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CARABID FAUNA IN AGRICULTURALLY MODIFIED LANDSCAPES: A CASE STUDY OF THE ARGEȘ RIVER CATCHMENT, ROMANIA, FROM HEADWATERS TO FLOODPLAINS

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Abstract

Riparian zones represent valuable riverine habitats that contribute to regional biodiversity and promote valuable ecosystem services within their catchments. Land use changes historically impacted riparian areas within most agrarian catchments, leading only to small land gains at high cost of ecosystem service loss. Ground beetles represent validated bioindicators and an important group of predators acknowledged as valuable cross-ecosystem trophic links and pest control agents. We studied the community composition of ground beetles along a land use gradient within the riparian zones of a moderately impacted agricultural catchment. We emphasize the importance of riparian forested buffers for sustainable agriculture through the support of multiple pest predators and the promotion of higher biodiversity across agrarian landscapes.

***Key words**: agricultural catchment, community composition, ground beetles, riparian buffers, sustainability.*

INTRODUCTION

Riparian zones are ecotones that connect lotic and adjacent terrestrial ecosystems across the different landscapes of large catchments (González et al., 2017; Naiman & Decamps, 1997). These riverine habitats are documented to possess distinct (Sabo et al., 2005) and often more diverse biotic communities compared to their surrounding areas (Naiman et al., 1993; Ramey & Richardson, 2017). In many instances, riparian zones have been shown to shelter rare and vulnerable species (Ramey & Richardson 2017; Tockner & Ward, 1999), further highlighting their importance for biodiversity conservation at local and regional levels (González et al., 2017; Zhang et al., 2023).

Historically, the increased demand for agricultural land led, in many cases, to the conversion of riparian areas, formerly perceived as unproductive habitats, into crops or pastures (Clerici et al., 2014; Fang et al., 2024). Land use changes have significantly affected riparian zones and their biodiversity, particularly in developed countries and continue to do so in developing and low-income regions (Hanna et al., 2020; Tockner & Stanford, 2002). More recent concepts such as green-blue infrastructure and sustainable agriculture led to increased awareness and conservation of wetlands such as riparian habitats (Burdon et al., 2020; Kohsaka & Uchiyama, 2021). Nowadays, an increasingly solid body of work advocates for the use of forested buffers as ecosystem features that facilitate sustainable practices and efficient ecosystem management across agricultural catchments (Burdon et al., 2020; Graziano et al., 2022).

Among riparian biota, ground beetles (family Carabidae) represent one of the most researched taxa (Ramey & Richardson, 2017), in part, due to their roles as cross-ecosystem trophic links (Murgu & Rîșnoveanu, 2023) and herbivory control agents (French et al., 2001, Murgu, 2023) and, in part due to their diversity and ubiquity in riverine habitats (Ramey &

Richardson, 2017). Conjointly, the strong habitat affinity and sensitivity to environmental conditions exhibited by carabids have made them commonly used biotic indicators (Januschke et al., 2011; Murgu & Rîşnoveanu, 2023). The pragmatic use and conservation of ground beetles for ecological assessment, pest control and for other ecosystem services they provide, as well as for scientific and moral purposes requires, first and foremost, an extensive knowledge of the taxa in the areas where sustainable ecosystem management is desired.

The Argeș River is one of the main tributaries of the Danube River in the lower part of its course, its catchment being one of the largest in the south of the Carpathians. More than half of its total area of 125 km^2 has been converted to agricultural lanscapes for crops, pastures, and orchards, with activity levels of varying intensites (Popescu et al., 2021). The carabid biodiversity of the Argeș cathcment has been addressed before throughout various research articles and monographs to different extents and degrees of complexity (Barloy & Prunar, 2010; Lotrean, 2010; Lotrean, 2012; Lotrean & Manu, 2017; Popescu, 2021; Teodorescu, 2010; Vizitiu et al., 2022).

However, to the best of our knowledge, the ground beetle communities of the Argeș river catchment have not been investigated, at least not for a long time, at the same spatial extent that we did, from headwater streams to the lowlands, across a diverse landscape and during a continuous multiseasonal period. In this research, we investigate the carabid fauna of the middle section of the Argeș catchment and aim to contribute to its comprehensive knowledge and to further emphasize the importance of riparian buffers in agricultural landscapes as shelters for rare and useful species which increase regional biodiversity and promote sustainable agricultural practices.

MATERIALS AND METHODS

Sampling of invertebrates took place monthly, from May to November of 2018 within the middle catchment of the Argeș River, in the territory of the Argeș and Dâmbovița counties in Romania (Figure 1).

The selected catchment serves as a good representation of both the sylvo-steppe landscapes in southeastern Europe and moderately modified agricultural catchments, as approximately 56% of its total area was converted for this purpose (Popescu et al., 2021).

Ground beetles were sampled following an altitudinal and anthropic impact gradient, from four types of riparian habitats (henceforth called site types): forest (F), unbuffered (I), buffered (R) and matrix (IC) and 17 sites (Figure 1, Table 1) located mostly along low order streams, between the 1st and 3rd order according to the Strahler classification (Strahler, 1957). All sampling sites were identified and characterized in the BioDivERsA Crosslink project (for details see Burdon et al., 2020 and Popescu et al., 2021).

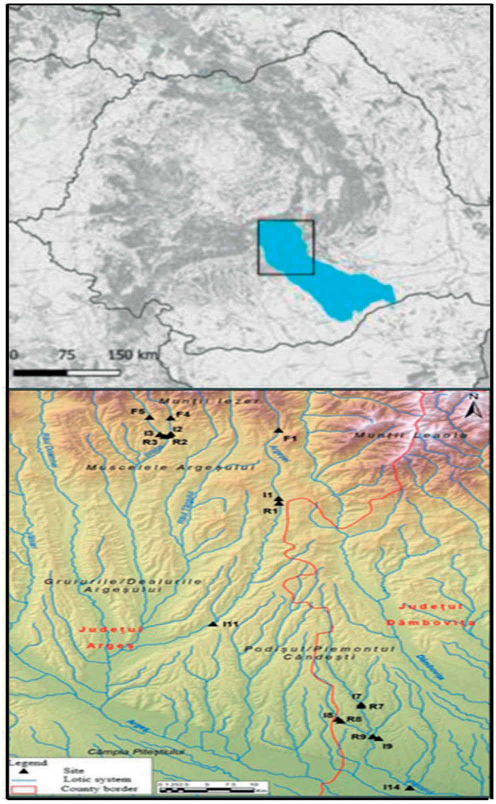

Figure 1. Map of sampling sites (adapted from Popescu et al., 2021 and Giurgincă et al., 2023)

