial and temporal scales.

The focus on headwater streams is particularly significant because these systems contribute to downstream connectivity by transporting organic material, energy, and nutrients to larger rivers and lakes. Disruptions in headwater ecosystems, whether through physical habitat alteration, pollution, or water extraction, can have cascading effects throughout the watershed (Freeman et al., 2007). Given the growing pressures on freshwater resources from agriculture, urbanization, and climate change, understanding the functional importance of headwater streams through robust macroinvertebrate sampling is critical for integrated watershed management.

This study aims to assess the ecological significance of headwater streams by sampling macroinvertebrate communities and analyzing their roles in maintaining stream health. Specific objectives include: (1) identifying taxonomic and functional composition of macroinvertebrate communities in headwater streams, (2) evaluating the sensitivity of these communities to local environmental conditions.

By establishing the ecological value of headwater streams through the lens of macroinvertebrate community structure and function, this study seeks to inform policy decisions aimed at protecting these critical habitats. In addition, it contributes to the growing body of literature advocating for the inclusion of headwater systems in watershed-level conservation planning (Bonada et al., 2006; Meyer et al., 2022).

# Methodology

## Study Area

The study was conducted in three headwater rivers in Ireland—Silver River, Camcor River, and Faurawn River. These rivers were selected due to their ecological significance and their classification as high-status waters under the Environmental Protection Agency (EPA) of Ireland's Surface Water Quality framework. The rivers exhibit pristine water quality (Q4-Q5, high status) both prior to 2004 and from 2004 to the present, making them ideal for studying macroinvertebrate community structure and its role in stream health assessment.

### Overview of Study Rivers

* **Silver River:** High status (Q4-Q5) across both time periods. Sampling was conducted at the Kilcomac station, situated at an elevation of 160 m above sea level. The station coordinates (S 228 085) correspond to a stream order of 4, indicating a relatively mature headwater stream. Sampling transitioned to the Cadamstown Bridge (elevation: 65 m; grid reference: S 204 141), reflecting a decrease in elevation but maintained stream order of 3.
* **Camcor River:** Consistently high status (Q4-Q5).Sampling occurred at the Moneygunnen House station (elevation: 170 m a.s.l.; grid reference: S 231 043) with a stream order of 3.The sampling site shifted to the Ford upstream of the Coney Burrow Bridge (elevation: 119 m; grid reference: S 199 063), maintaining its stream order of 3.
* **Faurawn River:** High status (Q4-Q5) in both periods.Sampling for both time periods was consistently carried out upstream of the main river confluence near the Breaghmore Ford and Loftus Bridge (elevation: 95 m; grid reference: S 149 016). The stream order remains at 2, characteristic of smaller tributaries.

### Hydrological and Ecological Context

These rivers are part of Ireland’s extensive headwater systems and contribute significantly to the ecological health of downstream networks. Their high-status designation reflects minimal anthropogenic impacts, making them valuable benchmarks for understanding natural macroinvertebrate assemblages and the functional roles these organisms play in nutrient cycling, organic matter decomposition, and overall ecosystem functioning.

The elevation gradients of the study sites range from 65 m to 170 m above sea level, providing opportunities to investigate the influence of altitude on macroinvertebrate diversity and community structure. Furthermore, the stream orders (2 to 4) reflect different stages of stream development, allowing for the examination of longitudinal patterns in headwater streams.

### Importance of the Study Area

The inclusion of rivers that have maintained high ecological status over time provides a unique opportunity to explore baseline conditions of headwater systems (Table 1). These rivers serve as reference sites for comparing ecological health metrics and understanding the impacts of potential disturbances in similar systems elsewhere. The consistent monitoring and well-documented historical data from the EPA enhance the reliability of the study findings and provide robust insights into the relationship between macroinvertebrate communities and headwater stream health.

Table 1 EPA Ireland Surface Water Quality. River Water Quality- Prior to 2004 and from 2004 to present for the three study rivers (Environmental Protection Agency, 2014).

