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Spatial and temporal assessment of the ecological status in a semiarid Mediterranean stream (Iberian Southeast)

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ABSTRACT

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The Mediterranean streams of semi-arid regions represent unique ecosystems, harboring a distinctive biodiversity adapted to variable environmental conditions. However, they are increasingly subjected to intense anthropogenic and climatic pressures, making it essential to assess their ecological status for conservation purposes. In this study, we analyse the spatial and temporal variability of the ecological status of the main water body of the Quípar stream (southeastern Iberian Peninsula), designated as a Special Area of Conservation (SAC) under the Natura 2000 network. To this end, we examined data from field surveys conducted at seven sites along the stream, as well as historical IBMWP index records (2006–2023) from one of these sites. While results did not reveal a significant spatial trend, high variability in ecological quality was detected within this water body. While some sites were classified as being in good condition the majority were categorized as "moderate". No significant temporal trend of improvement or degradation was identified, although notable annual fluctuations were observed. These results likely reflect a balance between conservation actions and improvements in wastewater treatment versus the negative impact of increasing intensive agriculture in the watershed. This study highlights the importance of conducting an ecological status assessment representative of heterogeneous water bodies. Thus, expanding the spatial coverage of monitoring efforts is recommended. Our findings underscore the need for management strategies tailored to the specific characteristics of semi-arid Mediterranean rivers, with a particular focus on restoring sections of lower ecological quality, mainly through regulating intensive agriculture.

KEY WORDS: aquatic macroinvertebrates, bioindicators, spatial patterns, temporal trends, spatial heterogeneity.

RESUMEN

Evaluación espacial y temporal del estado ecológico en un río mediterráneo semiárido (sureste ibérico).

Los arroyos mediterráneos de zonas semiáridas representan ecosistemas singulares, albergando una biodiversidad única adaptada a condiciones ambientales variables. Sin embargo, están expuestos a intensas presiones antropogénicas y climáticas, por lo que se hace imprescindible evaluar su estado ecológico en aras de su conservación. En este trabajo estudiamos la variabilidad espacial y temporal del estado ecológico de la principal masa de agua del río Quípar (sureste ibérico), declarado ZEC (Zona de Especial Conservación) como parte de la Red Natura 2000. Para ello, hemos analizado tanto datos de muestreos realizados en siete localidades a lo largo del curso del río como datos históricos del índice IBMWP (2006-2023) en una de estas localidades. Aunque los resultados no muestran una tendencia espacial significativa, se ha detectado

una alta variabilidad en la calidad ecológica dentro de la misma masa de agua, con algunos tramos en buen estado, y la mayoría dentro de la categoría "moderado". Tampoco se identificó ninguna tendencia significativa de mejora o degradación a lo largo del tiempo, aunque se observaron importantes fluctuaciones anuales. Los resultados pueden ser el reflejo del efecto combinado entre las acciones de conservación y la mejora del tratamiento de aguas residuales y el empeoramiento derivado del aumento de la agricultura intensiva en la cuenca. Este estudio resalta la importancia de realizar una evaluación del estado ecológico que sea representativa de los diferentes ambientes en masas de agua heterogéneas como es este caso, por lo que se recomienda ampliar la cobertura espacial del monitoreo. Los hallazgos subrayan la necesidad de adoptar estrategias de gestión adaptadas a las particularidades de los ríos mediterráneos semiáridos y que permitan la restauración de los tramos de menor calidad ecológica de estos ecosistemas, principalmente a través de la regulación de la agricultura intensiva.

PALABRAS CLAVE: *macroinvertebrados acuáticos, bioindicadores, patrones espaciales, tendencias temporales, heterogeneidad espacial.*

INTRODUCTION

Continental aquatic ecosystems, covering just 2.3% of Earth's surface yet hosting ~10% of known animal species, are key for global biodiversity conservation and the regulation of essential ecological processes and services (Zedler & Kercher, 2005, Dudgeon et al., 2006; Keddy et al., 2009, Irfan & Alatawi, 2019, Reid et al., 2019). However, despite their importance, they are experiencing the highest rate of habitat loss globally (Díaz et al., 2019). Fluvial systems are especially vulnerable to multiple anthropogenic pressures, including overexploitation of water, pollution, habitat destruction and the introduction of invasive species (Birk et al., 2020). These pressures have resulted in an unprecedented freshwater biodiversity crisis, threatening the conservation of their functions and thereby compromising the services and resources they provide to humanity (Harrison et al., 2010).