Table 1. Location of sites within the Argeș Catchment: F = forest; I = unbuffered, R = buffered, IC = matrix

Site	Lotic system	Strahler order	Altitude (m.a.s.l.)	Region
F1	Argeșel	1	795	Getic Subcarpathians
F4	Brătioara	1	720	Iezer-Păpușa Mountains
F5	Bratia	1	730	Iezer-Păpușa Mountains
I1	Argeșel	1	570	Getic Subcarpathians
R1	Argeșel	1	560	Getic Subcarpathians
I2	Brătioara	1	655	Getic Subcarpathians
R2	Brătioara	1	645	Getic Subcarpathians
I3	Bratia	1	649	Getic Subcarpathians
R3	Bratia	1	638	Getic Subcarpathians
I7	Potop	2	262	Getic Plateau
R7	Potop	2	258	Getic Plateau
I8	Strâmbul	2	265	Getic Plateau
R8	Strâmbul	2	260	Getic Plateau
I9	Potop (Aval)	2	230	Getic Plateau
R9	Potop (Aval)	2	229	Getic Plateau
I11	Argeșel	2	364	Getic Plateau
I14	Potop	3	192	Getic Plateau

Forest sites were placed at the highest upstream locations in undisturbed deciduous forest landscapes and were characterized by extensive lengths and widths of native arboreal vegetation as well as rocky substrates and thin layers of soil. Paired unbuffered and buffered sites were located downstream along the river continuum, usually in slightly hilly or flat terrain within landscapes modified by agriculture. Unbuffered sites, located upstream of their counterparts, were characterized as open habitats that lacked arboreal vegetation, dominated by grasses, herbs and occasional shrubs. Buffered sites were characterized by woody riparian vegetation with a minimal length of 50 m and widths at least 2 or 3 times wider than the wetted stream channel. The proximity between the paired sites was intentional, to allow for a viable comparison, based on the level of land use impact. The matrix sites were the furthest downstream, affected by cumulative impact from upstream and located in intensely agriculturally converted areas from the floodplains. They were selected to represent the highest level of impact along the gradient. These sites were dominated solely by grasses that bordered crops or pastures with intensive land use regimes. Three sampling plots were established on each bank, for a total of six plots per site, to cover existing heterogeneity as well as to provide replication in case of inherent sample loss or deterioration. Ground beetles were collected with pitfall traps, half-filled with ethylene glycol and usually emptied fortnightly, depending on the weather. Samples were collected at three distances from the stream within each site (1, 5 and 15 m), with a total of 18 traps per site, to accurately assess the diversity within the studied communities as some species exhibit stronger aggregative responses towards water than others. Upon collection, arthropods were transferred to plastic containers filled with alcohol and transported to the laboratory where they were stored in a cold room and identified as soon as possible based on the available taxonomic keys and other related resources (Ciubuc, 2021; Gîdei & Popescu, 2012; Klimaszewski & Watt, 1997; Luff, 2007; Makarov, 1994). Functional traits of each species were also gathered from the available literature (Ciubuc, 2021; Gerisch, 2014; Gîdei & Popescu, 2012; Klimaszewski and Watt, 1997; Luff, 2007; Makarov, 1994) to allow for a better assessment of how carabid communities change in relation to impact and for more detailed discussions.

To account for variation in exposure days and loss of traps within each site we divided the sum of daily catch rates (individuals/day) type by the total corresponding number of recovered traps ($\Sigma_{\text{individuals/day}}/\#_{\text{recovered traps}}$). We calculated the relative frequency and the relative abundance of each carabid species sampled within each of the sampled site types. The relative abundance (%) of a species within a site type was calculated as: $\Sigma_{\text{daily catch rates}}$ of a certain species/$\Sigma_{\text{daily catch rates}}$ of all sampled carabids within the assessed site type * 100. The relative frequency (%) of a species within a site type was calculated as: # of samples with confirmed presence of a certain species/# of samples collected from the assessed site type. We presented these values in increased order in the form of Whittaker plots, ranking species from the least abundant and rare to the most dominant and frequent. We opted for this type of approach since we consider it effective and clear to highlight the particularities of the carabid communities between the assessed site types.

RESULTS AND DISCUSSIONS

In total, at catchment level, we sampled carabids belonging to 14 subfamilies and 36 genera. We were able to identify 60 species (89.8% of the total carabids sampled), while some individuals were identified only to genus level, mostly due to their deterioration during sampling or difficulties in their group taxonomy, such as the case of *Bembidion* or *Ocys* (Table 2).

Table 2. List of carabid taxa identified within the studied sites: Habitat specialization: E = eurytopic, S = stenotopic; Pest predator: Ap = aphids, Co = coleopterans, Di = dipterans, Le = lepidopterans, Ss = slugs and snails, W = weeds; Status: E = endemic, P = protected, R = rare (For site code explanation see Table 1)

