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RESEARCH ARTICLE



Functional traits drive the inter-annual differences in the diversity of benthic macroinvertebrate communities associated with agricultural ditches

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ABSTRACT

Ditches are a key feature of the agricultural landscape, especially in relation to rice cultivation. Despite being affected by anthropogenic pressures in terms of flow regulation and channelisation, they can play an important role as habitats for aquatic species, thus maintaining biodiversity and ecosystem services at both the local and regional scale. Although their well-known role as consumers and bioindicators in freshwater ecosystems, benthic macroinvertebrates of agricultural ditches have received far less attention compared to other aquatic ecosystems. Previous studies have focussed almost exclusively on changes in taxonomic diversity across spatial gradients or under different management practices, while temporal variations in the functional diversity and composition of macroinvertebrate communities in agricultural ditches remain largely unexplored. In this study, benthic macroinvertebrates were sampled from eight sampling sites across five agricultural ditches and one river in October (autumn) of two consecutive years: 2022 and 2023. The two years were characterised by different climatic and hydrological conditions, with significantly lower precipitation and discharge in 2022 than in 2023. On average, the taxon richness, total abundance of benthic macroinvertebrates and functional richness were significantly higher in 2023 than in 2022; while the opposite trend was observed for the heterogeneity in the taxonomic composition of macroinvertebrate communities, as well as for functional evenness. Differences in the number and identity of significant associations between trait modalities of benthic macroinvertebrates and local environmental parameters were found between the two years, with seven and three significant correlations observed in 2022 and 2023, respectively. Overall, these results suggest that the taxonomic and functional diversity of ditch macroinvertebrate communities changed from 2022 to 2023 in this study. They also highlight the importance of considering the temporal dynamics of macroinvertebrate communities alongside anthropogenic practices and flow-related variations when evaluating the biodiversity of agricultural ditches in future research.

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Introduction

Agricultural landscapes typically include complex and dense networks of modified and artificial watercourses, such as irrigation ditches, which play a vital role in preserving biodiversity and maintaining ecosystem functioning in human-impaired environments (Sayer et al. 2012; Whatley et al. 2015). Despite being strongly shaped by anthropogenic pressures (e.g. water abstraction, nutrient enrichment, flow regulation and channelisation), these agroecosystems can provide suitable conditions for diverse faunal groups, including benthic macroinvertebrate assemblages, thereby contributing to both local and regional biodiversity as well as ecological connectivity (Herzon and Helenius 2008; Williams et al. 2010). However, the habitat provision and the ecological role of agricultural ditches are likely to be context-dependent due to the trade-off between the frequency and intensity of human-induced alterations and the proximity of

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natural areas that serve as sources of colonisers. Local habitat heterogeneity and presence of refuges are also expected to play a fundamental role in maintaining local biodiversity (Needelman et al. 2007; Davies et al. 2008).

By occupying all the consumer levels in food webs, benthic macroinvertebrates are widely recognised as important components of freshwater ecosystems in terms of biodiversity, density and biomass (Füreder et al. 2006; Heino and Tolonen 2017; Fornaroli et al. 2020; Burgazzi et al. 2023). Furthermore, owing to their taxon-specific sensitivity to physical and chemical alterations, benthic macroinvertebrates are valuable indicators for assessing the ecological status of lotic and lentic water bodies. With this respect, they are currently included in several institutional biomonitoring programs worldwide (Bonada et al. 2006; Buss et al. 2015), as well as in citizen science initiatives (Edwards 2016; von Gönner et al. 2023; Roccatello et al. 2025). Nevertheless, the scientific knowledge on benthic macroinvertebrates associated with agricultural ditches is still limited (but see: Vaikre et al. 2015; Hill et al. 2016), with previous studies primarily focusing on taxonomic diversity variation across spatial gradients or under different management practices (Verdonschot et al. 2011; Vallefucio et al. 2023). In contrast, the temporal dynamics of macroinvertebrate community composition and diversity remain poorly explored, despite agricultural ditches offer valuable chances to empirically test the response and resilience of macroinvertebrates to various disturbances, such as hydrological variability (Datry et al. 2017), pulses of contaminants (e.g. pesticides and nutrients) (Albou et al. 2024) and the periodic removal of riparian vegetation (Dollinger et al. 2015).

Functional trait-based approaches, rather than taxonomic ones, are expected to provide deeper insights into community assembly by linking species' ecological strategies and adaptations to environmental drivers (Violle et al. 2007; Villéger et al. 2008). Metrics such as functional richness, evenness and dispersion are thought to capture multifaceted aspects of how species occupy and structure functional trait space (Laliberté and Legendre 2010). Similarly, some multivariate analyses allow the testing of associations between environmental gradients and trait modalities (Dolédec et al. 1996; Dray and Legendre 2008). However, except for the classification into functional feeding groups (Leslie et al. 2012; Leslie and Lamp 2017), functional analyses and metrics are rarely used to examine the trait profiles of macroinvertebrate communities in agricultural ditches.

By combining trait-based approaches with multivariate analyses, this work aims to improve our understanding of the ecological mechanisms that structure the functional diversity of macroinvertebrate communities in agricultural ditches. To this end, macroinvertebrate data were collected from a rice-dominated agricultural landscape in north-western Italy, which is the largest rice cultivated area in Europe. The wide and complex network of agricultural ditches and rivers in the study area therefore offers excellent, but still poorly examined (Bo et al. 2025), chances to evaluate patterns in the diversity of the target faunal group in relation to different pressures associated with agricultural land use (Arcieri and Ghinassi 2020). Benthic macroinvertebrates were collected in autumn in two consecutive but hydrologically different years (i.e. 2022 and 2023) with the following specific aims: (1) to assess inter-annual changes in taxonomic and functional diversity metrics and (2) to statistically test the relationships between macroinvertebrate trait modalities and local environmental variables with the ultimate goal of evaluating the relative roles of habitat filtering and hydrological connectivity in shaping macroinvertebrate communities.

Materials and methods

Area of study

The first evidence of rice cultivation in north-western Italy dates back to the late Middle Ages (Pelloli 2024). The cultivation of this crop has modified the landscape to such an extent that, nowadays, the territory within the Provinces of Vercelli, Novara and Pavia represents the largest area of rice production in Europe (Arcieri and Ghinassi 2020). As a consequence, this lowland area is dominated by rice paddies as well as a dense and interconnected drainage network composed of rivers, ditches and springs.