Understanding and monitoring the ecological status of freshwater ecosystems is essential for evaluating the impact of anthropogenic pressures and guiding conservation efforts (Vörösmarty et al., 2010, Grizzetti et al., 2017, Feio et al., 2021). These programmes integrate biological and environmental data to assess anthropogenic impacts while considering natural variations. In recent years, studies have reported improvements in river ecosystems due to mitigation measures, but also highlight strong spatial variability, with recovery trends stalled in some areas due to emerging and intensifying stressors, such as climate change, land-use intensification, and emerging pollutants (Haase et al., 2023; 2025).

Despite these advances, long-term ecological assessments remain strongly biased towards Central and Northern Europe (Vaughan & Ormerod, 2012, Haase et al., 2023, Wynants et al., 2025), leaving a significant gap in our understanding of how Mediterranean river ecosystems, and particularly in the semi-arid southeast of the Iberian Peninsula, respond to environmental change. Addressing this gap is crucial for developing effective conservation and management strategies. In this context, the EU Water Framework Directive (WFD) provides a synthetic assessment of how anthropogenic pressures impact aquatic environments (Abily et al., 2022).

The Iberian Southeast is one of the few semi-arid areas within the European Mediterranean region and stands out for its unique freshwater ecosystems and high levels of endemism (Abellán et al., 2007, Millán et al., 2011, Sánchez-Fernández et al., 2008). In this area—the Segura River basin—, is also marked by a highly irregular hydrological regimes, with prolonged periods of drought followed by very intense precipitation events, which implies the need for strong adaptation of aquatic macroinvertebrate communities to different stress factors such as flow intermittency (Belmar et al., 2019) and sometimes to high natural water salinity by its geological characteristics (Gutiérrez-Cánovas et al., 2019). Flow intermittency, however, is not an exclusive feature of Mediterranean rivers, but a widespread phenomenon that affects more than half of the global river network across all climates and biomes (Messager et al., 2021). In this context, it should be highlighted that the Mediterranean basin is one of the 25 areas con-

sidered to be global biodiversity hotspots (Myers et al., 2000). Certain areas within the Segura River basin have been identified as of notable conservation interest due to their high terrestrial and aquatic biodiversity, shaped by strong environmental heterogeneity and the presence of rare habitats (Bruno et al., 2012). Within this context, the Quípar stream stands out for hosting Iberian endemic aquatic taxa such as Ochthebius jaimei & Jäch, 2007 and O. delgadoi, Jäch, 1994, linked to mineral-rich and saline environments (Sáez et al., 2024).

Over recent decades, the intensification of agriculture in southeastern Spain—including the Segura River basin—has driven extensive land-use changes, marked by the expansion of irrigation systems, increased use of agrochemicals, and soil sealing (Emmerson et al., 2016). These practices have globally reduced landscape heterogeneity and degraded habitat quality, negatively impacting biodiversity across trophic levels and spatial scales (Eugercios Silva et al., 2017, Schürings, 2022). In the Quípar stream, where irrigation strongly influences land and water management (García-Marín et al., 2020), extensive irrigated crops rely on surface water transfers and groundwater extraction, leading to hydromorphological alterations, nutrient enrichment, and diffuse pollution according to the Segura River Basin Authority (CHS, 2022). These pressures are exacerbated during low-flow periods, when the ecological impacts of eutrophication and metal toxicity intensify, resulting in reduced taxonomic and functional richness (Millán et al., 2006, Arenas-Sánchez et al., 2021; CHS, 2022).

To address this issue, it is essential to implement monitoring programs that assess both the spatial variability and temporal evolution of ecological status, ensuring effective conservation and management. However, many monitoring efforts rely on single-site sampling, assuming it represents the overall condition of a water body. This approach may be inaccurate in heterogeneous systems or when localized impacts cause spatial variations in ecological status. This becomes particularly relevant given that Mediterranean rivers, especially those in semi-arid areas, exhibit amplified responses to hydrological stress compared to other European systems (Feio

et al., 2023). In this sense, the Quípar stream represents a case study that exemplifies broader global patterns of river degradation under multiple stressors.