Subfamily	Species	F1	F4	F5	I1	I2	I3	I7	I8	I9	R1	R2	R3	R7	R8	R9	I11	I14	Habitat specialization	Pest predator	Status
Brachininae	*Brachinus crepitans* (Linnaeus, 1758)														X			X	E		
Broscinae	*Broscus cephalotes* (Linnaeus, 1758)		X	X			X			X									S	Co	
Carabinae	*Calosoma sycophanta* (Linnaeus, 1758)													X					S	Le	R
	Carabus coriaceus (Linnaeus, 1758)		X		X			X	X	X	X		X	X		X			E	Co	
	Carabus cancellatus (Illiger, 1798)		X	X	X						X		X	X					E	Co, Le	
	Carabus clatratus (Linnaeus, 1761)					X	X												S		R
	Carabus convexus (Fabricius, 1775)		X		X	X		X			X	X	X	X					S		
	Carabus glabratus (Paykull, 1790)										X								S		
	Carabus granulatus (Linnaeus, 1758)		X	X	X						X		X	X		X	X		E	Co, Ss	
	Carabus intricatus (Linnaeus, 1761)										X								S		R
	Carabus ullrichi (Germar, 1824)		X													X			E		
	Carabus variolosus (Fabricius, 1787)	X	X	X			X					X							S		P
	Carabus violaceus (Linnaeus, 1758)	X	X	X	X	X		X	X	X	X		X	X			X		E	Co, Ss	
	Cychrus caraboides (Linnaeus, 1758)	X	X										X	X	X				E		
Chlaeniinae	*Callistus lunatus* (Fabricius, 1775)													X					S		R
	Chlaenius nigricornis (Fabricius, 1787)			X			X						X				X	X	S		
	Chlaenius nitidulus (Schrank, 1781)					X	X	X	X	X		X		X		X		X	S		
	Chlaenius spoliatus (P.Rossi, 1792)					X	X												E		
	Chlaenius vestitus (Paykull, 1790)		X	X		X	X							X					E		
Cicindelinae	*Cicindela germanica* (Linnaeus, 1758)				X														S		
Harpalinae	*Diachromus germanus* (Linnaeus, 1758)																	X	E		R
	Harpalus griseus (Panzer 1796)					X		X	X		X	X		X				X	S	Ap, Di, Ss, W	
	Harpalus rufipes (De Geer, 1774)			X		X	X	X					X	X		X		X	E	Ap, Co, Di, Ss, W	
	Harpalus affinis (Schrank, 1781)							X	X				X						S	Ap, Di, W	
	Harpalus sp.		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	E	Ap, W	
	Stenolophus teutonus (Schrank, 1781)													X					E	W	
Lebiinae	***Syntomus sp.***		X	X		X						X				X			E		
Licininae	*Badister bipustulatus (Fabricius, 1792)*				X														E		
	Licinus depressus (Paykull, 1790)				X							X	X				X		S	Ss	
Nebriinae	*Leistus piceus* (Frölich, 1799)													X					S		R
	Nebria brevicollis (Fabricius, 1792)	X	X			X				X	X		X	X				X	E	Ap	
	Notiophilus palustris (Duftschmid, 1812)			X									X						E		
Panagaeinae	*Panagaeus cruxmajor* (Linnaeus, 1758)																X	X	S		R
Platyninae	*Agonum piceum* (Linnaeus, 1758)	X																	E	W	
	Agonum sexpunctatum (Linnaeus, 1758)	X		X			X				X						X	X	E		
	Agonum viridicupreum (Goeze, 1777)	X					X	X	X										S		
	Anchomenus dorsalis (Pontoppidan, 1763)							X						X				X	E	Ap	
	Oxypselaphus obscurus (Herbst, 1784)	X										X							E		
	Platynus assimilis (Paykull, 1790)	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	E		
	Platynus sp.		X	X									X				X		E		
Pterostichinae	*Abax parallelepipedus* (Piller & Mitterpacher, 1783)	X	X								X					X			E	Di, Ss	
	Abax sp.		X		X						X					X			E		
	Amara aenea (De Geer, 1774)	X	X		X		X		X			X	X	X		X	X	X	E	Co, W	
	Amara ingenua (Duftschmid, 1812)	X											X					X	E	Co, W	
	Amara nitida (Sturm, 1825)													X		X		X	E	Co, W	
	Amara sp.	X	X		X				X	X						X	X		E	Co, W	
	Calathus fuscipes (Goeze, 1777)						X							X		X		X	E	Ap, W	
	Calathus melanocephalus (Linnaeus, 1758)	X	X	X	X	X	X	X	X	X	X			X		X		X	E		
	Calathus piceus (Marsham, 1802)						X						X						S		
	Molops piceus (Panzer, 1793)		X		X														S		
	Poecilus cupreus (Linnaeus, 1758)	X	X	X	X	X	X	X		X	X	X	X		X	X	X	X	E		
	Poecilus sericeus (Fischer von Waldheim, 1824)								X										E		
	Poecilus versicolor (Sturm, 1824)	X				X	X						X						E		
	Pterostichus macer (Marsham, 1802)	X			X				X		X	X	X			X			E	Ap, Co	
	Pterostichus madidus (Fabricius, 1775)							X					X				X		E	Ap, Co, Ss	
	Pterostichus melanarius (Illiger, 1798)	X			X	X	X					X	X					X	E	Ap, Co, Di, Le	
	Pterostichus niger (Schaller, 1783)	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	E	Co	
	Pterostichus nigrita (Paykull, 1790)		X		X			X	X		X	X	X	X			X	X	E	Co	
	Pterostichus sp.				X		X						X	X	X		X	X	E	Co	
	Pterostichus vernalis (Panzer, 1795)							X								X		X	E	Co	
	Stomis pumicatus (Panzer, 1796)												X						E		
Scaritinae	*Clivina fossor* (Linnaeus, 1758)		X							X						X		X	E	Co	
Trechinae	*Asaphidion caraboides* (Schrank, 1781)							X				X	X			X	X	X	E	Co	
	Bembidion lampros (Herbst, 1784)	X	X	X		X	X					X	X			X		X	E	Ap, Co, Di, Le	
	Bembidion sp.	X				X	X	X	X			X		X		X			E	Co	
	Ocys sp.							X				X							E		
	Tachys sp.			X						X		X						X	E		
	Trechus carpathicus (Rybinsky, 1902)	X																	S		E
	Trechus pilisensis (Csiki, 1918)	X														X			E	W	R

From all sampled taxa, carabids accounted for 11% of the total individuals sampled per day (ind/day) from buffered (0.18 ± 0.37 carabids/day of 1.62 ± 2.47 epigean invertebrates/day) and matrix sites (0.20 ± 0.36 carabids/day of 1.70 ± 2.13 invertebrates/day) and 8% of unbuffered (0.12 ± 0.23 carabids/day of 1.36 ± 2.24 invertebrates/day), respectively 6% of forest sites (0.11 ± 0.21 carabids/day of 1.62 ± 2.02invertebrates/day) (Figure 2).

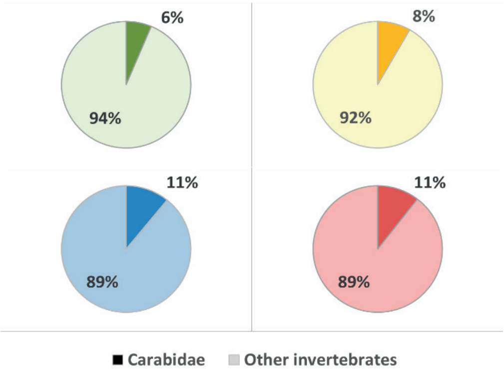

Figure 2. Proportion of carabids among total epigean invertebrates sampled at each site type: green = forest; orange = unbuffered, blue = buffered, burgundy = matrix