Eight sampling sites were selected within the Province of Novara (Figure 1): two sites were located on the Agogna River, one upstream (Agogna1) and one 9.5 km downstream (Agogna2), respectively; while six sites were chosen among the most representative and accessible agricultural ditches located in close



Figure 1. Map of the area of study. The colour dots and labels indicate the sampling sites.

proximity to the Agogna River (<2 km overland distance). The Agogna River was included in this study because it is the main watercourse within the study area. Two sampling sites were identified on the Roggia Caccesca, with Caccesca1 being close to Agogna1 while Caccesca2 was located 5 km downstream. Roggia Caccesca is an agricultural ditch that is directly fed by the Agogna River. The four sampling sites were allocated in the following agricultural ditches: Cavo Dassi, Cavo Cattedrale, Cavo Panizzina and Fontana Pietta (Figure 1). Except for Cavo Dassi, which is sometimes affected by a drying phase during the winter season (December–March), all the sampling sites are perennial.

Data on the daily discharge of the Agogna River and the daily precipitation, measured at the ‘Novara–Agogna’ gauging station (located 1 km upstream from the sampling site Agogna1), were freely downloaded from the website of the Local Agency for Environmental Protection (i.e. ARPA Piemonte; https://www.arpa.piemonte.it/rischi_naturali/snippets_arpa_graphs/map_meteoweb/?rete=stazione_idrologica). Since this is the only gauging station in the study area and none of the other ditches considered here are equipped with similar tools, the data gained from the Agogna River as well as the precipitation data measured at the ‘Novara–Agogna’ station were used as representative proxy for the hydrological conditions at all the sampling sites. On average, the daily discharge (m^3/s) was significantly higher in 2023 than in 2022, especially in spring and autumn. These data hence confirm the differences between these two years (Figure 2a and b). Similarly, total cumulative precipitation was higher (707.2 mm) in 2023 than in 2022 (560 mm) (Figure 2c and d).

Data collection

Macroinvertebrate sampling was always performed in autumn but in two consecutive years: namely on 20th and 27th October 2022 and on 9th and 10th October 2023. As rice was always harvested in September in the study area, there were no daily fluctuations in discharge due to agricultural practices and irrigation during

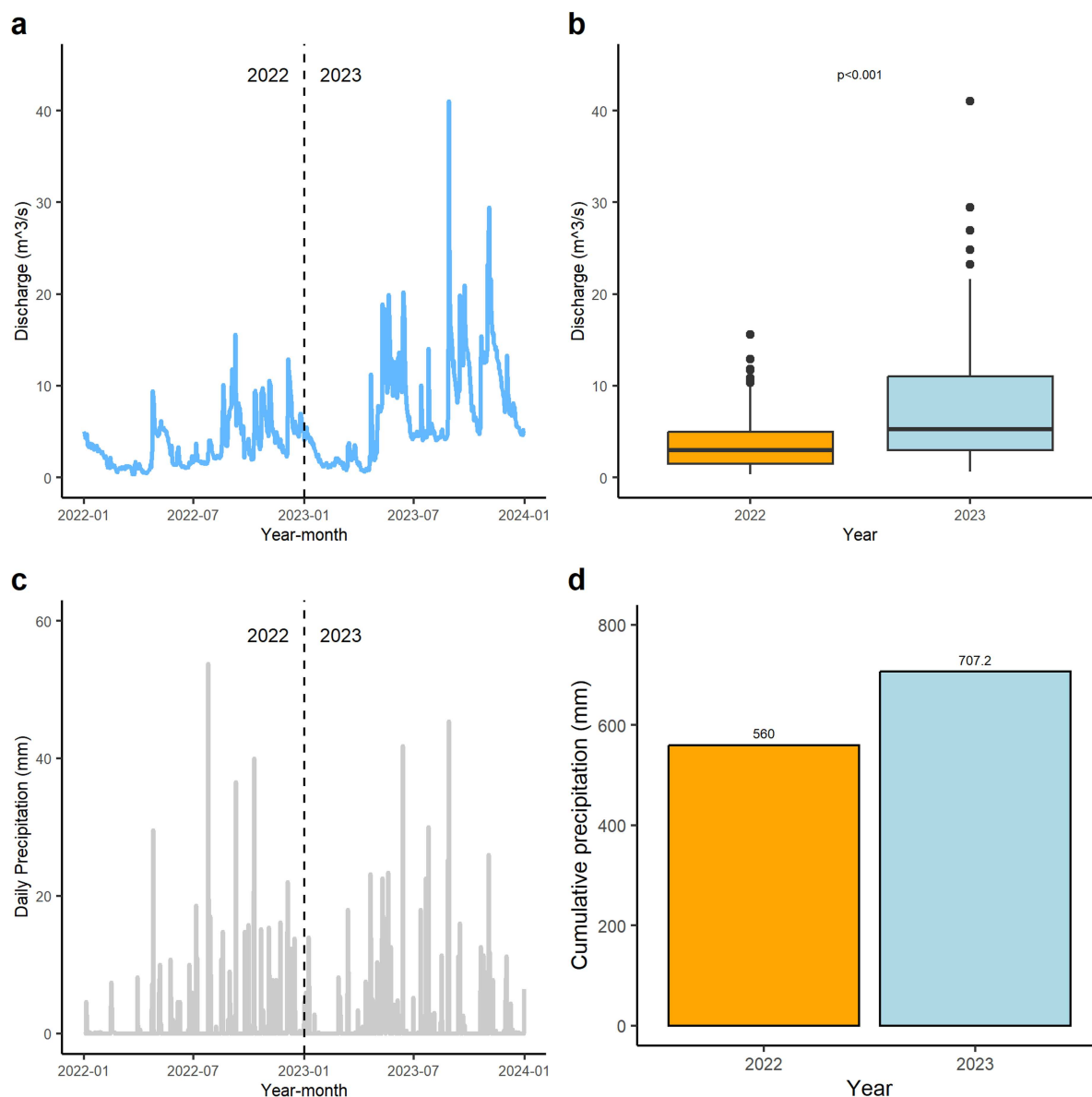


Figure 2. Hydrograph (a) showing the fluctuation in the daily discharge recorded at the ‘Novara–Agogna’ gauging station, located 1 km upstream from the sampling site Agogna, in 2022 and 2023 (from 1st January to 31st December in both years). Boxplots (b) illustrate the inter-annual differences in the daily discharge. Black horizontal line = median; upper and lower box edges = 3rd and 1st quartile, respectively; vertical lines = whiskers (± 1.5 interquartile distance). Statistical significance was verified by means of the *t*-test. Graph (c) illustrates the daily precipitation (mm) recorded at the ‘Novara–Agogna’ gauging station, while barplot (d) illustrates the total cumulative precipitation (mm) in the two years.

