

## Article

# Riparian Ground Beetles (Coleoptera) on the Banks of Running and Standing Waters

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**Abstract:** Rivers and their floodplains offer a wide variety of habitats for invertebrates. River ecosystems are subject to high anthropic influence: as a result the channel morphology is changed, swamps are drained, floodplains are built up, and rivers are polluted. All this has radically changed the environment for the inhabitants of the floodplains, including riparian stenotopic species. Although riparian arthropods are oriented primarily to the production of hydro-ecosystems, the type of water body—lentic or lotic—has a determining effect in the structure of communities. Most riparian arthropods have evolutionarily adapted to riverbanks with significant areas of open alluvial banks. This paper considered the structure of assemblages of ground beetles associated with the riverbanks and the shores of floodplain lakes and their differences. The banks of rivers and the shores of floodplain lakes were considered separately due to the differences in the habitats associated with them. Our results showed that riverbanks, which experience significant pollution, were actively colonized by vegetation and were unsuitable for most riparian ground beetles. The shores of floodplain lakes, being an optional habitat for riparian arthropods, cannot serve as refugia. Thus, the transformation of floodplain landscapes and river pollution creates a problem for the biological diversity of floodplain ecosystems, since riparian stenotopic species of the riverbanks become rare and disappear.

**Keywords:** riverbanks; floodplain lakes; Carabidae; stenotopic species; assemblage; overgrown

## 1. Introduction

Rivers with their floodplains are some of the most diverse and biologically productive ecosystems on Earth [1,2]. At the same time, they are among the most vulnerable [3–5]. Unlike the seas and oceans, river ecosystems are highly dependent on the state of their floodplains. This dependence is magnified in small rivers.

The dependence of the water quality in rivers on the state of the floodplain ecosystems is obvious today. In the 20th century, rivers, having lost their function as suppliers of water and food (a civilizational function), were turned into objects for recreation and sport fishing, and became receptors of wastewater from enterprises and municipal treatment facilities. River valleys include residential areas, agricultural lands, and industrial enterprises.

Since the 1950s, as a result of drainage, a strong degradation of floodplain ecosystems, with loss of their characteristic mosaic of water and land habitats and a decrease in biodiversity, has been observed

in Ukraine. Effluent has led to a drop in the water quality and an increase in the trophic status of most rivers, resulting in a significant decrease in their self-cleaning potential. River pollution has also promoted a change in the quality of the banks and overgrowth of vegetation.

A feature of intact lowland rivers is the presence of various coastal elements, with a significant part composed of open alluvial sandbars, constituting a unique biotope [6]. Over millions of years, wandering riverbeds, changing direction, left numerous meanders, which, over time, lost their connection with the channel, turning into floodplain lakes.

The banks of rivers and floodplain lakes are unique ecotones which form a complex gradient between aquatic and terrestrial ecosystems [7,8]. Ecotones in floodplains exist at the boundary between land and water, and between surface waters and groundwaters [9,10]. Unique communities are found on the banks of the rivers [11,12], the representatives of which are spatially limited by the shoreline and mainly trophically oriented to the production of the hydro-ecosystem [13–16]. Among riparian arthropods, ground beetles, staphylinids, and spiders have great species diversity [17–19]. Riparian arthropods are an important component of the diversity of floodplain ecosystems [20,21]. At the same time, most specialized riparian arthropods, unlike floodplain species, are unable to survive under the conditions of anthropically monotypic banks, which lack a habitat for riparian species, i.e., alluvial deposits. Since the end of the 1990s, regulation of river flows to increase the stability of bars has contributed to the succession of vegetation and has affected the communities of open sand sediments [22,23]. On anthropically altered rivers, many species, especially highly specialized ones, have become rare and disappeared in the absence of refugia. Since the end of the 1980s, there has been a significant reduction in the number of species typical of open riverbanks, some of which have become endangered in many European countries [24–27]. The changes caused by anthropic pressures on river ecosystems (water pollution, loss of riverine habitats) in many cases do not apply to floodplain lakes and oxbows. As a rule, wastewater is discharged mainly into flowing water bodies (rivers and streams), while the floodplain water bodies experience mainly recreational pressure and are rarely used for fish farming. This suggests that the shores of lakes could potentially act as refugia for riparian species.

Understanding how riparian species can adapt to different types of water bodies and their banks and shores, whether there are species common to the shorelines of riverbed and lakes (riparian and littoral zones), and whether riparian species can survive unfavorable periods on the littoral of lakes is important for conservation of biodiversity of the river valleys.