Buffered sites supported the highest number of species (48), followed by unbuffered (40), forest (38) and lastly matrix sites (28). Of all the ground beetle species sampled, 18 were found in all site types, 24 in three site types, 14 in two site types and 16 in just one site type, mostly in buffered (Table 2). None of the species were present in all sites, though 3 of them were highly widespread within the catchment, namely *Pterostichus niger* and *Platynus assimilis* in 16 sites and *Poecilus cupreus* in 15 sites (Table 2). Conversely, 13 species had their presence confirmed solely in one site (Table 2). As such, 7 species were found in just a single buffered site, 3 in a single unbuffered site, 2 in just a forest site and 1 just in one matrix site (Table 2). The Pterostichinae subfamily was by far the most diverse, with 18 identified species from 7 genera (Table 2). It is likely that more species for this subfamily can be found in our study area since a few individuals remained identified only to genus level. Carabids of this subfamily were the most widespread and frequently occurring throughout the different site types and site assessed, while also the most abundant in three of the four site types assessed. Species *Pterostichus niger* and *Poecilus cupreus* were some of the most frequently sampled species (Figure 3), with presence repeatedly confirmed in most sites. Both species were also among the most abundant regardless of site type (Figure 4). *P. niger* ranked second in buffered and third in matrix sites and had the third highest abundance at catchment level (Figure 4).

P. cupreus was, overall, the most abundant species, dominant in all site types except buffered, with relative abundances more than two-fold higher compared to the second most dominant taxa in all the cases (Figure 4). Oppositely, the rarest species of the subfamily were *Poecilus sericeus* and *Stomis pumicatus.* Each of the two species was present in just one site (Table 2) and both with very reduced relative abundances (Figure 4). Generally, Pterostichinae species were present at low abundances throughout the entire catchment, with only one species found to be subdominant, namely *Pterostichus nigrita,* in buffered and matrix sites (Figure 4). However, no rare, endangered or protected species belong to this subfamily were present within our study catchment.

Subfamily Carabinae was the second most diverse, represented by 12 species from 3 genera, with all but two belonging to the genus *Carabus* (Table 2). Of the genus, 4 species were recorded in just one site type, all but one in buffered sites, and each found in just one site: *Calosoma sycophanta* in R7 and *Carabus glabratus* along with *Carabus intricatus* in R1. By the contrary, *Carabus clatratus* was found only in unbuffered sites: I2 and I3. Rarities aside, most species were found in all or multiple site types and sites, the majority of them with reduced relative abundance, except for: *Carabus violaceus*, *Carabus granulatus*, *Carabus coriaceus* and *Cyhrus caraboides* (Figure 4). Notably, individuals of the vulnerable and protected species *Carabus variolosus* (Nitzu et al., 2021) were also observed throughout different site types and locations. However, they were not sampled in large numbers, with the highest relative abundance and frequency in forested sites (Figures 3 and 4). In addition, *C. sycophanta* is another species of the subfamily that is listed as vulnerable by the Romanian Red

Book of Invertebrates and a rarity in our samples, yet, at present, no enforced protection measures exist for it (Nitzu et al., 2021).

Six species from four genera were found to belong to the Platyninae subfamily (Table 2), thus making it the third most diverse within our area of study. *Platynus assimilis* was almost ubiquitous, missing from just one site. The species was dominant and most frequent in buffered sites, with relative abundances twice as high as *P. niger*, the second most dominant species (Figures 3 and 4).

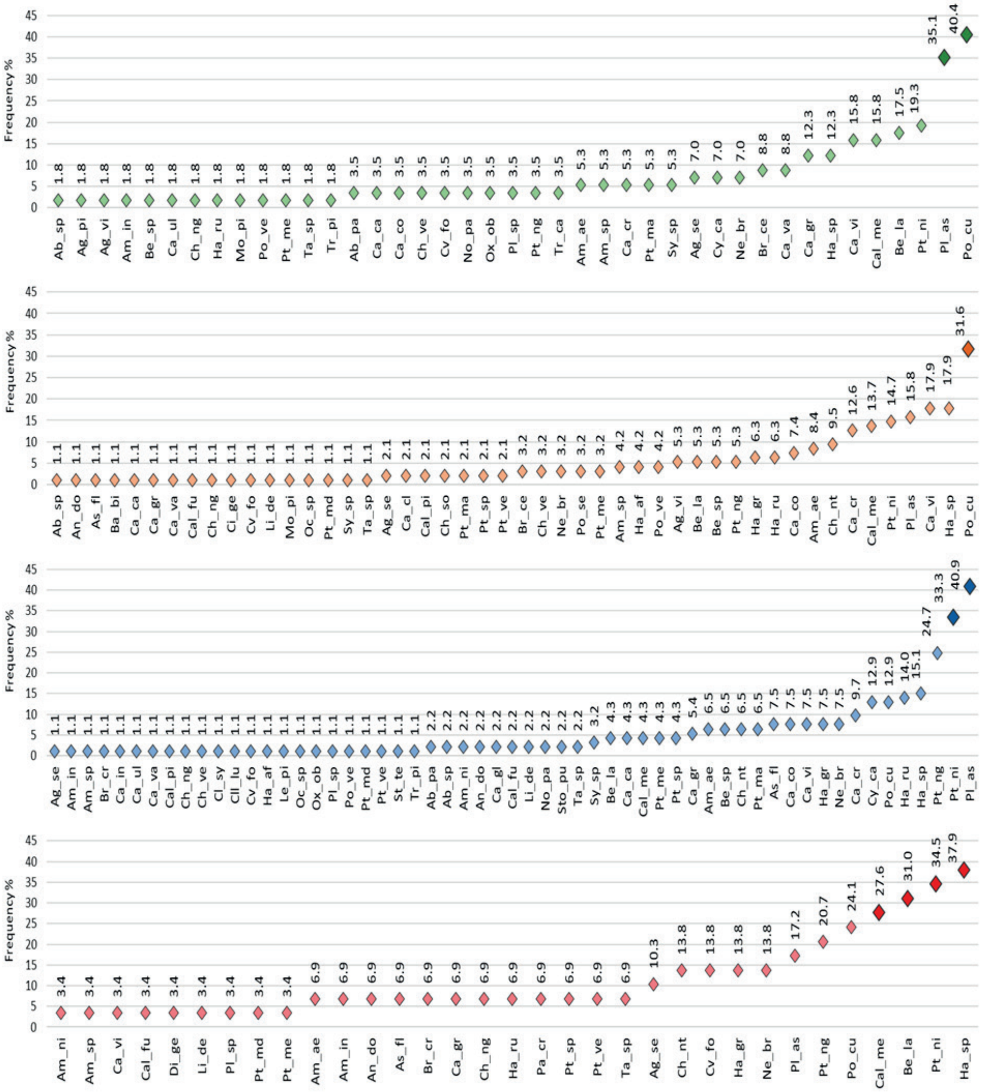

Figure 3. Relative frequency of species at site types: green = forest; orange = unbuffered, blue = buffered, burgundy = matrix

