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River functionality influences the distribution of the dipper *Cinclus cinclus* (Linnaeus, 1758)

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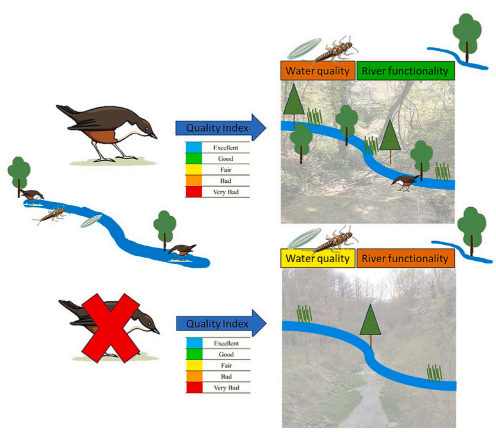
HIGHLIGHTS

- Ecological niche assessed to investigate locally endangered species.
- Dipper occurrence not related with water quality.
- Diatoms and macroinvertebrates biotic indexes not explain dipper frequency.
- Dipper occurrence significantly reflects River Functionality Index values.
- Habitat selection findings are important outputs for species conservation.

GRAPHICAL ABSTRACT



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ABSTRACT

The dipper (*Cinclus cinclus*) is a species strongly linked to the riparian ecosystem, known to feed on aquatic macroinvertebrates, which are sensitive to water pollution. For this, dippers have been proposed as useful bioindicators of water quality. While the distribution and ecology of the dipper are well known in Northern European rivers, few studies focus on this in Central Italy, lacking data for dipper conservation. Here, we aimed to (i) assess the dipper occurrence related to water quality using biotic indices based on diatom and macroinvertebrate communities, and (ii) evaluate the river ecosystem's overall state, through the River Functionality Index and land-use analysis in buffer areas. Overall, water quality alone does not explain the dipper occurrence, as the species was not found in many potentially suitable sites with good or high-water quality. Moreover, the diversity of the diatom and macroinvertebrate communities was not a sufficient constraint either. Conversely, the dipper occurrence significantly correlated with the River Functionality Index, which integrates several riparian ecosystem factors, indicating that well-preserved ecosystems with high functionality levels are important for dipper occurrence. Land use analyses in the areas surrounding the presence sites have shown, although not significantly, a fair level of naturalness, potentially favouring the riparian zone maintenance. As the dipper was

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considered in decline and threatened in Central Italy, further research on its auto-ecology and conservation threats is urgently needed. Finally, given the link between the species and the riparian ecosystem, a charismatic species such as the dipper could be used as an umbrella species in protection and conservation projects for the benefit of the entire riparian belt, which represents a buffer area of fundamental importance between terrestrial and aquatic ecosystems, although often resulted severely reduced and fragmented.

1. Introduction

In the Anthropocene Era, human activities have significantly intensified pressures on the ecosystems, particularly in riparian areas, acknowledged as vulnerable habitats (Cesarini and Scalici, 2022; Khan et al., 2022). The expansion of both agriculture and urban areas caused significant impacts on riparian areas, leading to declines in biodiversity and ecosystem services provided (Maúre et al., 2018; Raitif et al., 2019). Indeed, these areas are considered an ecotone between terrestrial and aquatic ecosystems that provide both regulation ecosystem services, such as filtering out diffuse pollution sources, thermal regulation, and hydrological stabilization, and support ones, like nesting sites, shelter, and food resources (Siligardi et al., 2007). Thanks to the latter ecosystem services, several organisms found a suitable habitat in riparian areas, such as birds, insects, and fishes, suggesting that riparian areas fit with the habitat selection of these species (Pusey and Arthington, 2003). Understanding the factors that influence species preference habitat is essential for conservation efforts, as it provides insights into the ecological requirements of species (Guisan et al., 2013). Consequently, literature has focused on studying environmental drivers to gain a better understanding of species occurrence by evaluating habitat offer (spatial) and selection (preference), as well as ecological niche, including factors such as food availability, water quality, features of the riparian corridor, and land uses. However, habitat selection for freshwater species has been overlooked, despite the significance of these habitats in the functioning and provision of ecosystem services in riverine systems (Parmesan et al., 2022). Traditionally, environmental constraints have been studied in relation to biotic indices considering the communities of aquatic organisms (Ruaro and Gubiani, 2013). In Europe, for example, diatoms, macroinvertebrates, fish, and macrophytes are considered to evaluate the ecological status of freshwaters according to the Water Framework Directive (Marcheggiani et al., 2019). Diatoms are excellent bio-indicators as they are present all year round and easy to sample, sensitive to changes in the environment's chemical and physical parameters, well known systemically and ecologically, and resilient to disturbance (Dell'Uomo, 2004). Macroinvertebrates have historically been the organisms most frequently used in biomonitoring and river quality assessment, and several indices based on the study of the macrobenthic community have been used (Armitage et al., 1983; Buffagni et al., 2004; Vaughan and Ormerod, 2012; Gallitelli et al., 2020; Cesarini et al., 2023). Moreover, the structure of the fluvial landscape and habitat are considered to obtain ecological indices about the status of the riverine ecosystems, and in this case, the Fluvial Functionality Index (FFI, hereafter) was proposed to consider river habitat quality and functionality (Siligardi et al., 2007). Nonetheless, while these bio-indicators directly mirror processes within the stream channel, the assessment of riparian and catchment-scale influences remains primarily indirect. Hence, riparian organisms like birds are regarded as valuable additions to river ecosystem assessments, as they are directly affected by terrestrial processes (Larsen et al., 2010). Therefore, water quality and riparian conditions can significantly influence the presence of birds, as the presence and integrity of riparian vegetation serve as an essential source of food and shelter (Miserendino et al., 2011).