This study aims to assess changes in the ecological status of the main water body of the Quípar stream using aquatic macroinvertebrates as bioindicators. To do so, we adopted a dual approach combining spatial and temporal perspectives. Specifically, our aims were: (1) to describe the structure and composition of macroinvertebrate communities along the stream longitudinal axis; (2) Assessing the spatial variability in ecological status along the stream longitudinal axis; and (3) Analysing temporal trends in ecological status using historical data from the Segura River Basin Authority (hereafter SRBA). We hypothesise that the ecological status of the Quípar stream will exhibit spatial variation along its longitudinal gradient and a general temporal decline, with the overall trajectory ultimately depending on the balance between anthropogenic pressures and recent management improvements.

MATERIAL AND METHODS

Study area

The Quípar stream basin, with an area of 826.4 km², is in the western part of the Region of Murcia (southeastern Iberian Peninsula). This area is characterised by a semi-arid climate, with a highly variable water regime, alternating long periods of drought with occasional heavy rainfall (Gil-Guirado & Pérez-Morales, 2019). The geology of the basin presents a large lithological diversity, highlighting the presence of limestone, sand and gypsum in the middle and lower areas, which contributes to increase water salinity and conductivity. Land use in the Quípar basin is dominated by agricultural areas (58.3%), mainly dryland farming due to the semi-arid climate. Natural areas cover 41%, mainly coniferous forests; urban land is minimal.

The Quípar stream, one of the main tributaries of the Segura River on its right bank, has been declared as a Special Area of Conservation (SAC; ES6200043), forming part of the European Natura 2000 Network of protected areas. This

designation is mainly due to the presence of 14 types of habitats of Community interest, two of which are priority habitats (Annex I of the Habitats Directive), as well as the presence of otter (Lutra lutra) and several species of bats included in Annex II (Directive 92/43/EEC, on the Conservation of Natural Habitats and of Wild Fauna and Flora).Within this area, the SRBA identified three water bodies. We focus here on the main water body (Quípar stream upstream of the reservoir; ES0701012002), which extends for over 55 km and belongs to the category R-T09: Low Mediterranean Mountain mineralized rivers, as it largely coincides with the SAC designated for biodiversity protection. The code in parentheses refer to the official water body identification numbers assigned by the SRBA. In this water body, seven sampling sites were distributed along the longitudinal gradient of the stream, with inter-site distances ranging from 3 to 10 km, including the official monitoring site managed by the SRBA (Fig. 1; Table 1).

Environmental and macroinvertebrate sampling

Environmental variables were measured in situ immediately before macroinvertebrate sampling to avoid potential bias. Water temperature, electrical conductivity, and salinity were recorded at each site using a multiparameter probe. Altitude was extracted from Google Earth based on the geographic coordinates of each sampling location.