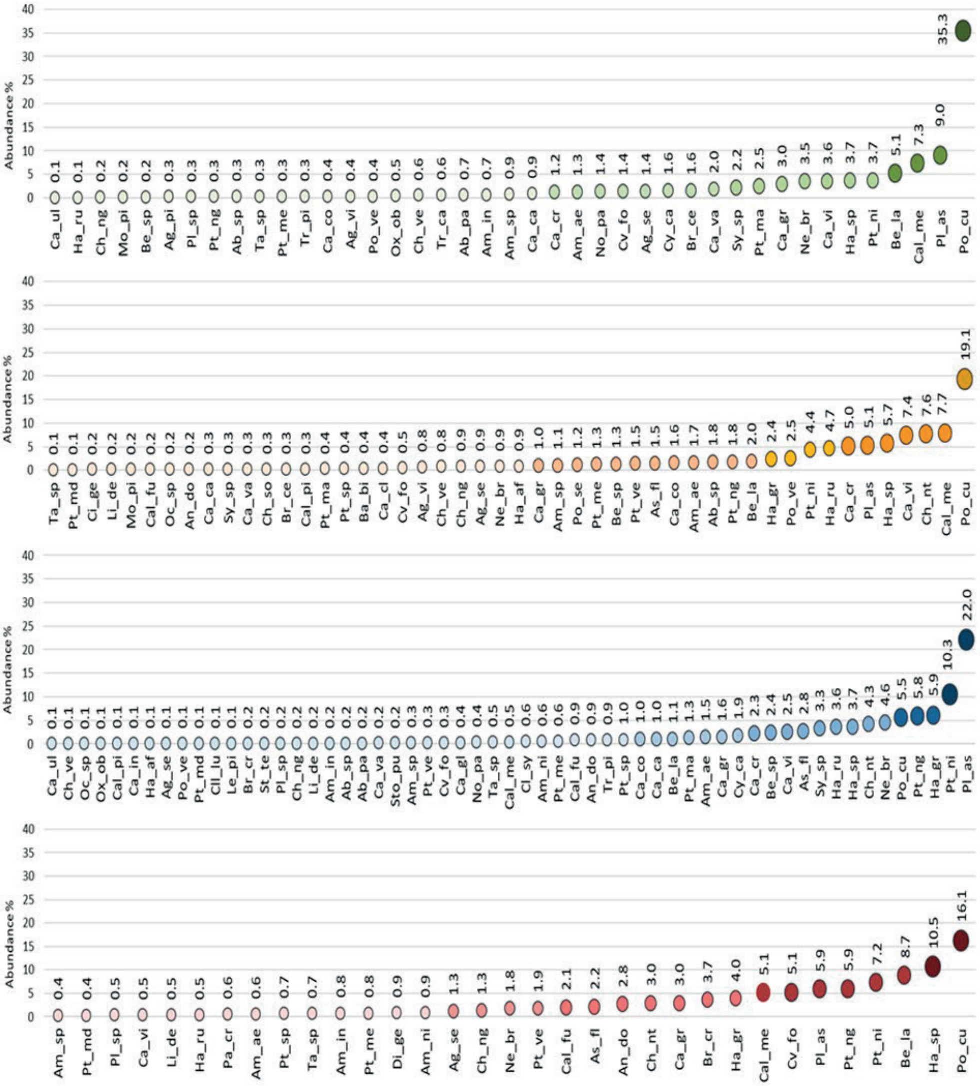

Figure 4. Percentage of species abundance at site types:
green = forest; orange = unbuffered, blue = buffered, burgundy = matrix

It showed high relative abundances in the other site types and occupied the second position in forest, fifth in matrix and sixth in unbuffered sites. Conversely, species like *Agonum piceum* and *Oxypselaphus obscurus* had reduced frequencies and abundances in communities, with the first present in just one forest site and the second in one forest and one buffered site (Figures 3 and 4). With the exception of *P. assimilis*, all species showed reduced relative abundance, with the notable exception of *Anchomenus dorsalis* in matrix sites where it could be classified as subdominant (Figure 4). Subfamily Trechinae was represented by five genera from which we could identify four species, while most individuals from genus *Bembidion*, *Ocys* and *Tachys* remained unidentified (Table 2). The most widespread, frequent and abundant species was *Bembidion lampros*, with *Asaphidion caraboides* ranking second within the group (Figures 3 and 4).

Species *Trechus carpathicus* and *Trechus pillisensis* had very sporadic and spatially restricted occurrences, as well as very reduced relative abundances (Table 2, Figures 3 and 4). *T. carpathicus* is a rare, endemic and stenotopic forest species from the Romanian and Ukrainian Carpathian range (Ciubuc, 2021), found during our survey in only one forest site (Table 2). Its endemic congeneric species, *T. pillisensis* was found in one forest and one buffered site, however in both locations with reduced numbers.

Also represented by five species was the Harpalinae subfamily. Three species belonged to genus *Harpalus*, one to *Diachromus* and one to *Stenolophus*, while some individuals remained identified just to the eponymous genus (Table 2). The majority of species were present in multiple site types and sites, with the exception of *Biachromus gemanus* and *Stenolophus teutonus*, with the first reported only in site I14 (matrix) and the latter only in site R7 (buffered) (Table 2), both with very reduced relative abundance and frequency (Figures 3 and 4). *Harpalus griseus* and *Harpalus rufipes* had the highest recorded relative abundance and frequency of occurrence among the species in this subfamily. Both species were subdominant, in most buffered sites, but also in matrix and unbuffered ones, in the case of the former, respectively of the latter.

The Chlaeniinae subfamily was represented by five species and two genera (Table 2). One aspect to be noted is that the species from this subfamily found within our sampled catchment were mostly stenotopic and habitat specialists. *Chlaenius nitidulus* was the only more abundant species, subdominant in buffered and unbuffered habitats. The rest of the species, had consistently low relative abundances and frequencies, as compared to other carabid species, and were distributed in most site types, with the exceptions of *Chlaenius spoliatus,* found just in unbuffered sites and *Callistus lunatus*, found solely in one buffered site, as a singular occurrence.