In this sense, the dipper *Cinclus cinclus* (Linnaeus, 1758) is the only species among the passerines to dive into water and exploit aquatic macroinvertebrates as a trophic resource. *C. cinclus* populates generally high-altitude, shallow watercourses with high current velocities, on which it establishes and defends linear territories during the breeding season (Boano, 1999; Ormerod and Tyler, 1986, 1991). Despite the dipper's extensive global distribution across Europe, Asia, America, and Africa, its presence in central Italy is relatively limited. More in detail, the population of *C. cinclus* is globally estimated at around 700,000-1,700,000 mature individuals and in the IUCN Red List the threat category assigned to the species is LC (Least Concern). The subspecies *aquaticus* is more common and abundant in the Alpine arc and central-northern Apennines, being present with less consistent populations in some areas of the Po Valley, in Tuscany and Lazio, while it is rarer and more localised in the southern Apennines. While in Sicily the species has undergone a sharp decline, reaching extinction status (Hourlay et al., 2008), in Latium region the estimated population size was 140 pairs, with a density of around 0.3–1 pairs/km (Boano, 1999). However, many historical nesting sites have been abandoned, especially at medium-low altitudes, due to the deterioration of water quality (Sorace et al., 2002). New estimates considered 11–100 pairs of dippers for the entire region, leading to the species being classified as 'Endangered' on the Latium Red List (Calvario et al., 2011), and thus subject to a very high risk of extinction in the wild.

Among the main constraints driving species' distribution and habitat selection, altitude, water permanence, and pH mainly play an important role in the abundance of food resources for the dipper (Tyler and Ormerod, 1994; Sorace et al., 2002; Pedersen et al., 2020). Furthermore, the artificialization of riverbanks may result in the dipper abandoning the watercourse (Sarà et al., 1994), indicating a loss of riparian habitats. Moreover, droughts and extreme events caused by ongoing climate change appear to be another threat (Sergio et al., 2018). Dipper's habitat selection is complex as characterized by many variables (Tyler and Ormerod, 1994), such as rivers with certain slopes, prey's presence, and occurring of riparian habitats (Tyler and Ormerod, 1994; Ormerod et al., 1985; Sorace et al., 2002). The ecological niche is of great importance for species conservation and management efforts, as the prevention of these habitats should also prevent this species (of high conservation concern).

Although dipper is a charismatic species (being an attraction for nature photographers) and can act as an umbrella species, its population status in Latium is in strong decline. Therefore, our main objective is to characterise the habitat selection of the dipper by summarising all the factors for the occurrence of the species, considering water quality, ecosystem functioning, and human impact. Specifically, we (i) assessed water quality through biotic indices using macroinvertebrates and diatoms, and (ii) evaluated the overall state of the river ecosystem in the sampled stretch, through the application of the FFI and the analysis of land-use classes in buffer areas.

This study aims to fill the knowledge gap on the dipper's presence in Italian watercourses. Although the dipper is well-studied species in northern-central Europe, where large populations exist, research on this species in Italy, particularly in Lazio, is limited and dated. Our focus on *C. cinclus aquaticus* at the edge of its range provides unique insights, despite a smaller sample size compared to studies targeting the core range of the subspecies. Therefore updating and accumulating new knowledge on the dipper and its relationship with Italian riparian habitats is crucial. We hypothesize that a deterioration in water quality and ecosystem functionality will negatively impact dipper populations and dipper will exhibit strong fidelity to specific habitat characteristics (i.e., habitats with minimal human disturbance and higher ecological integrity).

A bird with high fidelity to rivers can serve as a bioindicator of watercourse functionality, reflecting the health and integrity of aquatic ecosystems. Our findings could be applied to similar environments or other regions, providing valuable data for conservation strategies globally and underscoring the significance of preserving the dipper and the ecosystems it inhabits. To address this need, and also in view of the inclusion of the dipper on the Latium Red List in 2011, 19 stations along various watercourses in central Italy, historically reported as sites of presence of the species, were revisited.

2. Methods

2.1. Study area and ornithological sampling

The ornithological sampling of the dipper, along with the sampling of diatoms and macroinvertebrates, was conducted at 19 stations across 16 diversely classified watercourses (rivers, streams, brooks, ditches) (Fig. 1; Table S1). All the stations are located in Central Italy in the Lazio region and are mainly distributed along the Apennine and pre-Apennine belts, at an altitude between 97 and 1061 m a.s.l. The stretches of watercourses investigated include part of those selected for one of the most recent and detailed studies available in the literature on the distribution of the dipper in the Lazio region (Boano, 1999). Two other sampling stations were placed along watercourses historically occupied by the species: Tronto (TR), where the species was reported present in 1998–1999 (Sorace et al., 2002) and Montenero (MN), where the species was reported in 2015 (Boano, 2016). The selected stations were situated exclusively along mountain rivers, as dippers exhibit a preference for watercourses characterized by a calcareous substrate with a basic pH.

The eventual presence of the dipper at the selected stations was detected through ornithological samplings carried out during the breeding season of the species, between February and June 2021 when the probability of contacting the species is constant (Tyler and Ormerod, 1994; D'Amico and Hemery, 2003). Moreover, the presence has been collected either through direct observation of one or more individuals, young or adult, or, more rarely, through recognition by song. Indeed, the song of the dipper is fairly easy to recognize and cannot be confused with other species present in the same habitat type; moreover, both males and females sing (Tyler and Ormerod, 1994; Magoolagan et al., 2019). The dipper's territory, like that of numerous river birds (Tyler and Ormerod, 1994), is linear, aligning with the watercourse's path. Particularly during the breeding season, individuals are rarely observed far from the riverbanks, as nests are typically constructed directly above the flowing water or within close proximity, typically within one meter (Shaw, 1978). The most suitable sampling method is therefore the transect method. Samplings were carried out at each station along a transect following the stream bed, upstream of the macroinvertebrate and diatom sampling site. The length of the surveyed stretch, proportionate to the watercourse under examination, was at least 1 km at each station, covered by walking slowly, avoiding rainy or windy days and the central hours of the day, when the species is less active (O'Halloran et al., 1990), and alternating the walk with short stakes dedicated to observation with binoculars (Nikon Monarch 5, 10 × 42). Up to 3 visits were made to each station, enough to contact the species where present (D'Amico and Hemery, 2003). In some cases, the presence was detected on the first visit, and no further surveys were conducted. Where necessary, the transect was travel a second and if necessary, a third time, at intervals of