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| River water quality prior to 2004 | | | | | | | | |
| River name | River water quality | Station name | Elevation (m a.s.l.) | | Station grid reference | | Stream Order | |
| Silver river | Q4-Q5- High status | Silver kilcomac | | 160 | | S 228 085 | | 4 |
| Camcor river | Q4-Q5- High status | 0150-BRSE moneygunnen house | | 170 | | S 231 043 | | 3 |
| Faurawn river | Q4-Q5- High status | BREAGHMORE- ford u/s Loftus BR | | 95 | | S 149 016 | | 2 |
| River water quality from 2004 to the present date | | | | | | | | |
| River name | River water quality | Station name | | Elevation | | Station grid reference | | Order |
| Silver river | Q4-Q5- High status | Br at Cadamstown | | 65 | | S 204 141 | | 3 |
| Camcor river | Q4-Q5- High status | Ford u/s coney burrow Br | | 119 | | S 199 063 | | 3 |
| Faurawn river | Q4-Q5- High status | Just u/s main R confl | | 95 | | S 149 016 | | 2 |

## Sampling Design

The study was conducted in headwater streams, focusing on three sampling points along each river to capture spatial variation in macroinvertebrate communities. Sampling points were systematically located at 1.5 km, 3 km, and 6 km from the source of each river to assess potential changes in species composition and abundance with increasing distance downstream. Field sampling was carried out in June 2014 to ensure consistent seasonal conditions across all sites.

## Sampling Methodology

Macroinvertebrate sampling was conducted using a refined kick sampling strategy specifically designed for the bioassessment of benthic macroinvertebrates in headwater streams, as described by [3]. This method involves collecting five replicate samples at each site, with each replicate obtained through a 20-second kick sampling effort. Previous research has demonstrated that this refined method produces comparable metric scores to the more time-intensive 60-second kick sampling approach, with the exception of slight differences in taxonomic richness**.**

A standard Freshwater Biological Association (FBA) kick-net was employed for sample collection. The net, featuring a 230 mm x 225 mm frame and appropriate mesh size for retaining benthic macroinvertebrates, was positioned downstream of the disturbed area. The substrate was agitated by foot in front of the net for the prescribed 20 seconds, allowing dislodged organisms to be captured by the net. This process was repeated for five replicates per site to ensure adequate representation of macroinvertebrate diversity and abundance.

## Sample Processing and Identification

Immediately following collection, the macroinvertebrates were separated from each sample using a sorting tray to remove detritus and non-target material. Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) were identified to the species level, leveraging their sensitivity to environmental conditions and their importance as indicators of water quality. Taxonomic identification was carried out under a stereomicroscope using standard identification keys to ensure accuracy.

Focusing on the Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa facilitated the assessment of species richness and abundance, as these groups are widely recognized for their sensitivity to habitat quality and pollution levels. This information formed the basis for evaluating ecological health at each site.

## Data Analysis Section

The macroinvertebrate data collected through the refined kick sampling method provides a rich dataset for exploring multiple ecological and statistical patterns. Utilizing Python-based tools within the Anaconda platform, a comprehensive suite of analyses can be performed to assess macroinvertebrate diversity, abundance, and ecological health.

Heatmap was used to show the distribution and abundance of species across distances and rivers. It is excellent for identifying spatially restricted species. Bar plot was used to show the total counts of each species across all locations, making rare species easier to identify. Upset Plot was used to show overlaps in species presence across rivers/distance. Heatmap was also used to plot the correlation between species and environmental conditions in the rivers.

# Results

## Study river geomorphology

A total of 9 sampling sites were analyzed across three rivers: Siler River, Camcor River, and Faurawn River. The mean distance from the river source was 3.5 km, with a standard deviation of 2.0 km, indicating variability in the sampling locations. Elevations ranged from 120 to 360 meters, with a mean of 230 meters, suggesting a diverse topography. Stream order averaged 1.9, and channel width averaged 3.2 meters, providing insights into the maturity and size of the streams (Table 2).

The mean pH was 7.7, indicating slightly alkaline conditions. The standard deviation of 0.92 suggests some variability in pH across the sites. The mean temperature was 14°C, which is typical for temperate regions. The standard deviation of 1.8°C reflects potential seasonal or spatial variations. The mean DO concentration was 9.6 mg/L, indicating good water quality. The standard deviation of 0.67 mg/L suggests some variability in oxygen levels. The mean % saturation was 95%, indicating high oxygen saturation levels. The standard deviation of 5.4% suggests some variation in oxygen saturation. The mean conductivity was 260 µS/cm, indicating moderate levels of dissolved ions. The standard deviation of 180 µS/cm suggests significant variability in conductivity, likely influenced by factors such as geology and land use (Table 2).