macroinvertebrate sampling. Benthic macroinvertebrates were collected from the riverbed by using a Surber net (0.05 m², 250- μ m mesh size; Doretto et al. 2020). Six Surber samples were taken at each site by considering all the microhabitats, including mineral and biotic substrates (6 Surber samples \times 8 sites \times 2 years = 96 samples). Previous data from the same study area proved that this sampling effort was adequate to obtain a representative macroinvertebrate community (Chiorino et al. 2024). Moreover, the water velocity (m/s) and water depth (cm) were recorded for each sample using a flowmeter (Company: Scubla, model: N.01.200). The electrical conductivity (μ S/cm), water temperature ($^{\circ}$ C) and pH were instead measured once at each sampling site using a multiprobe (Company: Hanna, model: HI98194). Similarly, two water samples (0.5 L) were collected at each site and returned to the laboratory for the analysis of nitrates and phosphates (mg/L) according to standard spectrophotometric methods. Benthic macroinvertebrates were preserved in plastic tins with ethanol

(90%) and delivered to the laboratory where they were sorted, counted and taxonomically identified to the genus (Plecoptera, Ephemeroptera and Odonata) or family level using a stereomicroscope (Company: Leica, model: EZ4) and the taxonomic keys and atlas for the Italian and European fauna (Campaioli et al. 1994, 1999; Tachet et al. 2010).

Statistical analyses

Before analysing the data, the total macroinvertebrate community was obtained for each site by pooling together the six Surber samples. All the statistical analyses (significant threshold: p -value < 0.05) were performed using the R software (Wickham et al. 2016; R Core Team, 2025—version 4.5.1). Both basic and specific R functions were used as described in the following sections.

Differences in the taxonomic diversity and composition

Wilcoxon test for paired data was used to evaluate the differences in the total taxon richness and total macroinvertebrate abundance between years. Instead, changes in the heterogeneity of the taxonomic composition of benthic macroinvertebrate communities from 2022 to 2023 were visualised using Principal Coordinates Analysis (PCoA) and tested for significance by applying the test of homogeneity for multivariate dispersion (PERMDISP—Anderson 2006; betadisper function in the ‘vegan’ R package—Oksanen et al. 2015). Bray–Curtis dissimilarity indices were used as distance measures in both multivariate analyses.

Differences in the functional diversity

Based on the classification proposed by Tachet et al. (2010), functional traits were assigned to all the macroinvertebrate taxa collected in this study. Therefore, functional richness, functional evenness and functional dispersion (‘biomonitor’ R package; Laini et al. 2022) were calculated for each site and year. According to the approach of Villéger et al. (2008), functional richness represents the amount of functional space filled by the community, while functional evenness indicates how evenly the abundance of taxa is distributed in the functional trait space. Functional dispersion, instead, describes the spread of the taxa in the trait dimensional space (Laliberté and Legendre 2010). Statistical differences in the functional metrics between the two years were evaluated by means of the Wilcoxon test for paired data.

Relationships between diversity metrics and environmental parameters

To better investigate the strength of the relationships between the diversity metrics and local environmental parameters (i.e. habitat sorting effect) and to determine whether this relationship varied from 2022 to 2023, significant correlations (Pearson's correlation index) between each taxonomic and functional metric and the physical and chemical parameters were tested. Correlation matrices were created using the function `chart.correlation` of the ‘PerformanceAnalytics’ R package (Peterson et al. 2018) for each year. Moreover, Fourth Corner Analysis (function `fourthcorner` of the ‘ade4’ R package—Dray and Siberchicot 2017) was performed to test whether the local environmental parameters were significantly associated with the distinct trait modalities of macroinvertebrates in both 2022 and 2023. Fourth Corner Analysis is a multivariate technique that provides a correlation between each environmental variable and individual trait modalities by combining three different data tables: a species X sites table, a matrix of the environmental variables across sites and a species X traits table (Legendre et al. 1997; Dray and Legendre 2008). To this end, a total of 27 trait modalities belonging to five different traits (namely: water velocity preferences, dispersal, feeding strategy, resistance strategies, and transversal distribution) were selected for macroinvertebrates (Tachet et al. 2010). These five traits were chosen over the other traits because of their expected strong response to the typical environmental pressures of agricultural ditches in terms of hydrological permanence and connectivity, availability of energetic inputs, and habitat selection.

Results

Except for water temperature, which was significantly higher in 2023 than in 2022, all the physical and chemical parameters did not vary between years (Table S1). A total of 24,747 individuals belonging to 62 different macroinvertebrate taxa were collected (Table S2). The most abundant taxon was the Dipteran

family Chironomidae (39%), followed by *Echinogammarus* sp. (13%), *Baetis* sp. (12%) and Lumbriculidae (9%). Together, these four taxa constituted 73% of the total macroinvertebrates.

On average, the total taxon richness and total macroinvertebrate abundance were significantly higher in 2023 than in 2022 (Figure 3a and c). Indeed, both of these metrics increased in all the sampling sites from 2022 to 2023 (Figure 3b and d). The highest number of taxa (39 taxa) was observed at Cavo Cattedrale in 2023, while the lowest taxon richness (16 taxa) was found at Caccesca2 in 2022 (Figure 3b). Similarly, the