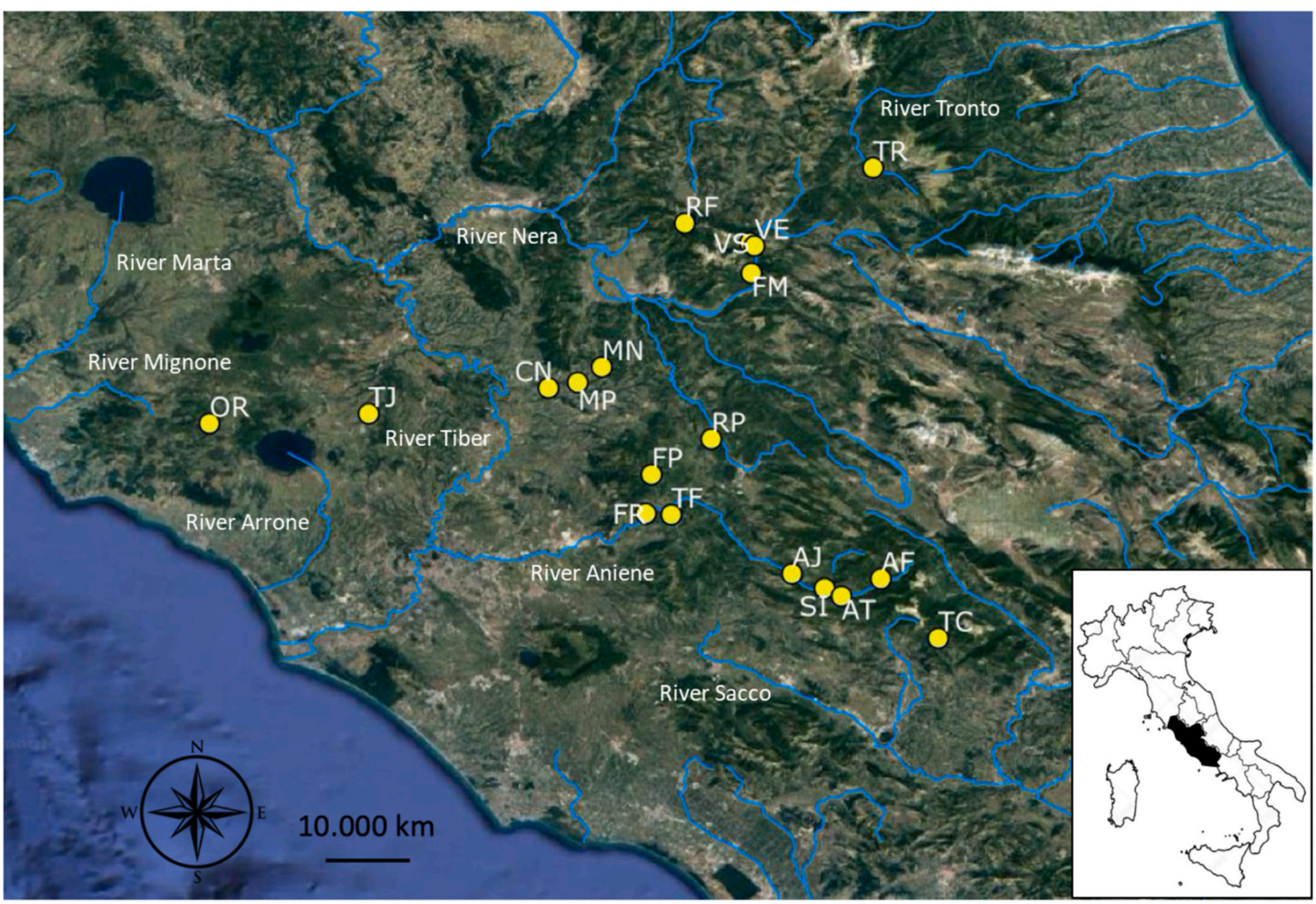

Fig. 1. Map of the study area in the Latium region, Italy. The map shows the main rivers, with yellow points indicating the rivers surveyed for water quality, fluvial functionality, and dipper occurrence assessment.

about two weeks. In stations where the species was not detected on the third visit, it was considered absent.

2.2. Sampling and processing diatom and macroinvertebrate communities for biotic and diversity indices

All the methods were carried out following the national protocol for sampling and analysis of benthic diatoms in watercourses to assess the ecological status (ISPRA, 2014), in line with the requirements of the Water Framework Directive (Directive 2000/60/EC). Briefly, diatoms were sampled from five pebbles with a total area of at least 100 cm^2 by a hard-bristled brush. The samples were conserved under 90 % ethanol for storage and transport to the laboratory. In the laboratory, the frustules were cleaned with hydrogen peroxide, and the permanent slide was prepared for taxonomic identification. Diatoms were morphologically identified at the species level by consulting taxonomic guides (ISPRA, 2014; Taylor et al., 2007) and counted under the light microscope (Leica DM750). For each slide, 400 valves were counted as indicated by the national protocol for calculating the ICMi. ICMi is a multimetric index composed of the Pollutant Sensitivity Index IPS (CEMAGREF, 1982) and the Trophic Index TI (Rott et al., 1999). The IPS index is mainly indicative of the level of organic pollution, considering the sensitivity of different species to this type of pollution; the TI index, on the other hand, takes into account the sensitivity of species to trophic pollution. For each species, the specific sensibility and indicator values for IPS and TI calculation were obtained. More information on this index (e.g. reference values, each species' pollution sensitivity, and river macrotype) can be found in Mancini and Sollazzo (2009). The ICMi value obtained is converted into a quality rating through a conversion table that lists the five class limit values of water quality.