The Nebriinae subfamiliy summed up three species, each from a different genera, all mostly encountered in densly vegetated sites. Of the three, *Nebria brevicollis* was by far the most numerous in all site types, ranking as the forth most abundant species in buffered sites. *Notiophilus palustris* followed as the second most abundant species of the subfamily, with presence observed solely in forested and buffered sites, alltogather with reduced relative abundances and frequencies. Lastly, the stenotopic species *Leistus piceus* was represented in just one buffered site by a lone individual, thus respresenting the rarest species of the group, and one of the rarest sampled within the entire catchment.

The Licininae subfamily was comprised of just two species, both of which with very reduced relative abundances and frequencies. *Licinus depressus* was found in few sites, in three of the four site types, with half of its total abundance at the most impacted sites, while *Badister bipustulatus* was found in just one buffered site in two instances (Table 2).

The Brachininae subfamily was represented by just one species, *Brachinus crepitans,* found to the highest degree in matrix sites, in I14 and to a much lesser extent in buffered sites, in R8 (Table 2, Figures 3 and 4). Subfamily Broscinae was also represented by a single species, *Broscus cephalotes*, found with reduced degree of representation, mainly in forest sites and sporadically in unbuffered sites (Figures 3 and 4). *Cicindela germanica* was the sole representative of the Cicindelinae subfamily though the middle catchment of the Argeș and it was found with very reduced relative abundance and frequency, solely in one unbuffered site (Table 2). The other singly represented subfamilies found during our survey consist of Panagaeinae and Scaritinae, represented by the rare *Panagaeus cruxmajor,* and, respectively, by the more common *Clivina fossor. P. cruxmajor* was found solely in one matrix site, with two singular occurrences. *C. fossor* was found to be relatively abundant in the matrix site where mostly present, yet a rare occurrence in the forest and unbuffered sites where it was sporadically found in low abundances. Lastly, the Lebiinae subfamily was found to be present in multiple site types and sites, however, mostly due to the state of the individuals, we were unable to identify them past genus.

The general patterns of distribution shown by carabid communities across the studied catchment and site types are generally in accord with tendencies reported in related literature. The higher percentage of carabid abundance in epigean invertebrate communities in buffered and matrix sites may be linked to increased food availability. However, different mechanisms are involved in the two kinds of sites: in buffered sites it is the dominance of larger bodied caddisflies and longer emergence periods associated with better aquatic microhabitat conditions (Paetzold et al., 2006; Kupilas et al., 2021), whereas in matrix sites higher aquatic emerged biomass rates are mainly associated with small bodied chironomids favored by higher aquatic primary production (Kautza and Sullivan., 2016; Terui et al., 2018). More complex terrestrial microhabitat conditions generally associated with buffered riparian zones are also expected to increase both the species richness and abundance of ground beetles of such areas as opposed to similarly located habitats that lack arboreal vegetation (Kautza and Sullivan., 2016; Popescu et al., 2021). Within our catchment, buffered sites supported a higher number of rare species and pest predators, which, in accord with previous findings (Popescu et al., 2021), emphasizes the importance of riparian conservation in agricultural landscapes. The higher abundance of carabids within invertebrate communities and reduced number of species from matrix sites are likely attributed to two distinct factors. The reduced microhabitat habitat diversity of this site type supported, almost entirely, a few highly eurytopic and generalist agrobiont species in high numbers. Additionally, the availability of easily accessible prey from the nearby agriculturally converted patches may have facilitated the occurrence of epigean, highly mobile and voracious predators such as ground beetles (Batáry et al., 2007; Gallé et al., 2018). While unbuffered sites hosted some distinct open habitat specialists, it is generally shown by our findings and previous research (Batáry et al., 2007; Gallé et al., 2018) that riparian deforestation reduces the diversity and complexity of riparian carabids and the benefits they provide (Popescu et al., 2021; Stockan et al., 2014). Notably, the carabid communities in forest sites are the most distinct in the catchment, harboring more rare and vulnerable species. These findings highlight the importance of conserving headwater habitats to protect their unique biodiversity (Richardson and Danehy, 2007). The reduced abundance of carabids relative to the total of individuals sampled in forest sites can be explained by the increase of dead wood and associated physical habitat structures usually encountered in densely vegetated habitats and known to support other type of riparian predators such as web building spiders (Hunt et al., 2020; Ramberg et al., 2020). The widespread and high abundance of P. cupreus in Arges basin, including in unbuffered and matrix sites, aligns with previous findings reported in our county (Varvara et al., 2011) and internationally (Brygadyrenko, 2016; Porhajášová et al., 2014). The species is almost ubiquitous in agricultural landscapes, frequently reported in high abundances (Porhajášová et al., 2014; Varvara et al., 2011). Given their highly eurytopic nature and wide distribution, individuals from the species were used as model organisms in response to pressures associated with land use change, as well as agricultural practices (Sowa et al., 2022). Such research reinforced the idea that even the most resilient organisms can be significantly affected by anthropic activities, mainly through the reduction of individual fitness rather than changes in abundance which sometimes might be less significant. They highlight that functional traits might be better suited indicators than population size or community structure, at least in certain cases and reinforces the importance of complementary approaches in biodiversity research. It was shown that extensive monocultures, habitat reduction, pesticide use and other sources of pollution affect traits of *P. cupreus* individuals and their overall fitness (Marrec et al., 2017; Sowa et al., 2023). For instance, females of the species from crops intertwined with naturally occurring herbs and grasses have been documented to possess higher body mass and to have higher fecundity as opposed to ones from conventionally managed crops (Labruyere et al., 2016). Additionally, good practices such as sustainable crop management and promotion of landscape diversity were shown to positively influence the populations of *P. cupreus* and of other carabids (Labruyere et al., 2016; Marrec et al., 2017; Sowa et al., 2022).