Aquatic macroinvertebrate communities were sampled to characterise their structure and composition, providing key insights into the stream ecological dynamics, and to assess ecological status. A standardised protocol was followed to ensure accurate assessment, based on the "Protocol for Sampling and Laboratory Analysis of Benthic Invertebrate Fauna in Wadeable Rivers", approved by the Spanish Ministry for Ecological Transition and Demographic Challenge of Spain. Sampling sites were evenly distributed along the stream, each covering approximately 100 me-
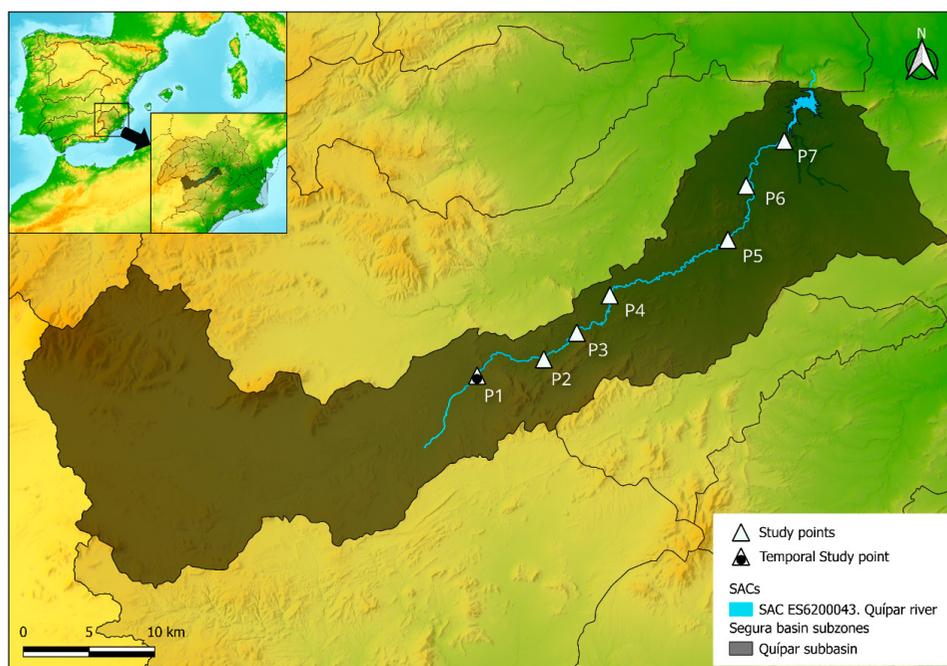

Figure 1. Study area with the location of the 7 sampling sites, in increasing order of water flow direction, framed in the Quípar stream basin. The limits of the water body studied are highlighted in blue. Site P1 is marked with a dot inside the symbol, as it was used for the temporal assessment of ecological status. *Área de estudio con la ubicación de los 7 puntos de muestreo, en orden creciente según la dirección del flujo del agua, enmarcadas en la cuenca del río Quípar. Los límites del cuerpo de agua estudiado se destacan en azul. El sitio P1 aparece señalado con un punto en el símbolo, ya que se utilizó para la evaluación temporal del estado ecológico.*

Table 1. List of study sites, with indication of geographical coordinates (UTM, 30S), salinity (Sal, in g/l), electrical conductivity (Cond, in mS/cm), temperature (Temp, in ºC) and altitude (Alt, in m a.s.l.). *Lista de puntos de estudio, con indicación de coordenadas geográficas (UTM, 30S), salinidad (Sal, en g/l), conductividad eléctrica (Cond, en mS/cm), temperatura (Temp, en ºC) y altitud (Alt, en m.s.n.m.).*

Site	Name	Coordinates UTM		Sal	Cond	Temp	Alt
		X	**Y**				
P1	"La Encarnación"	597356	4210016	0.8	1.6	15.2	722
P2	Between Encarnacion and Baera	602432	4211254	0.8	1.7	15.8	630
P3	"Baera de los Azudes"	604932	4213264	0.8	1.6	16.1	579
P4	"Vía verde; Begastri"	607450	4216092	1.2	2.6	16.9	527
P5	Upstream Gilico	616429	4220296	3.2	5.9	14.2	430
P6	Downstream Gilico	617828	4224384	3.2	6.0	14.7	372
P7	"Colas del embalse de Alfonso XIII"	620728	4227788	3.4	6.3	13.6	302

ters. Following the protocol, 20 sampling units ("kicks") were taken per site, proportionally distributed among mesohabitats according to their surface abundance and covering a total area of 2.5 m2. The sampling campaign took place between March and April 2023. Collected organisms were handled with entomological forceps, preserved in 96% ethanol, and later identified to the family level under a stereomicroscope in the laboratory.

Biological indices and ecological status classification.