Macroinvertebrate sample collection and analysis activities for the calculation of the Extended Biotic Index (EBI) were carried out based following Ghetti (1997). The samples were collected by using the Surber net, following the kick-sampling technique. The net was positioned in the central area of the riverbed with the mouth pointing in the opposite direction to the current. Samplings were standardized by using the same instrument for each station and performing a timed sampling (60 s). By standardising the semi-quantitative EBI index with time (60 s), we obtained quantitative data. Then, samples were stored in 70 % ethanol and analysed in the laboratory. Here, the samples have been analysed with sorting of macroinvertebrates from the organic debris using a stereomicroscope (Nikon SMZ445) and then identified to the possible lowest level using the dichotomous keys (Tachet et al., 2010). The double-entry table was used to calculate the EBI index. This index ranges between 1 and 14, which are then translated into the corresponding "Quality Classes" (QC), associated with a judgement on water quality.

Furthermore, to better characterise and analyse the sampled diatom and macroinvertebrate communities, diversity indices were calculated: Shannon (Shannon, 1948), Simpson (Simpson, 1949), and Evenness (Pielou, 1969). Moreover, the richness of EPT (Ephemeroptera, Plecoptera, and Trichoptera) and the EPT/E (the EPT standardized on the number of families of Ephemeroptera) were considered (Bonada et al., 2006).

2.3. Fluvial Functioning Index and land use

To have a complete assessment of the whole habitat status and functionality of rivers FFI was applied. This index considers the integration of key biotic and abiotic factors associated with both the aquatic ecosystem and its corresponding terrestrial environment (Siligardi et al., 2007). The final assessment is made in terms of deviation from an ideal reference condition, i.e. a condition of maximum functionality. The index value is calculated from the score of the answers to the 14 questions, divided into four groups on (i) vegetational conditions of the banks, (ii) morphological and physical structure of the banks, (iii) structure of the riverbed, and (iv) biological characteristics of the community. Each answer is associated with a score, or 'numerical weight', in a range from 1 to 40. The sum of the scores obtained from answering all questions provides the FFI value, calculated separately for the two banks, which can be between a minimum value of 14 and a maximum value of 300. The total score is then converted into 5 levels of functionality ranging from level I, which represents the state of highest functionality, to level V, which indicates the state of worst functionality. Each level is associated with a color, which is used in mapping to produce a graphical representation of the functionality rating. All the detailed further methods were followed by Siligardi et al. (2007).

For land use, the CORINE Land Cover (CLC) project allows the dynamic processes of land use changes over the years to be monitored (https://land.copernicus.eu). For this research, a land use analysis was carried out using QGIS 3.14.11 software, processing land cover data from the Corine Land Cover digital cartography at the 3rd level of definition, scale 1:100,000, from 2012. The decision to use the 2012 cartography was due to the presence of numerous geometric errors in the cartography updated to 2018 that occurred during the geoprocessing phase (clipping function). The land-use types were analysed, within a 1 km radius buffer around the 19 sampling stations.

2.4. Statistical analyses

Regarding diatom and macroinvertebrate communities, diversity indices (Shannon, Simpson, Evenness) were calculated using the Past 4.07b software.

To find the environmental drivers that mainly influenced the presence of dipper, a correlation analysis was performed between occurrence data and altitudes, values of the biotic indices (ICMi, EBI), FFI, EPT and EPT/E. Before conducting the analysis, the normality of the dataset was tested by Shapiro Wilks. For the FFI, the analysis was deepened by comparing the values of dipper occurrence and absence sites within the 4 thematic groups of questions into which the questionnaire is divided. Statistical analyses were conducted using GraphPad Prism version 8.0.1 (GraphPad Software, La Jolla, California, USA) and the significance level was set at 0.05.

The analysis of co-occurrence was conducted between the dipper and all macroinvertebrate taxa. In addition, to consider the taxa most sensible to pollution, a co-occurrence between the dipper occurrence and EPT families was tested. The co-occurrence analyses were performed by using the EcoSim Software (Gotelli and Entsminger, 1999).

The analysis of land use in the buffer areas around the sampling stations was carried out using QGIS Software 3.14.11. Specifically, the data acquired through QGIS were utilized to calculate the total area associated with each land use class within every buffer area, along with their corresponding percentages.

3. Results

3.1. Biotic drivers

The presence of the dipper was detected at 10 out of 19 stations (Fig. 2). In 8 cases adult individuals were observed and in 5 cases also the juveniles (Table S2). From statistical analysis, the detected presence of the dipper was not significantly correlated with altitude ($U = 0.939$; $df = 1$; $p = 0.348$), even though the dipper was observed in 80 % of cases above 340 m a.s.l..

Concerning the diversity indices based on diatoms and macroinvertebrates, the communities of 19 sampling stations were analysed (for diatoms 18 as sample from the Filettino station miss). The calculated diversity index values are shown in Fig. 3. As regards diatoms, overall, 91 species were identified and the most occurring species were *Gomphonema pumilum* (23.51 % of the total), *Gomphonema olivaceum* (9.42 % of the total), and *Cocconeis placentula* (8.56 % of the total). Regarding macroinvertebrates, a total of 5127 organisms belonging to 52 different taxa were identified. The most frequent taxa belonged to *Baetis* (30.9 %),