In the middle catchment of the Argeș, Carabinae subfamily include several stenotopic species with very selective feeding preferences and specialized foraging straegies, recognised as some of the most efficeint arthropod pest control predators (Ciubuc, 2021; Popescu et al., 2021). Species like *C. coriaceus, C. granulatus* and *C. caraboides* were fairly abundant in buffered sites, thus reinforcing the importance of such landscape structures to support varied populations of pest predators that are effective both numerically and functionally. Because the active periods of species vary throughout the year, more diverse communities are likely to sustain pest control over a longer duration. Increased species diversity may also facilitate a wider range of pest that can be prayed on by different carabids with different feeding preferences and degrees of specialization (Jaworski et al., 2023; Mitchell et al., 2014). The abundance of pest predators is also very important since the efficiency of the provided ecosystem service depends on the number of individuals actively hunting and on the quantity of prey consumed (Jaworski et al., 2023; Mitchell et al., 2014). Furthermore, the occurrence of protected (e.g., *C. variolosus*) and rare species (such as *C. sycophanta* and *C. intricatus*) indicates the relevance of forested and buffered riparian areas for supporting regional biodiversity within agricultural catchments. Among carabids and arthropods in general, *C. sycophanta* represents an archetype species for population control, as it was historically used to great effect against invasions of the larval stages of the gipsy moth (*Lymantria dispar*) and of other caterpillars, mostly within the United States (Weseloh, 1985). Aside from their rarity, species like *C. intricatus* represent valuable bioindicators used to assess the quality of woodland habitats since the presence of the species is generally correlated with old trees, as well as moist, cool and shady conditions (Pett et al., 2024). We argue this should emphasis not only the importance of buffer availability, but also of its characteristics, such as density and size, if such habitats are to effectively support rare and endangered species.

Platynus assimilis is one of the most interesting carabids sampled within the Middle Catchment of the Argeș River, given its clear dominance in buffered sites and relatively low abundances in other site types. The species is usually described as a stenotopic wetland specialist, though increasing reports of its presence in other nearby habitats, such as crops and meadows, tend to shift its perceived ecological preferences among researchers (Ploomi et al., 2012). It is clear, however, that individuals of this species can be used as biological control agents within agricultural landscapes, against a multitude of pest and with satisfactory effects (Kivimägi et. al., 2009). Furthermore, alongside the also dominant *P. cupreus*, *P. assimilis* represents perhaps one of the most studied ground beetles with regard to the effect of pesticide use on nontarget, beneficial taxa. Research on this topic commonly reported sublethal effects including prolonged hypoactivity (Tooming et al., 2014; Tooming et al., 2017), reduced pest consumption (Tooming et al., 2014; Tooming et al., 2017), reduced thermoregulation capacity (Kivimägi et. al., 2009; Merivee., 2015) and, increased respiration rate (Kivimägi et al., 2013). Evidence that less obvious traits and behaviors, such as shelter seeking, are affected by pesticides and reduce thermoregulation capacity highlights the need of incorporating trait-based approaches in studies of arthropods in agricultural catchments. In our context, *P. assimilis* is characteristic of buffered habitats and likely contributes to natural pest control due to its wide feeding spectrum and high abundances. As such, it serves as a clear example of the utilitarian value of forested riparian buffers in agricultural catchments. The low relative abundance and frequency of most other species, likely reflect normal community dynamics, where a few species, like *P. cupreus*, *P. assimilis,* dominate, while others are naturally less common. The sub dominance of *A. dorsalis* in matrix sites can be attributed to some evolutive adaptations of this species. Individual of *A. dorsalis* have been documented to be specialized aphid consumers, beneficial for pest control (Knapp, 2016; Kosewska and Nietupski, 2015) and perhaps the most resilient natural enemy with regard to agricultural land-use changes and pesticide use (Brygadyrenko et al., 2021). The species is extremely well adapted to starvation, with feeding gaps of individuals reported for as long as 218 days (Knapp, 2016). Individuals of the species seem to be extremely well adapted to avoid predation by implying a multitude of strategies, both morpho-physiologically such as aposematism (e.g., body odor defenses), as well as behavioral, such as fast hiding and aggregative strategies

(Brandmayer et al., 2006; Brygadyrenko et al., 2021; Knapp, 2016;). The species is one of the few among Carabidae that often aggregate, in its case, with individuals from genus Chlaenius, as also shown by our findings (Table 2 and Figure 4), strategy which increases their resistance to predators given the explosive defense strategy of Chlaenius (Brandmayer et al., 2006).

The more common occurring taxa from the Trechinae subfamily include individuals mostly associated with riverine habitats, such as Bembidion, Tachys and Ocys (Turin, 2000). Due to the reduced size of these carabids, it may be possible for the subfamily be underrepresented in our samples. The high frequency and abundance of *B. lampros,* preponderantly within matrix sites, is consistent with reports from literature which refer the species as mostly an open habitat specialist, often abundant in agricultural patches, feeding on aphids and lepidopteran larva (Mitchell, 1963). The species has been documented to exhibit a higher-than-average resistance to starvation (Petersen, 1999), a common characteristic reported for dominant species in matrix sites. *T. carpathicus* and *T. pilisensis* were sparse in the catchment, with the first also being endemic to the Romanian and Ukrainian Carpathian Range. Both species are strongly associated with old forests, humid conditions (Ciubuc, 2021) and have been encountered solely at higher altitudes.