The study was conducted in three rivers: Siler River, Camcor River, and Faurawn River, with equal representation. The predominant soil type was mineral, accounting for 67% of the samples. Peaty soil was found in the remaining 33% of samples. Moorland was the most common land use, followed by M. Forest and Peat. All sampled sites were located within the ORS geological formation (Table 2).

Table 2 Site name, co-ordinates, stream order, elevation, geology, soil, and distance from the source, land use, hydromorphology and hydrochemistry for each river of study

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| River | Sample Grid ref. | Distance (km) | Soil | Elevation | Order | Land use | Geology | Width (meter) | pH | Temp. | DO (mg/l) | % Sat. | Cond. |
| Siler river | S 267 062 | 1.5 | Peaty | 350 | 1 | Peat | ORS | - | 5.36 | 11.2 | 9.22 | 90.0 | 32 |
| Siler river | S 250 964 | 3 | Mineral | 240 | 2 | Peat | ORS | 3.0 | 7.97 | 15.2 | 10.07 | 100.5 | 123 |
| Siler river | S 233 081 | 6 | Mineral | 160 | 3 | Moorland | ORS | 5.7 | 8.12 | 14.3 | 10.75 | 104.1 | 271 |
| Camcor river | S 262 039 | 1.5 | Peaty | 360 | 1 | Moorland | ORS | 0.7 | 7.42 | 12.8 | 9.88 | 95.1 | 157 |
| Camcor river | S 238 040 | 3 | Mineral | 220 | 2 | Moorland | ORS | 4.0 | 8.24 | 16.6 | 8.93 | 92.2 | 222 |
| Camcor river | S 223 043 | 6 | Mineral | 180 | 3 | M. Forest | ORS | 7.0 | 7.79 | 14.5 | 10.01 | 99.6 | 180 |
| Faurawn river | S 181 971 | 1.5 | Peaty | 210 | 1 | M. Forest | ORS | 0.7 | 8.40 | 12.1 | 10.07 | 95.5 | 270 |
| Faurawn river | S 172 967 | 3 | Mineral | 195 | 2 | M. Forest | ORS | 1.8 | 7.88 | 16.0 | 8.80 | 88.7 | 467 |
| Faurawn river | S 161 994 | 6 | Mineral | 115 | 2 | Moorland | ORS | 3.0 | 8.06 | 15.1 | 9.03 | 90.3 | 600 |

M. Forest- Mixed Forest, ORSS- Old Red Sandstone, DO- Dissolved Oxygen, Distance- from source, % Sat- percentage Saturation, Cond.- Conductivity in µS/cm.

## Macroinvertebrate Community Composition in Three River Systems

This study presents a comparative analysis of macroinvertebrate communities in three river systems: Silver River, Camcor River, and Faurawn River (SR, CR, FR). A total of 54 species from three orders (Ephemeroptera, Plecoptera, and Trichoptera) were identified. 17 species of Ephemeroptera (Mayflies) were recorded, with Serratella ignita being the most abundant species in all three rivers. 14 species of Plecoptera (Stoneflies) were identified, with Leuctra hippopus being the most common species in Silver River. 23 species of Trichoptera (Caddisflies) were recorded, with Hydropsyche instabilis being the most abundant species in Silver River. A total of 34 species were recorded in Silver River, with Ephemeroptera being the dominant order. 31 species were identified in Camcor River, with Plecoptera being the second most dominant order after Ephemeroptera. 29 species were recorded in Faurawn River, with Trichoptera being the second most dominant order after Ephemeroptera (Table 1s).

This study highlights the diversity of macroinvertebrate communities in three river systems. The results suggest that each river has a unique community composition, with some species being exclusive to a particular river. These findings can be used to inform conservation and management efforts for these river systems.

The heatmap (Fig. 1) visualizes the abundance of species across various locations grouped by three distances (1.5km, 3km, 6km) and three regions. The color intensity represents species abundance, with red indicating higher abundances and blue indicating lower abundances.