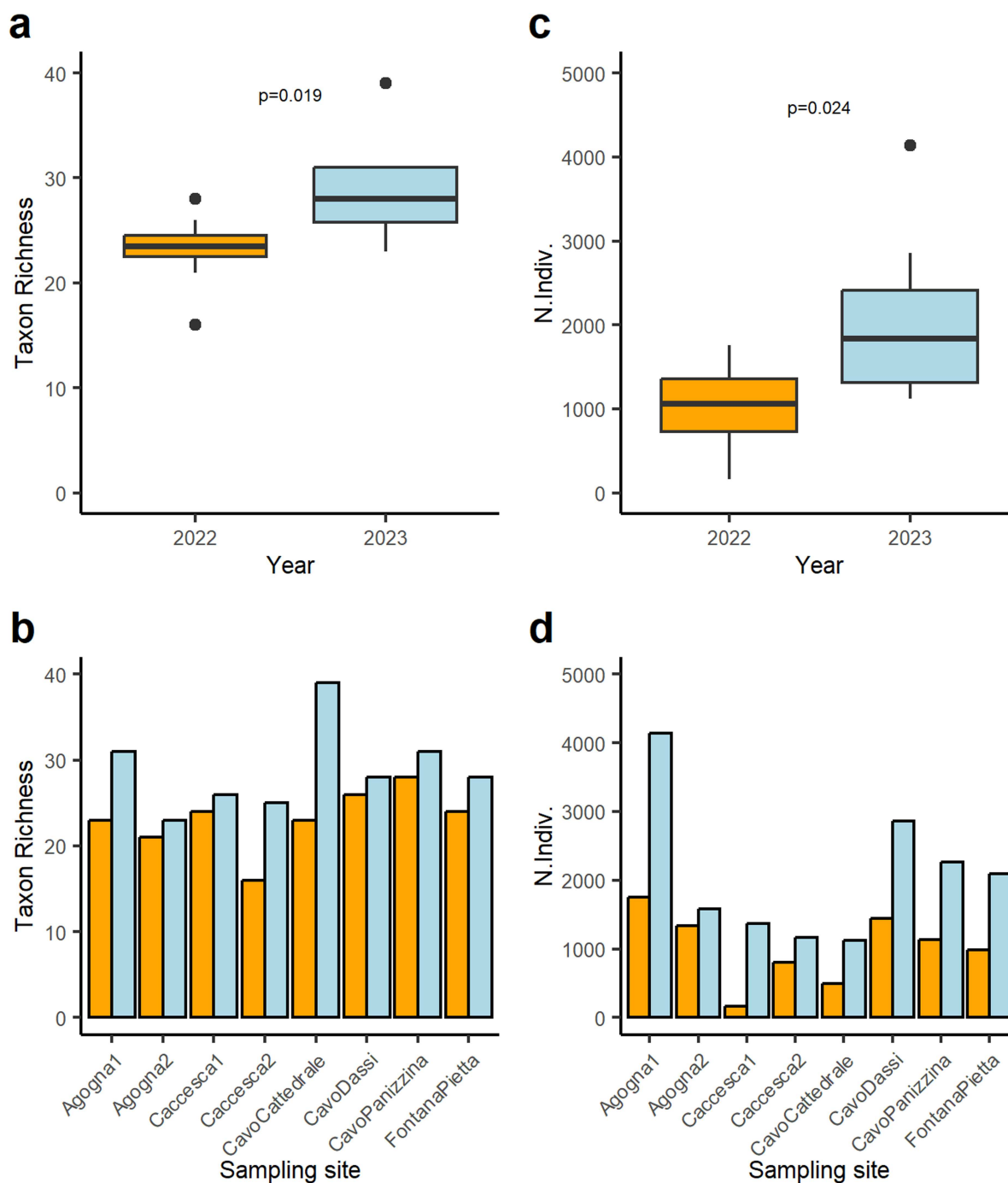


Figure 3. Boxplots and barplots illustrating the variation in the total taxon richness (a and b) and total abundance of macroinvertebrates (c and d) between years and among the sampling sites. For boxplots: black horizontal line = median; upper and lower box edges = 3rd and 1st quartiles, respectively and vertical lines = whiskers (± 1.5 interquartile distance).

highest abundance of macroinvertebrates was observed at Agogna1 in 2023 (4139 individuals), while only 135 individuals were recorded at Caccasca1 in 2022 (Figure 3d).

The heterogeneity of the taxonomic composition of benthic macroinvertebrate communities, measured as the distance from the centroid in the PCoA multivariate space, was higher in 2022 than in 2023 (Figure 4a and b). However, this difference was not statistically significant (Figure 4b).

On average, functional richness was significantly higher in 2023 than in 2022 (Figure 5a). This metric ranged from 0.91 at Agogna1 in 2023 to 0.28 at Caccasca2 in 2022 (Figure 5b). Caccasca2 was also the sampling site where the largest variation in functional richness was observed between years, while inter-annual changes were minimal at Cavo Dassi, Caccasca1 and Fontana Pietta (Figure 5b). The functional dispersion, instead, did not significantly vary from 2022 to 2023 (Figure 5c). Most of the sampling sites showed negligible variation in functional dispersion between the two years, with the highest values observed at Caccasca2 (0.30 in both 2022 and 2023), while the lowest value (0.16) observed at Cavo Dassi in 2022 (Figure 5d). On the contrary, functional evenness was higher in 2022 than in 2023, despite this difference was not significant (Figure 5e). The functional evenness increased from 2022 to 2023 at Agogna1, Agogna2 and Cavo Cattedrale, while the opposite trend was observed at the other sampling sites. Both the highest (0.66) and the lowest (0.29) values of functional evenness were found in 2022 at Cavo Dassi and Agogna1, respectively (Figure 5f).

When looking at the relationships between the functional metrics and the local environmental parameters, only the distance from the centroid (i.e. as a measure of the heterogeneity of the taxonomic composition) showed a significant positive correlation with the concentration of phosphates, albeit only in 2023 (Figure 6a). The other taxonomic metrics (i.e. total taxon richness, total abundance and distance to the centroid) showed weak, not significant correlations with the physical and chemical parameters (Figures S1 and S2). Among the functional metrics, two significant correlations were found for functional evenness in 2022. In both cases, this latter metric was negatively correlated with the water velocity and concentration of nitrates (Figure 6b and c, respectively). No other functional metrics were statistically correlated with the physical and chemical parameters (Figures S3 and S4).