By the contrary, *H. griseus* and *H. rufipes* are two of the most common and abundant species found in open habitats of agricultural landscapes (Farinós et al., 2008; Matalin, 1997; Tallósi et al., 2008). Both members of the Harpalinae subfamily are often found together, with one usually dominant and the other subdominant (Andrici et al., 2015; Farinós et al., 2008; Talmaciu et al., 2016; Talmaciu and Talmaciu, 2005; Varvara et al. 2001). Research results are divided regarding the dominance of one over the other and to the cause of such responses. Most findings seem to indicate that ratios between the two species fluctuate in response to habitat particularities, landscape characteristics, as well as seasonal and annual weather conditions (Farinós et al., 2008). Both species are known to be omnivorous and have a long history as predators of invertebrate pest, mainly aphids, slugs and flies (Farinós et al., 2008; Luff, 1980; Monzó et al., 2011), and, to a lesser extent, contribute to weed control by consuming seeds (Gaba et al., 2019; Harrison and Gallandt, 2012). However, some reports of crop damage also exist (Gîdei and Popescu, 2012). Generally, it is considered that *H. grisus* is less common than its sibling (Ciubuc, 2021), as some sources classify it as stenotopic and more attracted to less disturbed habitats within agricultural landscapes (Desender and Turin, 1989; Tallósi et al., 2008). This is also the case in our catchment since the species is dominant and have the highest abundance in buffered sites. Of the two, *H. rufipes* is undoubtedly the most studied, as research of its potential for pest control (Luff, 1980) and response to insecticides is around half a century old (van Dinther, 1963) and since individuals of the species were extensively observed in multiple studies related to carabid migration (Matalin, 1992) and bioindication (Allegro & Sciaky, 2003; Sipos et al., 2024). The other species of the subfamily were much less abundant and widespread, however, equally of interest from scientific and conservation standpoints. *H. affinis* is an adaptable, polyphagous species, primarily associated with open and dry agrarian habitats, and has been extensively studied for its broad-spectrum weed seed predation. *S. teutonus* and *D. germanus* were among the rarest occurring species we identified. However, *S. teutonus* is an agrobiont species used as a bioindicator of crop habitats quality, found in spring in organic, biodynamic agroecosystems, or set-aside field for the purpose of regional biodiversity. Though documented to exhibit a strong affinity for open and sparsely vegetated habitats, it was also documented in riverine habitats and even in the presence of arboreal vegetation since it may be attracted by supplemental food sources available in edge habitats (Turin, 2000). The presence of this species in buffer sites support its bioindicator value within agricultural catchments. The presence of *D. germanus* in the matrix sites, can be indicative of lack or reduced use of pesticide. Historically abundant in crops and open habitats, the species significantly declined within its distribution range to the point where it has become endangered and rare in its European habitats (Müller-Motzfeld, 2023). The increased use of pesticides and other intensive practices, such as lack of reserve patches, riparian included, or intensive tillage represent some of the main drivers of biodiversity decline within agricultural landscapes. Preservation of riparian buffers should be prioritized among agricultural catchments as one of the most effective means of producing more sustainable crops and food for the human population. *Chlaenius nitidulus* is a riparian specialist frequently associated with moist and open habitats (Stančić, 2010; Turin, 2000), features also supported by our findings. As most species from its subfamily to be found within our studied catchment, it is regarded as stenotopic and fairly rare among carabid communities in general (Boscaini et al., 2000; Kędzior et al., 2016). *Chlaenius spoliatus,* also associated with riparian habitats, has been reported as relatively frequent, but typically occurs in low abundances within wetland carabid communities (Boscaini et al., 2000; Cardarelli & Bogliani, 2014). Its scarcity appears to be a species-specific trait, and with other confamilial taxa, highlights the potential importance of non-forested riparian habitats in supporting specialized predators along riverine corridors. *C. lunatus* represents the rarest species of its subfamily found within our study catchment and one of the rarest of Chlaeniinae in general, however not protected. It is an open habitat specialist, usually found in xerophilous meadows and places with chalky soils (Gîdei & Popescu, 2012).

Licinus depressus is a stenotopic, xerophilous species, known to prefer chalky soils and generally associated with open, as well as, sparsely or mildly vegetated habitats (Brygadyrenko, 2015). Individual of the species are well documented feeding specialists, known to voraciously attack and consume land snails (Baur et al., 2023). Though their hunting strategy and feeding preference have been thoroughly addressed, we were unable to find any research where the species has been clearly referenced or used as a biological control agent. We argue this may be due to the generally reduced abundances of *L. depressus* reported throughout various habitats (Brygadyrenko, 2015), also recorded in our research area. Contrarily, *B. bipustulatus* is a highly eurytopic and hygrophilous species, relying extensively on scavenging and widely used as indicator of land use change, especially of urbanization (Brygadyrenko, 2015). The species has been used as a pest predator and is seemingly more resistant than other carabids to the effect of pesticides (Brygadyrenko, 2015). In our agriculturally dominated catchment, this species is rare and sporadic, likely as a result of multiple interacting factors, including the absence of urban habitats in the immediate vicinity of the sampling sites and competition with better adapted species within the areas sampled.

The prevalence of the bombardier beetle, *B. crepitans*, in agricultural habitats aligns with previous reports (Brigić et al., 2009; Fiera et al., 2013; Varvara, 2016). While the species shows a preference for dry, open habitats, it is not restricted to them, as it has also been recorded in forested habitats (Varvara and Șerban, 2002). Notably, this is the only species we found that develops as larval ectoparasite of other carabids, mainly of the genus *Amara,* with which it commonly co-occurs (Saska & Honek, 2004; Saska & Honek, 2008), a pattern also noticed in our samples. The species does not pose conservation concerns, yet some sources mention its potential for crop pest control either during larval and adult stages (Saska & Honek, 2004).

The distribution and abundance of *B. cephalotes* within the middle catchment of Argeș are somewhat unexpected given the usual preference of this stenotopic species for relatively dry, open habitats and to a lesser extent for densely vegetated habitats (Matalin & Budilov, 2003). Generally, it usually occurred as subdominant in their respective communities (Aleksandrowicz et al., 2009; Lövei, 1984; Sorokin, 1981). Especially in unbuffered habitats, its presence can be reduced by competition with often co-occurring, eurytopic and more voracious species such *as P. cupreus* (Kabacik-Wasylik, 1971). Its use as a pest control agent may be hindered by its reduced effectives and high plasticity in feeding behavior (Mossakowski, 2003). However, multivoltine development of the species (Matalin & Budilov, 2003) might provide an advantage to pest predation (Kabacik-Wasylik, 1971; Mossakowski, 2003) when competition is lower. We found only a few individuals of the Lebiinae subfamily, all in poor condition and unidentifiable to species level. Individuals of the genus *Syntomus* are typically small and usually very mobile (Turin, 2000). Due to the taxonomic uncertainty and their overall reduced abundance, we cannot asses their significance to our research. However, it is worth noting that all the documented European species are carnivorous (Turin, 2000) and in our case, they were most abundant and widely distributed in buffered and forest sites. This pattern may further support the role of such riparian habitats in enhancing the diversity and effectiveness of natural pest control.

CONCLUSIONS

Our main findings align with the central tendencies of previous research, with increased diversity of stenotopic, rare and protected species recorded in buffered riparian habitats. In addition to their contribution to the overall species diversity within the catchment, despite the lower relative abundances, buffered riparian zones supported a more diversified array of specialized predators known as some of the most efficient crop pest predators.The occasional or accidental occurrence of certain vulnerable species, many with limited geographic ranges, highlights the urgent need for conservation efforts not only along the headwaters and downstream riparian zones, but also in adjacent habitats where biodiversity regulations have historically been scarce. Sustainable practices, such as promoting biological control through natural pest predators and preserving of buffered riparian habitats, should be widely adopted in agricultural landscapes, where both crops and biodiversity face growing threats from pollution, invasive species and other anthropogenic pressures.

Other landscape features, such as set aside fields or, at least, patches spared of intensive agriculture, can also contribute significantly to overall landscape diversity.

Future research on carabid communities within the Middle Argeș catchment should include a detailed analysis of functional traits and diversity metrics, while also prioritizing the identification of key environmental variables that shape their dynamics. This approach is essential for advancing our understanding of their ecological roles and for emphasizing the importance of riparian zone conservation as a sustainable land management practice.

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