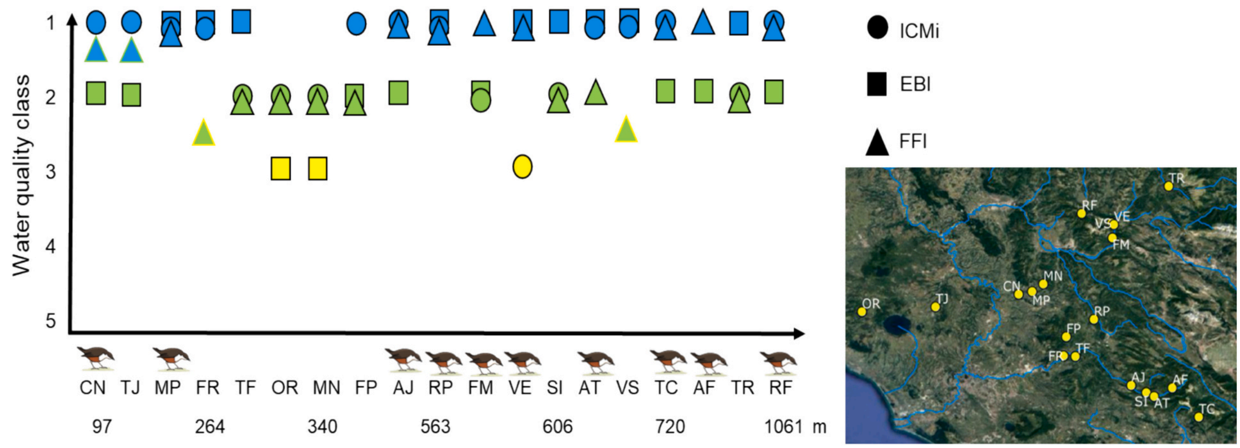

Fig. 2. Presence of dipper in relation to the water quality class considering ICMi, EBI, FFI for each sampling station. Stations are ordered in increasing altitude. The color of ICMi, EBI, FFI values corresponded to different quality classes (blue = excellent; green = good; yellow = sufficient; orange = bad; red = very bad). Triangles with green or yellow edges indicate FFI quality classes that span two different categories. The map of the study area is reported.

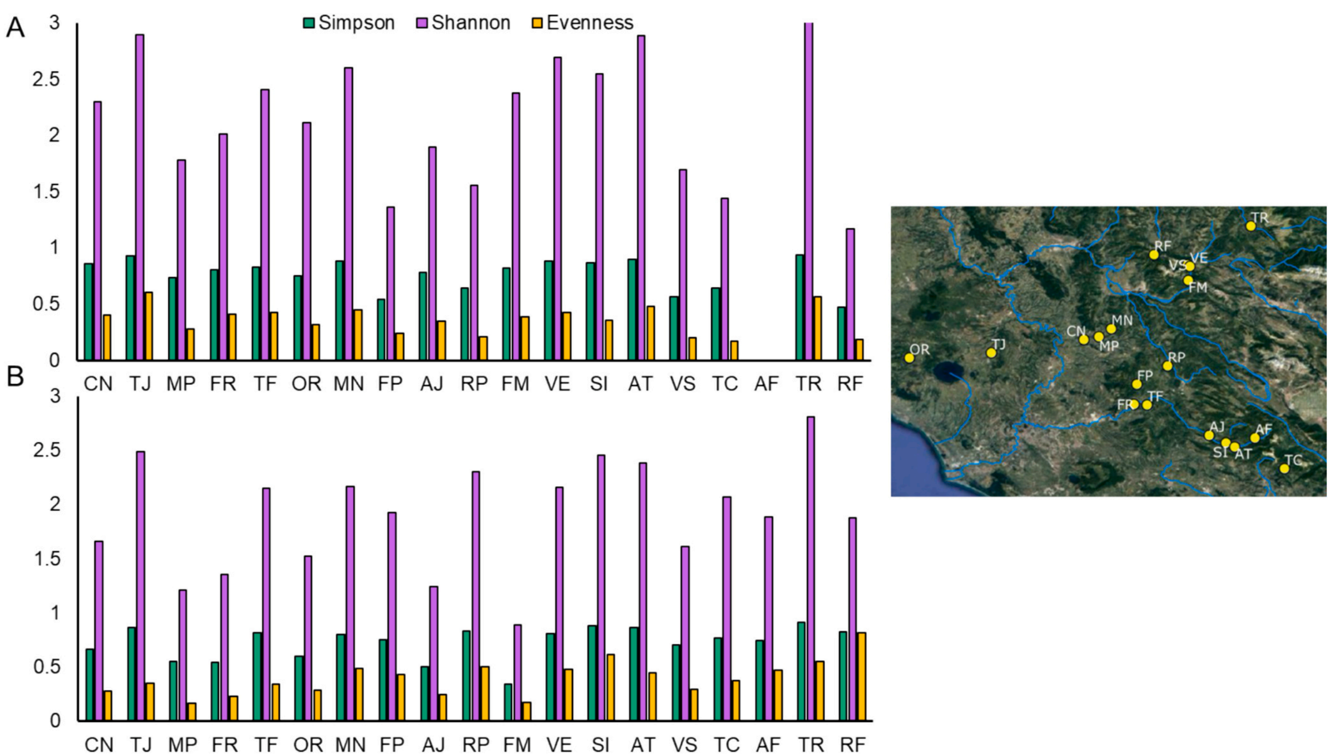

Fig. 3. Diversity indices applied to diatoms (A) and macroinvertebrates (B) in the sampling stations. The map of the study area is reported.

present in all stations, Chironomidae (18 out of 19 stations, 10.9 % on total stations), and Elminthidae (15 out of 19 stations, 3.9 % on total stations).

Results of biotic indices are shown in Fig. 2 and the relative scores are reported in Table S3. On the ICMi based on diatoms, a good water quality (high/good) was found at all stations, except at station VE (sufficient). Regarding macroinvertebrates, EBI index showed quality class I (high) in 9 stations, class II (good) in 8 stations and class III (sufficient) in 3 stations. From the Spearman correlation analysis any significant correlations were found between the presence of dipper and ICMi, EBI, EPT and EPT/E values (Table 1).

More in detail, co-occurrence analysis did not show any relationship between the presence of the dipper and the macroinvertebrate community nor between the presence of the dipper and the EPT families

Table 1
Spearman correlation analysis between presence/absence of dipper and environmental drivers (Spearman correlation coefficient r and *p* values). The significant values are reported in bold.

	P/A vs. Quote	P/A vs. ICMi	P/A vs. IBE	P/A vs. FFI	P/A vs. EPT	P/A vs. EPT/E
r	0.23	0.19	−0.10	**0.83**	−0.02	0.01
p value	0.34	0.44	0.68	**<0.0001**	0.94	0.97

found in the samples. In particular, as the observed index is greater than expected and $p > 0.05$, then the presence of the dipper and the macroinvertebrate community are not significantly aggregated and are therefore homogeneously distributed.