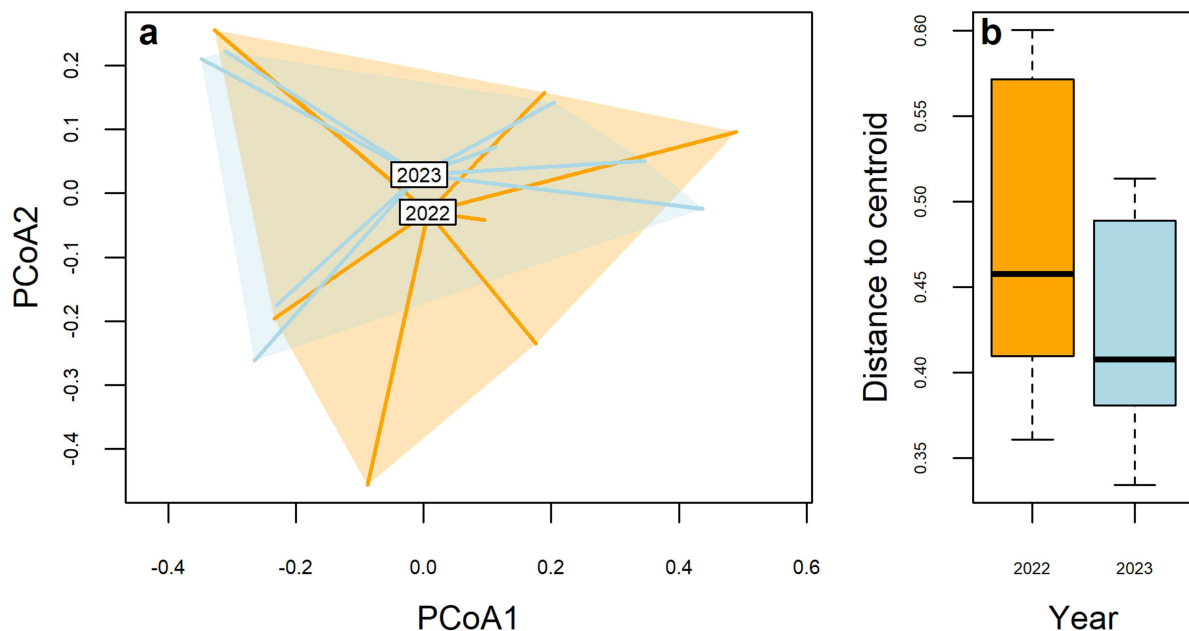


Figure 4. Output of the multivariate analyses: (a) Principal Coordinates Analysis (PCoA) plot for the benthic macroinvertebrate communities. The labels with the years (i.e. 2022 and 2023) indicate the corresponding centroids for these years. (b) Boxplot illustrating the distance from the centroid of the benthic macroinvertebrate communities. For the boxplot: black horizontal line = median; upper and lower box edges = 3rd (75th percentile) and 1st (25th percentile) quartile, respectively; whiskers indicate ± 1.5 interquartile distance.

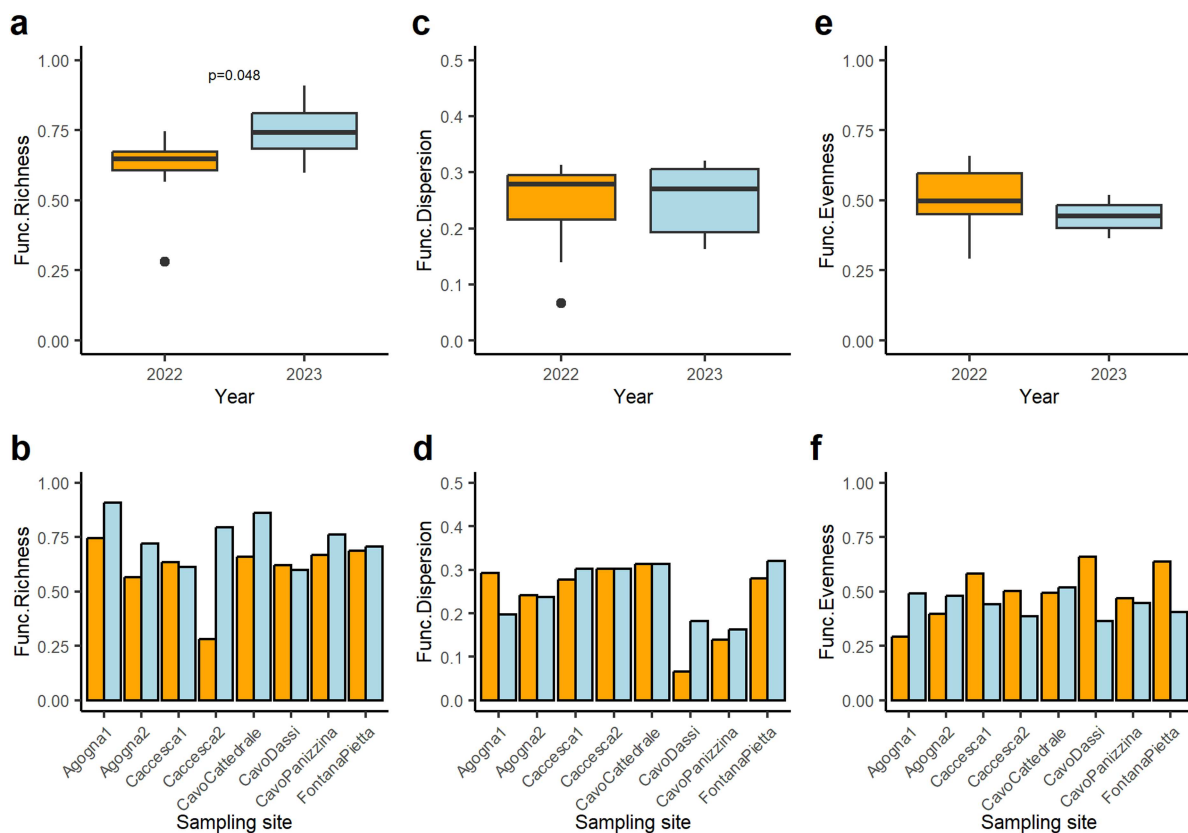


Figure 5. Boxplots and barplots illustrate the variation in the functional richness (a and b), functional dispersion (c and d) and functional evenness (e and f) between years and among the sampling sites. For boxplots: black horizontal line = median; upper and lower box edges = 3rd and 1st quartiles, respectively; vertical lines = whiskers (± 1.5 interquartile distance).

According to the results of the Fourth Corner Analysis, differences were observed in the total number of significant associations between trait modalities and local environmental parameters, as well as the identity of these modalities and environmental parameters, between the two years. In particular, seven significant associations were found in 2022 (Figure 7). A positive correlation was found between aquatic and passive dispersers and water depth. Among the feeding modalities, shredders were negatively correlated with water velocity, depth and the concentration of nitrates, while the parasite modality was positively associated with water depth. Water velocity and depth were also positively and negatively correlated with macroinvertebrates that use eggs and/or statoblasts as resistance strategy and macroinvertebrates with no resistance strategy, respectively (Figure 7).

In 2023, only three significant associations were detected by the Fourth Corner Analysis (Figure 8). Macroinvertebrates preferring medium water velocity were positively correlated with the concentration of nitrates, while macroinvertebrates associated with fast-flowing waters were negatively affected by pH. Similarly to 2022, a positive correlation was also detected between parasite macroinvertebrate taxa and water depth (Figure 8).