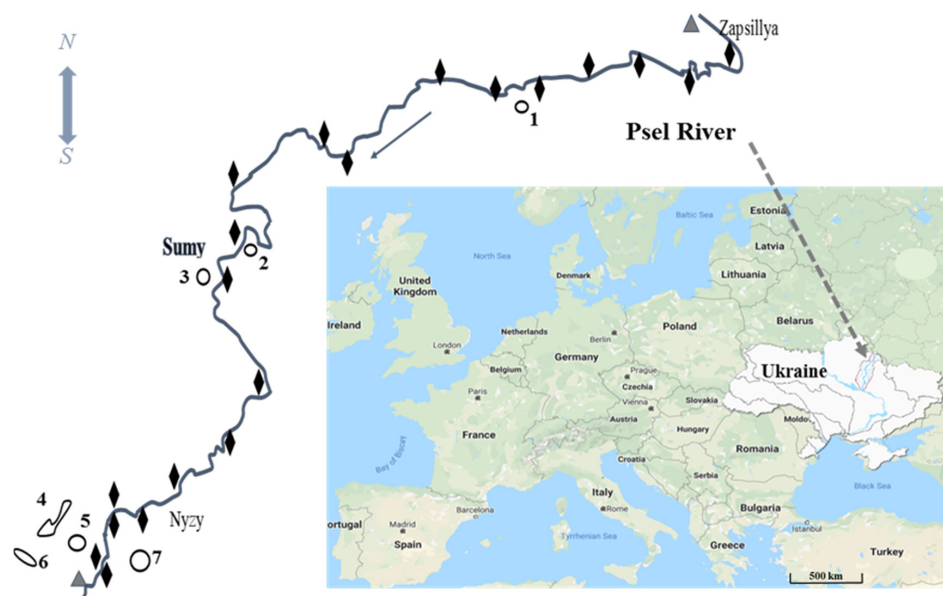
Most works to date are devoted to the study of the diversity of riparian arthropods of lowland and mountain rivers [16,28–33] and to the influence of changes in river hydrology on soil invertebrates [34–37], and little is known about the terrestrial fauna in the banks of stagnant water bodies [38–42].

In this study, using ground beetle assemblages, the following questions are addressed. The first relates to the extent to which banks of flowing and stagnant reservoirs of one flat river system differ in the composition and structure of the arthropod communities. The second is whether the shores (littoral) of floodplain lakes act as refugia for riparian species, i.e., whether they can preserve the diversity not only of floodplain species, but also of specialized riparian species.

## 2. Materials and Methods

### 2.1. Study Area

The study was conducted in a 80-km section of the Psel River (starting with Zapsillya), a first-order tributary of the Dnieper River, in the Sumy region (northeastern Ukraine, Figure 1). In the transverse profile of the studied section, alder forests grow on the wetlands situated near terraces, while oak forests, wet meadows, and riparian shrubs grow in the central part of the floodplain. There also are patches of artificial plantations: trees (birch, oak, pine) and shrubs (hazel, common ninebark). Part of the floodplain has been reclaimed and turned into meadows.



**Figure 1.** The study area, with the location of river stations (marked by black rhombs) and floodplain lakes (1–7) surveyed in the Psel River. The arrow indicates the river flow direction; the grey triangles are marked the study section; the dashed arrow shows the study area in the river basin of Psel.

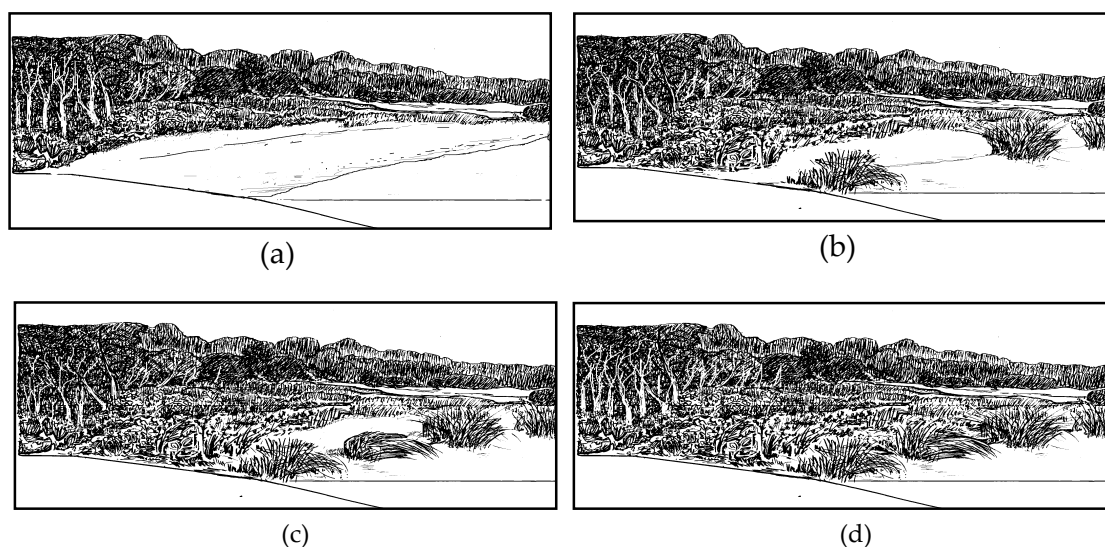
The study included various habitats of the channel of the Psel River, covering the riverbed form units (open sand bars, referred to as exposed riverine sediments, ERS, by other researchers), which alternate with sections of the bank overgrown with different levels of vegetation (vegetated bars). A part of the open banks has been colonized by vegetation. At the same time, the open sandy riverbanks accounted about 40%.