3.2. Dipper presence in relation to riparian ecological niche

FFI values obtained for the different stations, with their functionality levels, functionality judgements and associated colours are shown in Fig. 2 and Table 2. The Spearman correlation analysis highlighted a significant correlation between the presence of dipper and FFI ($r = 0.83$; $p < 0.0001$; Table 1). In particular, the score (average between left and right bank) assigned to the answers for the four FFI question blocks is significantly different between the presence and absence sites for Group 1 (U = 2.048; df = 1; $p = 0.041$), for Group 2 (U = 2.703; df = 1; $p = 0.007$) and for Group 4 (U = 2.506; df = 1; $p = 0.012$); the score assigned to Group 3 responses was not significantly different between the sites of presence and absence (U = 1.239; df = 1; $p = 0.215$).

Regarding land use, overall, "wooded and semi-natural areas" (Level I, class 3) amounts on average 73.31 % within the buffer areas surrounding the dipper stations and 59.42 % within the buffer areas of the other stations. However, this disparity lacks statistical significance (U = 1.104; df = 1; $p = 0.270$). At a more detailed level, the predominant class within the buffer areas surrounding the sampling stations was class 3.1.1, labelled " broad-leaved forest," which accounted for 62.38 % on average in stations with dippers present and 50.64 % on average in the others (Fig. 4).

4. Discussions

Our results showed that the occurrence of the dipper is explained neither by water quality, calculated through different biotic indices, nor by the composition and diversity of the macrobenthic community, which is the main food resource of the species. Even though these elements may have a certain relevance and are the most widely used in bioindication (see Marcheggiani et al., 2019; Gallitelli et al., 2020), they do not seem to be the main factors characterising the ideal ecological niche of the dipper. Indeed, the habitat selection of the species was closely related to high FFI values and thus to the functionality of the entire ecosystem, reflecting to some extent its integrity. The calculation of the FFI integrates the assessment of several aspects of the riparian ecosystem, among which the presence and continuity of the riparian vegetation belt, the state of the surrounding area, the morphological and physical structure of the banks and the biological characteristics of the community were most significant. This shows how a healthy riparian ecosystem, predominantly surrounded by natural areas and woodland, as seen from land use, offers ideal conditions for the presence of the dipper.

The values FFI are crucial for bird populations because they provide insight into the ecological health and functionality of riparian habitats. High FFI values indicate well-functioning riparian zones that support typically a greater diversity and abundance of bird species by offering essential resources such as food, shelter, and nesting sites. Therefore, understanding and maintaining high FFI values is essential for the conservation of bird populations, including the dipper.

4.1. The dipper occurrence in relation to environmental drivers and water quality

Although the relationship between the species and altitude was not significant in our analyses, it is nevertheless interesting to note that the main part of dipper observations occurred at stations above 350 m a.s.l.. This evidence was widely confirmed in the literature, notably in Great Britain and Ireland by Shaw (1978), and in Wales by Ormerod et al. (1985), where 87 % and 90 % of nests were observed below 300 m, respectively. In Italy, a positive relationship between the number of dipper pairs and altitude was observed by Sorace et al. (2002) with 83.3 % of the sites abandoned by the species being at an altitude below 300 m a.s.l.. This phenomenon could be attributed to the degradation of water quality in lowland and hillside watercourses, resulting in a reduction of the species' distribution at higher altitudes. Dippers exhibit a preference for mountain riverine zones due to the high productivity in terms of feeding sources, reduced impacts on water quality and the presence of greater altitudinal gradients, characterized by rapid flow and riffles (Ormerod et al., 1985; Tyler and Ormerod, 1994).

The water quality assessed through the biotic indices IBE and ICMi was good or high in almost all the stations analysed. The findings reveal that the species did not display a higher occurrence at the lower impacted sites as indicated by high values of biotic indexes. These results align with those observed in previous studies by Andreotti et al. (1998) and Del Guasta (2003), who documented the species across IBE Quality Classes I, II, and II/III. Conversely, other researchers in Italy, such as Sorace et al. (1999) and Larsen et al. (2010), exclusively or predominantly found dippers in stations characterized by Quality Class I, as determined through EBI assessment. They identified a notable association between the presence of dippers and water quality, leading to the

Table 2
FFI values (mean between right and left bank) reported for the stations according to absence (A) and presence (P) of the dipper. FFI scores divided for 4 groups of questions and compared between sites of presence and absence of the dipper. Group 1: vegetation status banks and surrounding territory; Group 2: morphological and physical structure of the banks; Group 3: riverbed structure; Group 4: biological characteristics of the community. * = significant difference between absence and presence of the dipper.

Stations		FFI values		Group 1*		Group 2*		Group 3		Group 4*	
A	P	A	P	A	P	A	P	A	P	A	P
TJ	CN	255	255	85	65	35	45	110	100	25	45
FR	MP	190	290	60	90	20	45	75	110	35	45
TF	AJ	221	277.5	70	92.5	26	45	90	100	35	40
OR	RP	237.5	270	82.5	90	15	45	110	100	30	35
MN	FM	212.5	280	87.5	90	35	45	60	95	30	50
FP	VE	230	282.5	80	87.5	35	45	70	105	45	45
SI	AT	245	245	85	75	25	45	90	90	45	35
VS	TC	186	270	70	100	35	25	50	100	31	50
TR	AF	230	262.5	45	67.5	35	45	110	105	40	45
	RF		262.5		92.5		25		95		50