The IBMWP index (Alba-Tercedor et al., 2002), a widely applied metric for assessing water quality and ecological status based on macroinvertebrate communities was used. It corresponds to a mandatory standardised procedure in the official ecological status monitoring networks managed by the river basin management authorities, in accordance with the Water Framework Directive (Directive 2000/60/EC). The IBMWP is calculated by summing the tolerance values of the sampled macroinvertebrate families. These values range from 1 to 10 per taxon, where higher values indicate more pollution-sensitive taxa.
To classify ecological status, the Ecological Quality Ratio (EQR) is obtained as the ratio between the IBMWP index value obtained and its reference value (see Table S1 in Supplementary information, available at https://www.limnetica.com/en/limnetica). These reference values are established by the Royal Decree 817/2015, which reg-

ulates the criteria for monitoring and evaluating the status of surface waters and environmental quality standards in Spain. The reference values represent the ideal conditions of a water body of the same category "R-T09: Low Mediterranean Mountain mineralized rivers", reflecting the highest achievable ecological status. Based on EQR thresholds, one of the following five ecological status classes are assigned: high, good, moderate, poor, or bad (Table S1). This allowed comparison of ecological status across sites.

Spatial variation

Spatial variability in ecological status was assessed using the macroinvertebrate data collected in 2023. For each site, IBMWP and EQR values were calculated, allowing comparison of ecological status across reaches. In addition, family richness and community composition were analysed to explore spatial patterns in biological assemblages. Additionally, a heatmap was generated to visualize the occurrence and distribution of each macroinvertebrate family across sampling sites (see Fig. S1 in supplementary material, Supplementary information, available at https://www.limnetica.com/en/limnetica).

Temporal variation

Temporal trends in ecological status were analysed using IBMWP data from site P1 (La En-

Table 2. Results of linear regression models. (A) Linear regression model of the spatial variation of macroinvertebrate richness along the longitudinal gradient of the Quípar stream. (B) Linear regression model of the spatial variation of IBMWP values along the longitudinal gradient of the Quípar stream. (C) Linear regression model of temporal variation in IBMWP values at sampling point P1 (La Encarnación). *Resultados de los modelos de regresión lineal. (A) Modelo de regresión lineal de la variación espacial de la riqueza de macroinvertebrados a lo largo del gradiente longitudinal del río Quípar. (B) Modelo de regresión lineal de la variación espacial de los valores de IBMWP a lo largo del gradiente longitudinal del río Quípar. (C) Modelo de regresión lineal de la variación temporal de los valores de IBMWP en el punto de muestreo P1 (La Encarnación).*

Predictor	Estimate	Std. Error	t value	*p* value
A. Richness vs. Position				
Intercept	21.29	2.94	7.24	<0.001
Position	-0.29	0.66	-0.43	0.682
B. IBMWP vs. Position				
Intercept	106.14	18.72	5.67	0.002
Position	-3.43	4.19	-0.82	0.450
C. IBMWP vs. Year				
Intercept	76.03	10.14	7.50	<0.001
Year	1.04	1.05	0.99	0.338

carnación), obtained from the SRBA monitoring programme for the period 2006–2022. The 2023 value obtained in this study was added to the series. To ensure comparability, only spring–summer values were considered. EQR values were calculated for each year using the same typology-specific reference value. This allowed consistent classification of ecological status over time and enabled the evaluation of potential long-term trends.

Statistical analyses

To determine whether there were significant trends in macroinvertebrate richness along the longitudinal axis of the Quípar stream, we applied a linear regression model using richness as the response variable and sampling position as the explanatory variable. No transformation was required, as residuals met the assumptions of normality and homoscedasticity. Likewise, community composition was analysed using non-metric multidimensional scaling (NMDS) based on Bray–Curtis dissimilarities computed from family-level data (Kruskal, 1964). To explore potential environmental influences, four variables (salinity, conductivity, temperature, and elevation) were fitted onto the ordination using the envfit function (package vegan; R Core Team, 2023).

Temporal variation in ecological quality was assessed by applying a linear regression model to IBMWP scores using sampling year (numerical index) as the predictor. Residuals of all models were visually inspected to verify normality and homoscedasticity. Additionally, IBMWP and EQR values were plotted along the stream gradient to visually explore temporal trends in ecological status. Statistical analyses were performed using R software, using vegan package (Oksanen et al., 2023) for ordination analysis and ggplot2 (Wickham, 2016) for graphical visualisation of the results.