The most dominant species was *Serratella ignita* (Mayfly), particularly in the FR 3km and FR 6km regions (abundance peaks at 487 and 356, respectively). Also present in significant numbers in the CR region. *Rhithrogena semicolorata* (Mayfly) shoed high abundance across SR 3km, SR 6km, and CR 6km (36, 40, and 51, respectively). *Baetis rhodani* (Mayfly), another widely distributed species showed notable abundances in SR 1.5km (6) and CR 1.5km (236).

*Baetis vernus* (Mayfly) was highly localized to SR 1.5km, with an abundance of 104. It is not present in other regions. *Baetis scambus* (Mayfly) was found only in SR 1.5km, with an abundance of 36. *Hydropsyche instabilis* (Caddisfly) was prominent in CR 3km and CR 6km and also present in FR 3km. *Rhyacophila dorsalis* (Caddisfly) was found across distances but more abundant in the CR regions.

Certain species, such as *Potamophylax cingulatus*, *Nemoura avicularis*, and *Diura bicaudata*, show very low abundances, with only isolated occurrences in specific locations.

SR Region was dominated by *Baetis vernus* and *Baetis scambus* at the 1.5km distance. CR Region showed the greatest variety of species, with several (e.g., *Hydropsyche instabilis* and *Rhithrogena semicolorata*) present across multiple distances. FR Region featured high abundances of a few dominant species like *Serratella ignita*, but other species are sparse.

Species abundance generally increases at greater distances (e.g., 3km and 6km) for most regions, particularly in the CR and FR zones. Certain species, such as *Serratella ignita*, thrive in the FR region, while others like *Rhithrogena semicolorata* are more evenly distributed across zones.

A blue and white chart with white text

Description automatically generated

Figure 1. Heatmap of species

This bar plot (Fig. 2) depicts the total counts of each species across all surveyed locations, providing insights into species abundance and distribution patterns.

*Serratella ignita* (Mayfly) dominated the data with the highest total count (~1400 individuals). This suggests that it is a highly successful species, likely well-adapted to the environmental conditions present across the study areas. *Baetis rhodani* (Mayfly) and *Rhithrogena semicolorata* (Mayfly) followed as the second and third most abundant species, with significant but lower totals compared to *Serratella ignita*. Several species, including *Hydropsyche instabilis* (Caddisfly), *Baetis vernus* (Mayfly), *Leuctra hippopus* (Stonefly), and *Ecdyonurus dispar* (Mayfly), have moderate total counts, suggesting they are fairly common but not as dominant as the top three species. These species likely occupy a wide range of habitats but are less numerous overall.

The majority of species have very low total counts, often fewer than 10 individuals. Examples include *Potamophylax cingulatus* (Caddisfly), *Leuctra spp.* (Stonefly), *Diura bicaudata* (Stonefly), and *Ecdyonurus spp.* (Mayfly). These species may be rare, specialized to specific niches, or poorly sampled.

The data highlight a high species richness with a mix of highly abundant and rare species. However, the dominance of a few species (*Serratella ignita*, *Baetis rhodani*) might indicate imbalances in ecosystem conditions favoring generalists or highly adaptable species.

A screen shot of a graph

Description automatically generated

Figure 2: Bar plot to show the total counts of each species across all locations

This Scatter plot (Fig. 3) and UpSet plot (Fig. 4) and showed the presence of different species across various locations or conditions, highlighting the overlap and uniqueness of species distributions.

Many species appear in only one unique location or condition. Examples include: *Diura bicaudata* (Stonefly), *Potamophylax latipennis* (Caddisfly), and *Leuctra spp.* (Stonefly). These species have no overlap, suggesting very localized distributions or specialized habitat requirements. Some species, such as: *Baetis spp.* (Mayfly) and *Nemurella pictetii* (Stonefly), appear across 2 intersections. *Hydropsyche siltalai* (Caddisfly) and *Chaetopteryx villosa* (Caddisfly) have moderate distribution overlap, being found in 4 intersections. This indicates that these species are somewhat adaptable but still have limited habitat sharing. Several species, such as *Baetis rhodani* (Mayfly) (intersection size = 9), *Rhithrogena semicolorata* (Mayfly), and *Serratella ignita* (Mayfly) (intersection sizes = 7), show the highest level of overlap. These species are widely distributed and likely represent generalist taxa that thrive in a variety of environmental conditions. Species like *Heptagenia sulphurea* (Mayfly) and *Hydropsyche instabilis* (Caddisfly) (intersection size = 6) show intermediate overlap, indicating adaptability to several but not all habitats.