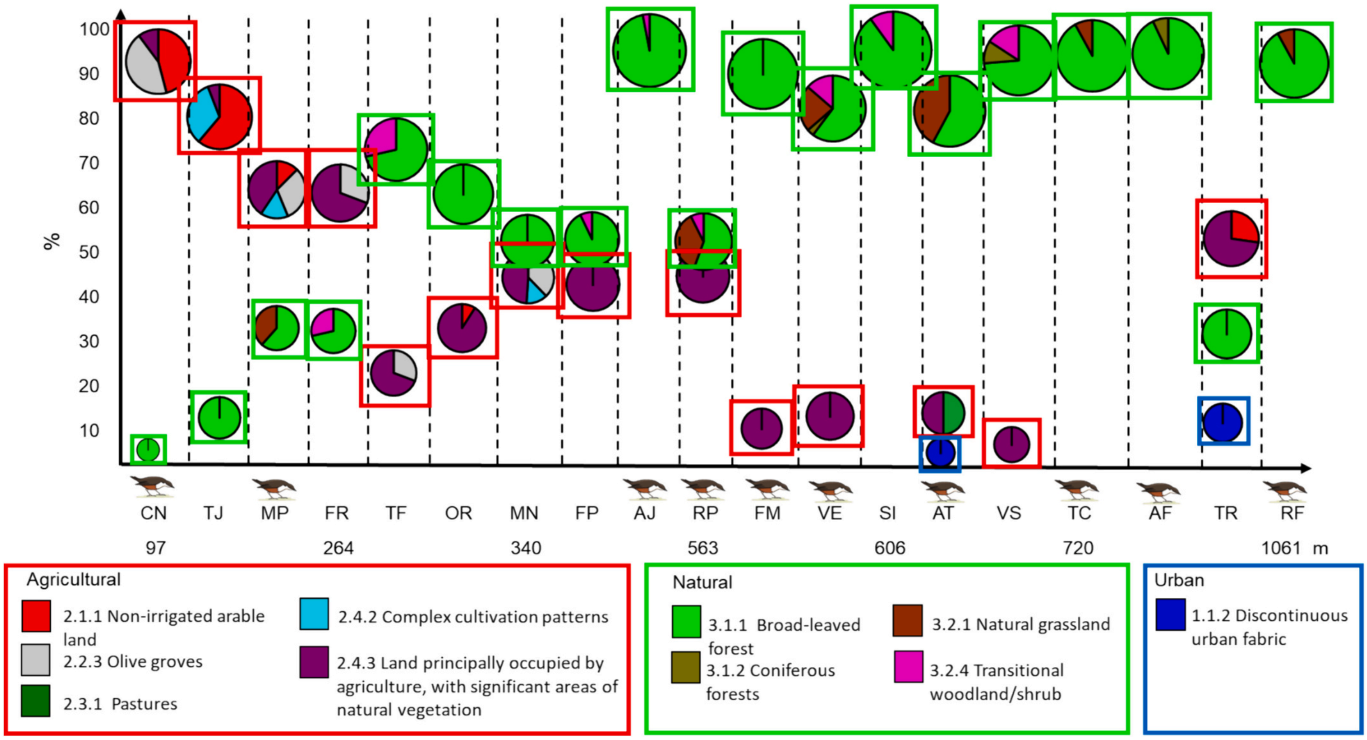

Fig. 4. Percentage of land use macro-classes (agricultural: red square, natural: green square, and urban: blue square) and their relative classes at the third level of Corine Land Cover for each station considering the absence and presence of dipper. Larger circles indicate a higher percentage of coverage for specific macro-classes. Elevation data are displayed below the x-axis. Site codes are shown in the maps.

proposition of the species as a reliable bio-indicator for aquatic status in Mediterranean river ecosystems (Sorace et al., 2002).

The relationship between the dipper and water quality largely stems from dietary studies predominantly conducted in Northern Europe. These studies indicate that the dipper's preferred prey are species highly sensitive to pollution, such as Plecoptera and Trichoptera (Ormerod et al., 1985). As our study was conducted during dipper breeding season coincidental with the peak of macroinvertebrates (Tyler and Ormerod, 1994; Tyler, 2010), we think that the absence of Plecoptera, which often correlates with lower EBI values, might prompt dippers to exploit other significant resources, such as more pollution tolerant Trichoptera taxa, if they are abundant. This could explain the presence of dippers even in areas with lower water quality (Andreotti et al., 1998; Del Guasta, 2003). Nevertheless, EPT values were not notably higher at dipper-contacted stations. In detail, in these stations were found an average of 3.1 families of Ephemeroptera compared to 1.7 of Plecoptera and 2.4 of Trichoptera. However, to have a more holistic view of dipper preferences, more studies are needed to verify the other food offers more than those informed by biotic indexes.

The use of the dipper species in bio-indication and water quality monitoring necessitates a thorough exploration of the relationship between dipper occurrence and water quality. As of now, this relationship appears ambiguous, highlighting the need for enhanced understanding of the species' trophic ecology in the Mediterranean. Nevertheless, the feasibility of utilizing the species in water quality monitoring is constrained by its low population density in the Latium region, rendering it more of an auxiliary than a foundational element in field activities. However, the data collected suggests that all the stations surveyed, with Quality Classes I and II, where the dipper has not been contacted, are potentially suitable for its presence. Water quality is a relevant parameter that directly impacts the availability and density of macroinvertebrates, which are a primary food source for species like the dipper that feed in aquatic environment. In addition, good water quality ensures clear water, which is essential for dippers to catch their prey. However, water quality alone is not sufficiently explanatory for the current observed distribution of the species. Thus, other factors have a strong influence in determining the suitability of a watercourse for the presence of the dipper. Thus, it becomes evident that other influential factors, such as suitable nesting sites and availability of perches for hunting, play a significant role in determining the suitability of a watercourse for dipper occurrence that could be considered in future research.

4.2. *Dipper occurrence in relation to the status of riparian habitat*

Although literature highlighted that dipper presence depends on river water quality (Sorace et al., 2002; Vaughan and Ormerod, 2012; Maznikova et al., 2024), this research suggests that dipper's presence is dependent on the whole status of riparian habitat. This study underscores the Fluvial Functionality Index as the sole parameter distinguishing dipper occurrence in stations from others, with the potential to elucidate its current distribution. The results reveal significantly higher scores at stations where dippers were observed, typically achieving an "Excellent" rating, in contrast to other stations which typically scored "Good" or "Good/Sufficient". Unlike measures of river system quality or naturalness, this index evaluates various parameters known to influence species presence, as documented in the literature. Among the index's four thematic groups of questions, those garnering higher scores at dipper-present stations primarily pertain to vegetation conditions along the banks and surrounding areas, the morphological and physical structure of the banks, and the biological characteristics of the community.