RESULTS

Richness, structure and composition of macroinvertebrate assemblages

A total of 48 taxa, primarily at the family level, have been identified (Table S2, Supplementary information, available at https://www.limnetica.com/en/limnetica). Insecta is the most represented taxonomic group, with the Diptera (9 families), Coleoptera (9 families) and Hemiptera (8 families) orders standing out as the groups with the highest number of families occurring in the Quípar stream.

To assess community structure, the number of aquatic macroinvertebrate families identified at each study site was counted, ranging from 16 families at the poorest sites (P4 and P6) to 24 at the richest one (P7). No significant trend (R^2= 0.0082;

$p > 0.05$; Table 2A) was observed in family richness along the longitudinal axis of the stream (Fig. 2A). Regarding community composition, the results of the NMDS analysis do not show a clear ordering of the samples along the longitudinal axis (Fig. 2B). The environmental fitting did not identify any significant relationships between the NMDS configuration (Table S3, Supplementary information) and the environmental variables considered ($p > 0.05$). However, altitude and conductivity showed relatively higher explanatory power ($r^2 = 0.39$ and 0.38, respectively), suggesting potential, though non-significant, trends in their influence on macroinvertebrate community structure (Table S3, Supplementary information).

Spatial variation in ecological status

The ecological status of the stream showed a slight negative trend of deterioration of ecological status along its longitudinal axis (Fig. 3A), although it was not significant ($R^2 = 0.118$, $p > 0.05$; Table 2B). Most of the sites fall within the "moderate" category (P1, P4, P5, and P6), one of them on the borderline with the "poor" category (P4) and three of them were assigned to the "good" category (P2, P3, and P7). Sites P2 and P3

in the mountainous area downstream of the Encarnación and Baera de los Azudes villages registered the highest values of IBMWP index.

Temporal variation in ecological status

Site P1 ("La Encarnación") showed considerable variability in terms of IBMWP scores throughout the time series (Fig. 3B), with a very slightly and not significant positive trend ($R^2 = 0.065$; $p > 0.05$; Table 2C). EQR was "moderate" except in 2012, 2014, and 2021 when it reached the "good" category, and in 2022 when it declined to "poor".
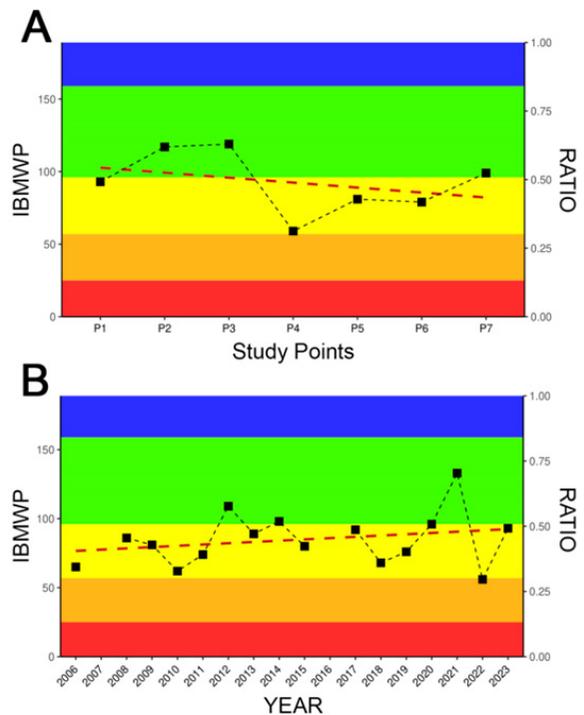
Figure 3. Spatial trend based on ecological status values along the longitudinal axis of the Quípar stream (A) and temporal trend of the ecological status of the Encarnación site; P1 (B). The IBMWP index values are shown on the left axis and the Ratio value on the right axis. The coloured bands indicate the ecological status classes: blue (high), green (good), yellow (moderate), orange (poor) and red (bad). The red dashed line represents the regression line of the linear model. *Tendencia espacial basada en los valores de estado ecológico a lo largo del eje longitudinal del río Quípar (A) y tendencia temporal del estado ecológico de la sección de la Encarnación; P1 (B). Los valores del índice IBMWP se muestran en el eje izquierdo y el valor de la Ratio en el eje derecho. Los colores de las bandas representan la clase de estado ecológico: azul (muy bueno), verde (bueno), amarillo (moderado), naranja (deficiente) y rojo (malo). La línea discontinua roja representa la línea de regresión del modelo lineal.*
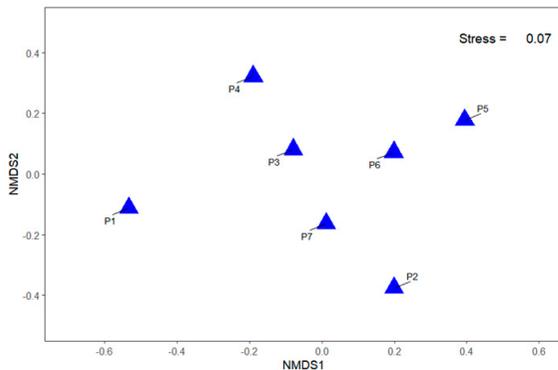