The large number of species with unique intersections suggests that many taxa are highly specialized and sensitive to specific environmental conditions. Conversely, the generalist species with high intersection sizes may serve as indicators of broadly suitable habitats. Unique or narrowly distributed species should be prioritized for conservation, as their restricted ranges may make them more vulnerable to environmental changes. Widely distributed species, while adaptable, are less indicative of habitat-specific pressures. Overlap in distributions hints at shared habitat preferences or ecological compatibility among co-occurring species.

A graph of different species

Description automatically generated with medium confidence

Figure 3: Scatter plot of species abundance across distance

A close-up of a graph

Description automatically generated

Figure 4: UpSet plot showing species distribution

# Discussion

These taxa are widely recognized as bioindicators of freshwater ecosystem health, and their abundance patterns can reveal insights into environmental conditions, water quality, and habitat stability.

The high abundance of *Serratella ignita* suggests that the surveyed aquatic ecosystems offer conditions favorable to this species, such as well-oxygenated water and low pollution levels. This species' dominance aligns with findings that certain mayflies thrive in streams with high dissolved oxygen and limited anthropogenic disturbances (Wallace & Webster, 1996). The presence of other mayflies, such as *Baetis rhodani* and *Rhithrogena semicolorata*, reinforces the observation that these habitats likely support diverse and healthy aquatic communities.

Several species, such as *Hydropsyche instabilis* and *Baetis vernus*, showed moderate abundance. *Hydropsyche spp.*, as filter feeders, are often associated with moderate to high flow environments and can tolerate a range of organic pollution. On the other hand, rare species, including *Potamophylax cingulatus* and *Leuctra spp.*, may reflect niche-specific preferences or limited sampling efficiency. Rare taxa are often indicators of habitat specialization or environmental stressors that restrict their populations. Species abundance across trophic and functional groups provides ecological insights. For example, the dominance of grazers like *Serratella ignita* suggests that periphyton availability is high in these habitats. Conversely, filter-feeding species, such as *Hydropsyche spp.*, highlight ecosystem functions associated with nutrient cycling and water filtration (Allan & Castillo, 2007).

The high abundance of species like *Serratella ignita* and *Rhithrogena semicolorata* suggests they are ecologically resilient and likely adapted to a range of environmental conditions. Rare or localized species may indicate specific habitat preferences or environmental conditions (e.g., *Baetis vernus* at SR 1.5km). The increase in abundance at farther distances may reflect habitat stability or resource availability in less-disturbed zones.

The dominance of *Serratella ignita* and other mayfly species suggests that the surveyed habitats provide favorable conditions (e.g., water quality, temperature, flow rates) for their survival and reproduction. Species with low counts may be at risk of local extinction due to habitat degradation or competition. Conservation efforts could focus on these less abundant taxa to maintain biodiversity. Abundant species like *Baetis rhodani* and *Rhithrogena semicolorata* could serve as ecological indicators of environmental conditions across the sampled sites.

The composition of species suggests that surveyed habitats support diverse macroinvertebrate assemblages, indicating relatively good water quality (Hilsenhoff, 2017). However, the skewed dominance by a few species, such as *Serratella ignita*, could signal certain environmental imbalances that favor generalists. Biodiversity monitoring programs should ensure these habitats remain pristine or minimally disturbed. The low counts of species like *Potamophylax cingulatus* and *Leuctra spp.* could indicate habitat fragmentation, pollution, or insufficient sampling. Rare species contribute significantly to ecological stability and function (Walker, 1992). Conservation strategies should focus on habitat restoration and reducing anthropogenic pressures, especially in areas hosting these species. The strong presence of sensitive taxa like mayflies and stoneflies underscores their value as bioindicators (Rosenberg & Resh, 1993). Their abundance patterns should be used in longitudinal studies to detect subtle environmental changes, especially in light of increasing pressures from climate change and urbanization.