Discussion

Irrigation ditches in rice-dominated agricultural landscape offers chances to test the mechanisms and causes of changes in the taxonomic and functional biodiversity especially in relation to aquatic organisms such as benthic macroinvertebrates. These communities are simultaneously shaped by local environmental filters, which often reflect management intensity gradients, as well as regional processes such as hydrological connectivity and dispersal from source rivers (Herzon and Helenius 2008; Williams et al. 2010). In the

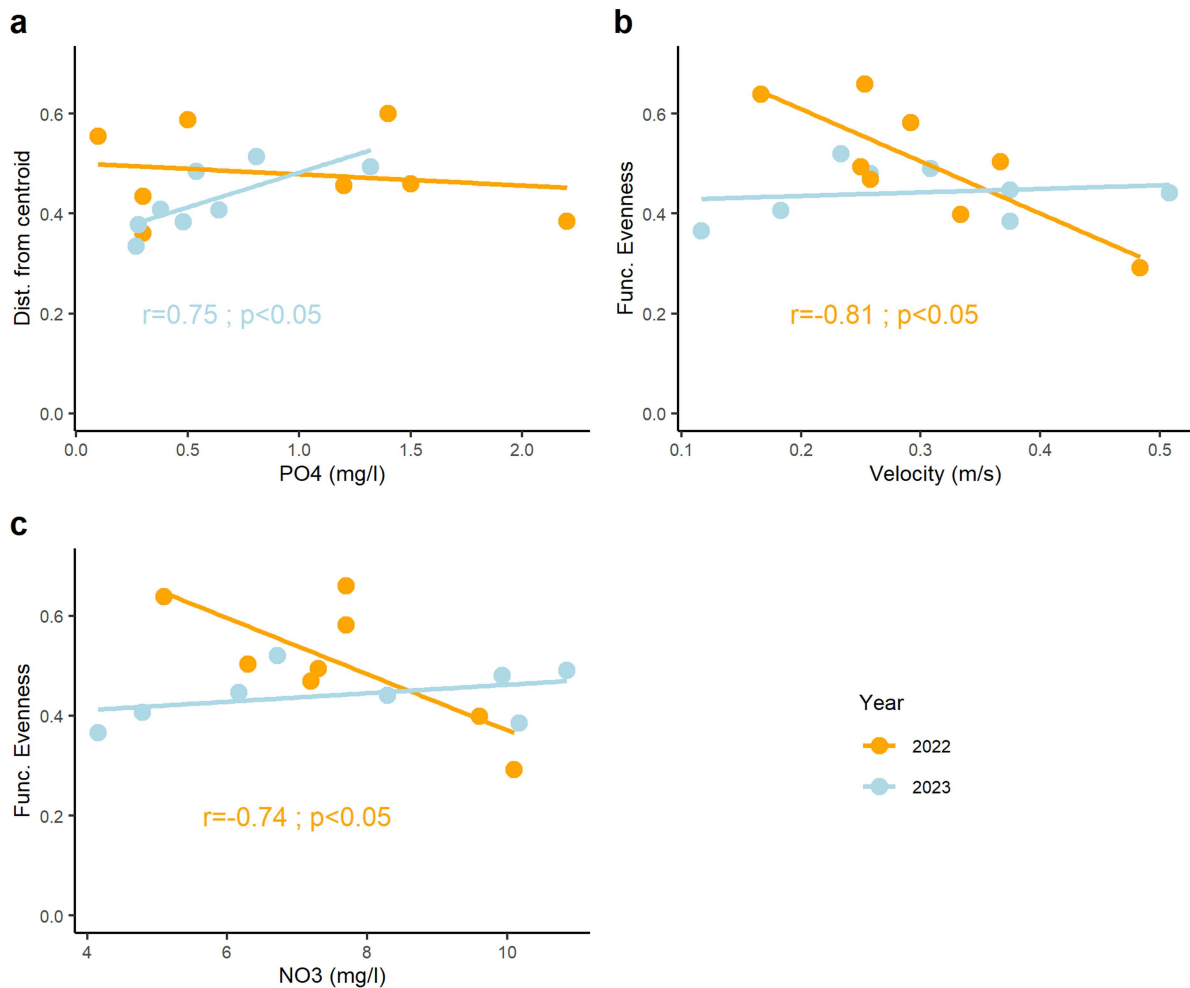


Figure 6. Pearson's correlations between the (a) distance from the centroid and the concentration of phosphates (PO4) and (b and c) functional evenness with the water velocity and concentration of nitrates (NO3), respectively. The colours indicate the data of the two different years (i.e. 2022 and 2023), while the text indicates the statistics of the significant correlations: $r = \rho$; $p = p$ -values.

Po Plain (northern Italy), where this study was conducted, irrigation networks form one of the largest artificial hydrographic systems in Europe. These networks have been developed over centuries and are ecologically relevant (Arcieri and Ghinassi 2020). Nevertheless, the macroinvertebrate biodiversity associated with these aquatic habitats (e.g. ditches and rice paddies) has been largely overlooked (Bo et al. 2025), with previous research that was mostly focused on hydrology, water chemistry or some selected taxa (Cesari de Maria et al. 2018; Lupi et al. 2013).

This study aimed to evaluate the interannual variation in the taxonomic and functional diversity of macroinvertebrate communities in agricultural ditches by sampling them in two consecutive years with different hydrological and climate conditions. It is widely recognised that hydrological conditions, and particularly flow regime, are key drivers of lotic ecosystem structure and function. The flow regime has been defined as the 'master variable' controlling all the other physical and biological processes in river ecosystems, including sediment transport, substrate stability, macroinvertebrate drift and biogeochemical cycles (Poff et al. 1997; Bunn and Arthington 2002).