Figure 2. Family richness by study sites. The red dashed line represents the regression line of the linear model (A). Non-metric multidimensional scaling of aquatic macroinvertebrate families for the different study sites. Sites are coloured according to ecological status classes: green indicates good status and yellow indicates moderate status, (B). *Riqueza de familias por puntos de estudio. La línea discontinua roja representa la línea de regresión del modelo lineal (A). Escalamiento multidimensional no métrico de las familias de macroinvertebrados acuáticos para los diferentes sitios de estudio. Los puntos son coloreados en función de su clase de estado ecológico: el color verde indica una buena clase de estado y el amarillo una clase de estado moderado (B).*

DISCUSSION

The results indicate that the ecological status of the Quípar stream exhibits no consistent spatial or temporal patterns. Neither a clear gradient of degradation along the longitudinal axis nor a directional trend over time was observed. However, ecological quality rarely reached the "good" category. One of the main findings of this study is that the assessment of the ecological status based on a single sampling point does not accurately reflect the overall condition of streams, mainly in (spatially and temporally) heterogeneous systems like Mediterranean streams, where traditional assessment tools face significant limitations (Dallas, 2012). Although the Water Framework Directive emphasises the need to account for internal variability, monitoring practices often remain spatially limited (Santos et al., 2021). Recent studies in Mediterranean rivers have further shown that taxonomic composition and habitat structure can differ substantially among sites within the same basin, reinforcing the need for multi-site monitoring to ensure representative ecological diagnoses (Abily et al., 2022, Alcaraz-Hernández et al., 2024).

In addition, the surveys revealed comparatively high taxonomic richness, in line with the well-known biodiversity of Mediterranean rivers (Bonada et al., 2006, Munné & Prat, 2011). However, the NMDS analysis did not show consistent associations between community composition and the measured environmental variables. This outcome is consistent with previous studies indicating that, in Mediterranean streams, hydrological variability - such as droughts, intermittence, and sudden floods – and water salinity, can obscure clear ecological patterns (Bonada et al., 2006, Durance & Ormerod, 2007, Cid et al., 2017, Skoulikidis et al., 2017). In a stream characterised by high salinity, more robust analyses would be required to disentangle the relative importance of different stressors (Leigh & Datry, 2017).

Spatial variability along the Quípar stream did not reveal a clear longitudinal gradient, but rather a mosaic of local conditions. Low values at the uppermost site (P1) may be explained by the fact that upstream of this site the riverbed remains dry for much of the year, which limits recolonisation and generating disconnection typical of Mediterranean rivers (Skoulikidis et al., 2017). In contrast, the deterioration observed at midstream sites, particularly around P4 in the town of Cehegín, may be related to agricultural and urban influences, consistent with previous evidence of land-use effects on Mediterranean aquatic communities (Bruno et al., 2014, Tóth et al., 2019). The spatial distribution (see Figure S1; Supplementary material) of taxa suggests a marked loss of sensitive families downstream, where tolerant groups become dominant. Families scoring the highest in the IBMWP index (Heptageniidae, Athericidae or Aeshnidae) are confined to the upper reaches, indicating that good-quality sites still sustain taxa strongly associated with oxygenated and heterogeneous habitats. Unexpectedly, the downstream site (P7) showed higher richness despite elevated natural salinity derived from gypsum and marl substrates. Such moderate increases in salinity can enhance environmental heterogeneity, favouring the coexistence of halophile and freshwater taxa (Gutiérrez-Cánovas et al., 2019), and may even obscure the detection of anthropogenic impacts (Picazo et al., 2012). Overall, the Quípar illustrates how local hydrogeological and human factors interact to produce non-linear spatial patterns, reinforcing the need for multi-site monitoring to adequately represent ecological status in Mediterranean rivers (Cid et al., 2017).