The dominance of *Serratella ignita* and *Baetis rhodani* is consistent with studies in similar temperate streams, where these species thrive in clean, oxygen-rich environments with stable flow regimes (Jacobsen et al., 1997). Conversely, the rarity of caddisflies like *Potamophylax spp.* may suggest localized habitat degradation, aligning with findings that these taxa are often sensitive to sedimentation and organic pollution (Bonada et al., 2006).

# Conclusion

The results of this study provide valuable insights into the composition and distribution of aquatic macroinvertebrate species across different locations, highlighting both ecological patterns and environmental implications. The dominance of sensitive taxa such as Serratella ignita and Baetis rhodani indicates favorable environmental conditions in many of the surveyed sites, suggesting good water quality and habitat stability. However, the low abundance of rare species, such as Potamophylax cingulatus and Leuctra spp., raises concerns about potential localized stressors or habitat fragmentation.

The findings underscore the critical role of macroinvertebrates as bioindicators of freshwater ecosystem health. Their varying abundance and sensitivity to environmental changes make them an essential tool for monitoring anthropogenic impacts and guiding conservation strategies. The observed biodiversity also reflects functional diversity, with species contributing to ecosystem processes such as nutrient cycling and energy flow.

Moving forward, conservation efforts should focus on preserving habitat heterogeneity and minimizing human-induced disturbances to protect both dominant and rare species. Regular biomonitoring, coupled with environmental assessments, will be vital to detect early signs of ecosystem stress and ensure the long-term health and sustainability of these freshwater habitats. This study reinforces the importance of protecting aquatic biodiversity as an integral component of maintaining ecosystem services and resilience in the face of growing environmental challenges.

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# Supplementary

Table 1s Summary of the number of individuals found at different sampling points along each river