To this end, we hypothesised that hydrological conditions, particularly discharge, influence community assembly by affecting connectivity and, in turn, the dispersal of macroinvertebrates. In 2022, low flows likely increased site isolation, strengthening local habitat filtering and resulting in lower richness and higher compositional heterogeneity among the macroinvertebrate communities at different sampling sites. Conversely, in 2023, higher flows enhanced connectivity, favouring the dispersal and gain of new taxa and

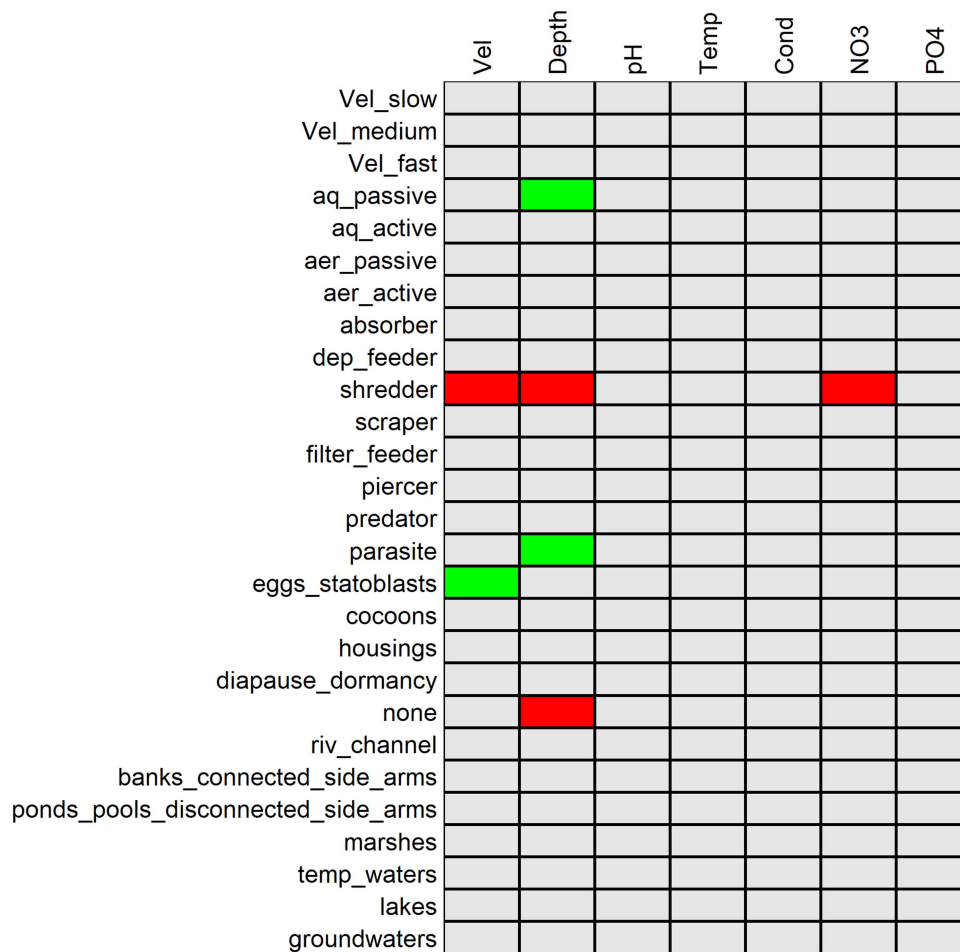


Figure 7. Fourth Corner Analysis on the 2022 data showing significant relationships between trait modalities and environmental variables: Vel = water velocity (m/s), Depth = water depth (cm), pH, Temp = water temperature (°C), Cond = electrical conductivity ($\mu\text{S}/\text{cm}$), NO₃ = concentration of nitrates (mg/L) and PO₄ = concentration of phosphates (mg/L). Green cells indicate positive and significant correlations, while red cells indicate negative and significant correlations.

their associated functional traits, thus resulting in richer but more compositionally similar macroinvertebrate assemblages (Leibold et al. 2004; Brown and Swan 2010). These hypotheses were confirmed by our results: taxonomic richness and abundance were higher in 2023, while multivariate dispersion from the centroid was greater in 2022, suggesting stronger local habitat sorting under low discharge conditions when connectivity was likely reduced.

Previous research proved that variations in flow regime and precipitation can significantly influence the structure and diversity of aquatic communities, including macroinvertebrates. For example, in regulated alpine streams, experimental flooding events have been shown to cause an immediate reduction in macroinvertebrate density, with habitat-specific responses and recovery dynamics modulated by disturbance intensity and frequency. In boreal environments, hydrological alterations linked to land use have led to reductions in taxonomic richness and changes in community composition (Huttunen et al. 2012). At a watershed level, Fornaroli et al. (2020) documented spatial and temporal variations in macroinvertebrate diversity in the Po River basin. They found that altitudinal gradients, which act as proxies for precipitation and temperature, were associated with changes in taxonomic and functional patterns. Finally, Larsen et al. (2023) demonstrated that multi-decadal climate oscillations, such as the North Atlantic Oscillation, influence the synchrony of populations and the stability of macroinvertebrate communities in temperate rivers.