Similar patterns of spatial heterogeneity in ecological quality have been reported in other Mediterranean and European river systems, where global change drivers such as hydrological alteration, pollution, flow regulation and biodiversity loss interact across scales (Oberdorff et al., 2022, Skoulikidis et al., 2017, Aguilera et al., 2015). These pressures tend to be especially pronounced in Mediterranean basins, which are characterized by strong climatic seasonality, recurrent water scarcity and intense anthropogenic occupation (Pascual et al., 2015). Moreover, differences in habitat quality between fluvial sections can lead to variations in biological indices used to assess ecological status (Feld et al., 2011, Hering et al., 2006).

Although no clear trend of deterioration or improvement was detected in IBMWP values over

time, this does not imply that the ecological status of the Quípar stream has remained stable. Instead, the pronounced variability suggests a strong influence of hydrological fluctuations, which are well known to drive interannual changes in Mediterranean streams (Belmar et al., 2019, Cid et al., 2017, Skoulikidis et al., 2017). Long-term analyses across Mediterranean river networks have shown that shifts in flow permanence and hydrological isolation strongly determine community turnover and diversity patterns (Cañedo-Argüelles et al., 2020). Seasonal shifts in flow regimes, prolonged droughts, and sudden flood events can temporarily reduce macroinvertebrate diversity and IBMWP scores until communities recover, thereby masking long-term trajectories (Bonada et al., 2006, Durance & Ormerod, 2007). This mechanism is consistent with the Quípar record: between 2018 and 2021 an apparent improvement was observed, but in 2022 a sharp decline occurred, coinciding with exceptional climatic variability marked by drought periods followed by intense rainfall. According to data from the Spanish State Meteorological Agency (AEMET), 2022 was one of the driest years of the last decade in southeastern Spain, with a spring rainfall deficit of over 20% compared to the long-term average, followed by intense autumn storms exceeding 60 mm in a single day.

Such hydrological instability complicates the interpretation of bioassessment indices, as short-term oscillations may obscure underlying processes of degradation or recovery (Soria et al., 2020). Furthermore, recent Europe-wide analyses show that even when improvements occur, they often plateau, as restoration gains are increasingly counterbalanced by persistent or emerging pressures such as climate change, water abstraction and contaminants (Haase et al., 2023, Cano-Barbacil et al., 2025). Consequently, the apparent "stability" of the Quípar record should not be read as a sign of ecological equilibrium, but rather as the result of compensating forces that may conceal future deterioration.

This study highlights the importance of continuous and spatially representative monitoring of the ecological status of aquatic ecosystems. Our findings show that both spatial and temporal variability can mask underlying ecological patterns, underscoring the risk of drawing misleading conclusions from single-site or short-term assessments. Integrating long-term, multi-site monitoring with complementary approaches—such as physicochemical analyses and functional community metrics—will improve the reliability of ecological diagnoses in heterogeneous systems. Such efforts are essential to advance the implementation of the Water Framework Directive and to guide effective conservation strategies under the challenges posed by climate variability and emerging pressures.

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AUTHOR CONTRIBUTIONS

C.S.: Conceptualization, Data curation, Investigation, Methodology, Supervision, Validation; Visualization, Writing - original draft; Writing - review & editing; F.P.: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Supervision, Validation, Visualization, Writing - review & editing; A.M.: Investigation, Validation, Writing - review & editing; A.J.G.M.: Investigation, Validation, Visualization, Writing - review & editing; J.V.: Funding acquisition, Validation, Writing - review & editing; D.S.F.: Conceptualization, Funding acquisition, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing - review & editing.

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