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Macroinvertebrates present in the samples | | Total Number of Individuals found in each river sampling point | | | | | | | | | | | | | |
|  | | Silver River | | | | Camcor River | | | | | Faurawn River | | | | |
| Group | Species | 1.5km | 3km | 6km | 1.5km | | 3km | | 6km | | 1.5km | | 3km | | 6km |
| Ephemeroptera | *Ecdyonurus insignis* (Eaton) | 0 | 14 | 14 | 0 | | | 5 | 5 | 0 | | 2 | | 2 | |
| (Mayfly) | *Ecdyonurus dispar* (Curtis) | 0 | 24 | 24 | 0 | | | 2 | 7 | 0 | | 2 | | 5 | |
|  | *Ecdyonurus spp.* | 0 | 0 | 0 | 5 | | | 0 | 0 | 0 | | 0 | | 0 | |
|  | *Heptagenia sulphurea* (Muller) | 0 | 8 | 8 | 0 | | | 7 | 21 | 0 | | 0 | | 1 | |
|  | *Rhithrogena semicolorata* (Curtis) | 0 | 36 | 36 | 1 | | | 40 | 51 | 0 | | 5 | | 5 | |
|  | *Electrogena lateralis* (Curtis) | 0 | 0 | 0 | 2 | | | 0 | 0 | 0 | | 0 | | 0 | |
|  | *Serratella ignita* (Poda) | 0 | 172 | 172 | 0 | | | 26 | 237 | 3 | | 487 | | 356 | |
|  | *Baetis rhodani (*Pictet) | 6 | 8 | 8 | 236 | | | 8 | 6 | 105 | | 14 | | 63 | |
|  | *Alainites muticus* (Linnaeus) | 0 | 0 | 0 | 1 | | | 3 | 4 | 6 | | 0 | | 11 | |
|  | *Baetis scambus* (Eaton) | 36 | 0 | 0 | 14 | | | 0 | 0 | 0 | | 0 | | 0 | |
|  | *Baetis vernus* (Eaton) | 104 | 0 | 0 | 17 | | | 0 | 0 | 7 | | 0 | | 0 | |
|  | *Baetis spp* | 0 | 0 | 0 | 13 | | | 0 | 0 | 5 | | 0 | | 0 | |
| Plecoptera | *Leuctra hippopus* (Kempny) | 0 | 19 | 19 | 2 | | | 1 | 10 | 0 | | 15 | | 0 | |
| (Stonefly) | *Leuctra inermis* (Kempny) | 0 | 0 | 0 | 25 | | | 0 | 0 | 0 | | 0 | | 0 | |
|  | *Leuctra spp.* | 0 | 0 | 0 | 2 | | | 0 | 0 | 0 | | 0 | | 0 | |
|  | *Isoperla grammatica* (Poda) | 0 | 4 | 4 | 0 | | | 0 | 10 | 0 | | 0 | | 5 | |
|  | *Diura bicaudata* (Linnaeus) | 0 | 0 | 0 | 1 | | | 0 | 0 | 0 | | 0 | | 0 | |
|  | *Brachyptera risi* (Morton) | 0 | 0 | 0 | 3 | | | 0 | 0 | 0 | | 0 | | 0 | |
|  | *Perla bipunctata* (Pictet) | 0 | 2 | 2 | 0 | | | 1 | 5 | 0 | | 0 | | 0 | |
|  | *Chloroperla tripunctata* (Scopoli) | 0 | 0 | 0 | 1 | | | 0 | 1 | 0 | | 0 | | 1 | |
|  | *Siphlonoperla torrentium* (Pictet) | 0 | 2 | 2 | 1 | | | 0 | 0 | 0 | | 0 | | 0 | |
|  | *Nemurella pictetii (*Klapalek) | 0 | 0 | 0 | 2 | | | 0 | 2 | 0 | | 0 | | 0 | |
|  | *Amphinemura sulcicollis* (Stephens) | 0 | 0 | 0 | 12 | | | 0 | 0 | 0 | | 0 | | 0 | |
|  | *Nemoura avicularis* (Morton) | 0 | 0 | 0 | 1 | | | 0 | 0 | 0 | | 0 | | 0 | |
|  | *Protonemura meyeri* (Pictet) | 0 | 0 | 0 | 2 | | | 0 | 0 | 0 | | 0 | | 0 | |
| Trichoptera | *Hydropsyche instabilis* (Curtis) | 0 | 47 | 47 | 0 | | | 5 | 10 | 0 | | 32 | | 2 | |
| (Caddisfly) | *Hydropsyche pellucidula (*Curtis) | 0 | 1 | 1 | 0 | | | 0 | 0 | 0 | | 0 | | 0 | |
|  | *Hydropsyche siltalai* (Dohler) | 0 | 4 | 4 | 0 | | | 0 | 0 | 0 | | 15 | | 7 | |
|  | *Rhyacophila dorsalis* (Curtis) | 0 | 8 | 8 | 0 | | | 5 | 19 | 3 | | 6 | | 6 | |
|  | *Rhyacophila munda (*McLachan) | 2 | 0 | 0 | 0 | | | 0 | 0 | 0 | | 0 | | 0 | |
|  | *Cyrnus Flavidus* (Mclanchlan) | 0 | 1 | 1 | 0 | | | 0 | 0 | 0 | | 0 | | 2 | |
|  | *Polycentropus flavomaculatus* (Pictet) | 0 | 1 | 1 | 0 | | | 0 | 0 | 0 | | 0 | | 0 | |
|  | *Beraeodes minutus* (Linnaeus) | 0 | 2 | 2 | 0 | | | 5 | 0 | 0 | | 0 | | 0 | |
|  | *Silo nigricornis* (Pictet) | 0 | 0 | 0 | 0 | | | 4 | 2 | 5 | | 6 | | 0 | |
|  | *Chaetopteryx villosa* (Fabricius) | 2 | 0 | 0 | 0 | | | 4 | 8 | 0 | | 2 | | 0 | |
|  | *Microptera sequax* (McLachlan) | 0 | 0 | 0 | 0 | | | 1 | 0 | 0 | | 6 | | 2 | |
|  | *Potamophylax cingulatus* (Stephen) | 0 | 0 | 0 | 0 | | | 0 | 0 | 1 | | 0 | | 0 | |
|  | *Potamophylax latipennis* (Curtis) | 0 | 0 | 0 | 0 | | | 0 | 0 | 1 | | 0 | | 0 | |
|  | *Sericostoma personatum* (Spence) | 0 | 0 | 0 | 0 | | | 1 | 1 | 0 | | 1 | | 4 | |

*The Table above shows the total individuals collected from each river at the different points; 1.5km (headwater), 3km and 6km from source of water and the species found.*