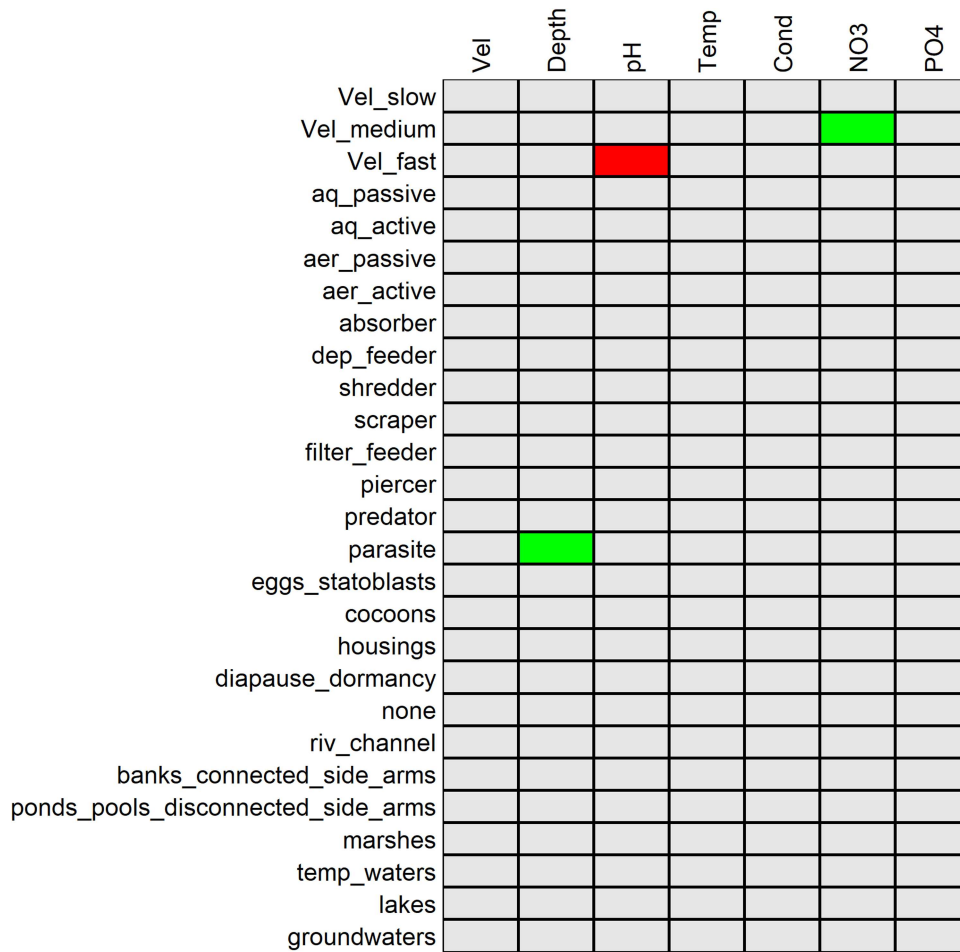


Figure 8. Fourth Corner Analysis on the 2023 data showing significant relationships between trait modalities and environmental variables: Vel=water velocity (m/s), Depth=water depth (cm), pH, Temp=water temperature (°C), Cond=electrical conductivity (µS/cm), NO3=concentration of nitrates (mg/L),and PO4=concentration of phosphates (mg/L). The green cells indicate positive and significant correlations, while red cells indicate negative and significant correlations.

The previously mentioned references reinforce the principle that aquatic communities, even in artificial systems, are highly sensitive to hydrological conditions. This aligns with studies showing that channelisation and flow depletion compromise diversity in urban waterways (Chen et al. 2025). The observed increase in richness and functional richness under high flow is directly linked to enhanced dispersal, a mechanism supported by evidence from other engineered systems. For instance, Nagel et al. (2022) demonstrated that nature-like fish bypass channels actively increase the density and diversity of drifting macroinvertebrates by functioning as source habitats. Thus, the high discharge in our study acted as an efficient dispersal vector, ensuring that key ecological processes such as passive drift operate fully in agricultural ditches and maintain the network's overall functional diversity.

Interannual differences were also found in relation to functional diversity metrics. For instance, functional richness was greater in 2023, which is consistent with enhanced dispersal under higher connectivity. In contrast, functional evenness peaked in 2022, which suggests that the reduced connectivity and abundances of macroinvertebrates under low-flow conditions likely resulted in a more even distribution of functional traits within assemblages.

Comparable patterns have been observed linking hydrological variability and functional diversity in natural watercourses. For instance, Schneider et al. (2018) found that reduced flow velocity and discharge resulted in lower functional richness. This is consistent with more intense environmental filtering under hydrologically stable, low-flow conditions, which excludes taxa with specialised functional traits. In a

similar vein, Li et al. (2019) demonstrated that flow-related and environmental variables were the primary drivers of functional richness and dispersion across river networks in southern Tibet. These findings suggest that high local water stability fosters the coexistence of species with complementary trait combinations.

The findings of this study demonstrate an increase in functional evenness in 2022 and enhanced functional richness in 2023, which are in accordance with the aforementioned mechanisms. Similar to the findings obtained by Drost et al. (2022), it can be hypothesised that the phenomenon of flow intermittency and isolation in 2022 exerted a selective pressure, leading to trait homogenisation. This process has been demonstrated to occur as a consequence of the exclusion of rheophilic and dispersive taxa. The concurrent rise in functional evenness causes the flattening of the abundance distribution within the constrained trait space, which is a hallmark of communities under elevated stress levels that are predominantly comprised of a small number of resilient, generalist taxa. Conversely, elevated flow levels in 2023 facilitated a broader array of ecological strategies, thereby restoring functional richness.

While previous studies have mainly examined the taxonomic diversity of ditch macroinvertebrate communities (Vaikre et al. 2015; Hill et al. 2016; Chiorino et al. 2024; Bo et al. 2025), the analysis of their trait profiles and functional metrics of ditch macroinvertebrate communities has largely been overlooked (but see Leslie and Lamp 2017; Vallefucio et al. 2023). The findings of this study, therefore, attempt to partially fill this research gap and underscore the effectiveness of trait-based methodologies for prospective biomonitoring and ecological assessment in freshwater ecosystems, where hydraulic management exerts a strong influence.

Fourth-corner analyses highlighted that the strength of trait–environment associations differed markedly between the two years. In 2022, when discharge was low, hydraulic variables such as velocity and depth acted as dominant environmental filters, being negatively associated with shredders and deposit feeders. This pattern likely reflects the reduced transport and accumulation of CPOM under low-flow conditions, which constrained functional groups that depend on organic detrital resources. In contrast, in 2023, the number of significant associations decreased, and the role of hydraulic factors diminished, suggesting that enhanced connectivity promoted dispersal and reduced the influence of local filtering. Analogous patterns have been observed in regulated river systems. The findings of trait-based studies imply that flow regulation functions as a significant environmental filter, thereby influencing the composition of macroinvertebrate communities (Calderón et al. 2025). Furthermore, recent studies have demonstrated that functional diversity and trait–environment relationships are reliable indicators of habitat quality in fluvial ecosystems (Sotomayor et al. 2025). This finding indicates that although agricultural ditches are man-made systems, they respond to hydrological variability in ways that are, at least partially, similar to those observed in rivers. This underscores the importance of employing trait-based metrics in these habitats to identify the ecological processes underlying community assembly.

Overall, our findings demonstrate that agricultural ditches offer opportunities to better investigate biodiversity patterns in agricultural landscapes. They may also serve as a benchmark against which to compare findings from other geographical settings with different farming practices and agricultural pressures. By providing evidence of annual variations in taxonomic and functional macroinvertebrate diversity, we showed that community assembly reflects a dynamic interplay between local filtering and regional dispersal, which is mediated by temporal hydrological variability. This duality highlights the importance of preserving both habitat heterogeneity and hydrological connectivity to protect aquatic biodiversity in intensively managed landscapes. Notably, our results suggest that benthic macroinvertebrate communities in agricultural ditches respond to temporal fluctuations in flow. This finding indicates that key ecological processes, such as trait-based filtering and dispersal, can still operate even in modified and human-impaired ecosystems such as ditches. However, owing to the limited number of studies conducted on agricultural ditches, further research is required to gain a comprehensive understanding of their ecological dynamics and refine biomonitoring approaches for managing freshwater networks.

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Author contributions

A.D.: conceptualisation, funding acquisition, methodology, formal analysis, writing—original draft preparation, data collection and writing—review and editing. A.V.: formal analysis, writing—original draft preparation, data collection and writing—review and editing.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

The data are available from the corresponding author upon reasonable request.

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