When evaluating vegetation conditions along the banks and surrounding areas of a watercourse, the level of human impact on the environment is assessed by examining the presence, quality, extent, and continuity of riparian formations. The presence of dense riparian vegetation, particularly trees, appears to be linked to the presence of the dipper (Del Guasta, 2003). The likelihood of finding dippers increased there where riparian vegetation functionality is maintained at a certain level. Thus, riparian vegetation should show a continuity along river rod and a consistent width (thickness at least between 10 and 30 m, according to the FFI, Siligardi et al., 2007). Apart from width and three-dimensionality vegetation (see Gallitelli et al., 2024), fragmentation of vegetation patches and the occurrence of alien species could be factors affecting dipper presence. Specifically, vegetation structure in terms of diversity (i.e., species richness) and form (i.e., branches and individual numbers for each species) provide a denser and tridimensional structure that could enhance dipper presence. Concerning the presence of alien species, competition with native species and modification of vegetation structure due to invasive plants can increase the vulnerability of dipper nests to predators (Fernández-Bellon, 2018; Grzędzicka and Reif, 2020). Also, some invasive plants can change the hydrology of rivers by altering water flow and sedimentation patterns (Catford, 2017). This might affect the aquatic invertebrates that dippers feed on, thus impacting their food supply. The morphological and physical characteristics of the banks are also considered, with attention given to any disturbances or fluctuations in water flow. This is because floods can impact food availability, influence diet composition, and even lead to temporary drying up of watercourses, discouraging the presence of dippers (Tyler and Ormerod, 1994). Moreover, various aspects of the biological communities are assessed, including the presence of periphyton, plant detritus, tolerant macrophytes, and the structure and diversity of the macrobenthic community. These criteria, along with potentially other unmeasured factors by the FFI, contribute to determining the suitability of a watercourse stretch for the presence of dippers, complementing the EBI and ICMi calculation.

4.3. Land-use driver for the dipper occurrence

Regarding the land use in the buffer areas around dipper stations, the most common land use classes are 'broad-leaved forest', 'agricultural crops with important natural areas' and 'natural grassland', which account for an average of 84.6 % of the areas. The areas surrounding dipper stations are characterized by a high degree of naturalness and a significant presence of woodland, which contributes to maintaining the quality of riparian habitat (Hanna et al., 2020). The results from the FFI suggest that the dipper's habitat selection is influenced more by overall habitat integrity rather than by any single factor. In this analysis, land use does not appear to play a significant role in explaining the species distribution. However, it's worth noting that the CLC digital mapping, operating at a scale of 1:100,000, may not accurately depict the presence of riparian vegetation strips, despite their extensive nature, as they are often incorporated into adjacent land use classifications.

As both the literature and the FFI analyses suggest, the presence, extent, and continuity of the riparian vegetation strip are crucial factors for species like the dipper, which rarely strays far from watercourses and predominantly disperses along them. It is highly unusual for the species to frequent areas adjacent to the watercourse outside the riparian vegetation belt. However, the land use in the surrounding areas could still exert an indirect influence on the species' presence, altering riparian vegetation, water quality and macroinvertebrate assemblages. For instance, heavy urbanization and the presence and expansion of permanent crops, such as hazelnut trees (*Corylus avellana*), could lead to an alteration and degradation of the riparian ecosystem. Moreover, macroinvertebrate assemblage diversity and their size were lowest in agricultural catchments (Stenroth et al., 2015; Fierro et al., 2017).

Our findings underscore the significance of riparian habitats and the overall health of riverine landscapes for the presence of dippers. It is important to note that our study focused on *C. cinclus aquaticus* at the edge of its range and distribution, resulting in a smaller sample size compared to studies targeting the core range of the subspecies. This discrepancy can be attributed to the distinct climate and environmental conditions of the Mediterranean biome compared to central Europe. Despite operating within the peripheral range, we emphasize that our results hold considerable conservation value for this species. Despite inhabiting a marginal area with a Mediterranean water regime prone to drought, understanding the habitat selection of a listed species is critical for its conservation. Therefore, identifying the environmental factors influencing the occurrence of dippers is mandatory.

5. Conclusions

Our findings highlighted the efficacy of using an integrated index like the FFI, which comprehensively evaluates environmental and biotic factors together, crucial for understanding the multitude of factors need for the dipper. Instead, individual parameters such as water quality, macrobenthic diversity, and altitude alone are insufficient to characterise the species' ecological niche. Furthermore, the current mapping of riparian vegetation in geographic information systems may not detect it due to its small size, meaning significant structural features of riparian vegetation might be overlooked, and land use analysis may fail to identify these areas. Therefore, there is the need to further investigate land use to provide a better-detailed scale to map riparian vegetation.

The decline in dipper populations in Lazio and southern Italy highlights the need for comprehensive research on this species, which has received limited attention in the Mediterranean region. Indeed, the species was classified as "Endangered" in the Lazio Red List in 2011, coinciding with the last thorough survey of its distribution conducted for the publication of the New Atlas of Breeding Birds in Lazio (Calvario et al., 2011). Acquiring new data on their current distribution and population size in Latium are essential tasks. Moreover, investigating the auto-ecology of the species in the Mediterranean region and identifying the key factors influencing its presence and distribution are mandatory. Understanding these factors is crucial for determining the most urgent threats and implementing effective conservation strategies for this species, especially considering riparian habitat loss, water management issues, and human-induced alterations to riparian ecosystems. These challenges, compounded by climate change and specific land use practices, demand focused attention for the species' conservation efforts.

Finally, a species as charismatic to the public as the dipper could serve as an umbrella species in conservation projects aimed at protecting and restoring the riparian zone. This zone acts as a buffer between the terrestrial and aquatic environments, playing a crucial role in maintaining biodiversity, ensuring good ecological status, and providing numerous ecosystem services.

CRediT authorship contribution statement

G. Cesarini: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **L. Gallitelli:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **C. Lembo Fazio:** Visualization, Validation, Investigation, Data curation. **M. Scalici:** Writing – review & editing, Visualization, Validation, Supervision, Resources, Project administration, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All data are present in the manuscript and Supplementary Materials.

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Appendix A. Supplementary data

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