Considering the vegetation cover on sandy and silted riverbanks (or bars) as a gradient, the following three stages of overgrowth by vegetation were distinguished [43]: stage 1—appearance of small spots of higher aquatic vegetation along the shoreline and solitary land plants; stage 2—expansion of terrestrial grassy vegetation on the surface of the bank and plant coverage of about 50% of the shoreline; and stage 3—complete coverage of the surface of the bank by grassy and woody–shrubby vegetation and almost complete separation of the dry land from the shoreline by the higher aquatic vegetation (Figure 2).

The choice of stations along the river was determined by the presence open bars and banks with varying degrees of vegetation coverage development. Accordingly, the distances between the 20 stations on the riverbanks (Figure 1) were not equal, ranging from 5 to 20 km.

The floodplain lakes under study are separate from the riverbed by different distances—from 100 to 300 m (Figure 1). These lakes are either mesotrophic or eutrophic and are 1.5 to 7 m deep. The lakes shores are mostly covered with vegetation and the few sections of the open shore are either silted alluvial sediments or alluvium covered with a layer of plant debris. The shores of oxbow lakes were analyzed in terms of their openness/closeness and categorized into shores overgrown with meadow hygrophytic vegetation (opened habitats) and those with trees and shrubs (closed).

Thus, the banks of the riverbed at different stages of vegetation cover development and the shores of floodplain lakes (opened and closed) were considered as separate types of habitats.



**Figure 2.** A graphical representation of the stages of overgrowth by vegetation of open alluvial bars along the riverbanks: (a) open sand bar (ob), (b) stage 1 (os1), (c) stage 2 (os2), and (d) stage 3 (os3) of overgrowth.

## 2.2. Sampling Methods

Sampling was conducted from April to October in 2008–2010 at 27 stations, with 20 along the banks of the river and 7 in the shores of the floodplain lakes. The beetles were collected using pitfall traps with 0.3-L plastic cups (diameter 7.2 cm) partly filled with a preserving solution. The traps were set parallel to the shoreline: 15 traps in three rows in accordance with the width of each station. Samples were collected 7 days after the installation of the trap, twice a month.

Carabid beetles were identified to the species level [44,45]. The species were classified as “riparian” based on the previous studies [43]. The concept of riparian, as used here, means that the species mainly or exclusively occurs in riverbanks with open riverine sediments [20,46]. The groups of species associated with the floodplain and the shores of floodplain lakes were also distinguished.

## 2.3. Data Analysis

A matrix containing the data on the abundance of 95 species of ground beetles in the 27 stations studied was used for analysis. The abundance for each species was averaged over habitats and years to obtain the average statistical density of each population.

Non-metric multidimensional scaling (NMDS) was used to uncover variation in beetle assemblages among stations and habitats and to analyze the patterns of the spatial distribution of ground beetles across the floodplain Psel River. This method is especially suitable for environmental data [47–50]. The Kulczynski distance was used, because it has shown good results in the biological and environmental applications [51–55]. The data on ground beetles abundances were Hellinger-transformed. The data analysis was performed in R through the core and vegan packages [56]. The results were plotted through the ggplot2 package [57].

## 3. Results

During the study period, a total of 95 species of ground beetles from 32 genera were recorded (Table 1). The largest numbers of species were found for the genera *Bembidion* (21 species), *Pterostichus* (9), *Agonum* (7), *Dyschirius* (5), and *Badister* (5). In overall, 81 species were recorded on the banks of the river and 51 species on the shores of floodplain lakes. Moreover, 36 species (38% of the total number of species) were found in both types of habitats.

**Table 1.** Ground beetles species caught on the banks of the river Psel and the shores of floodplain lakes, with their frequencies of occurrence (%) in the habitats and codes. Species are grouped according to their habitat requirements. rip: riparian, lit: littoral.

Species and Their Codes		River Banks		Shores of Lakes		Habitat Requirements
		Open Bars	Stages 1–3, Backwaters	Open	Closed	
<i>Agonum impressum</i>	Ag.impr	-	100	-	-	rip
<i>Asaphidion flavipes</i>	As.flav	22.1	77.4	-	0.5	rip
<i>Bembidion argenteolum</i>	Be.arage	100	-	-	-	rip
<i>Bembidion azurescens</i>	Be.azur	55.7	44.3	-	-	rip
<i>Bembidion cruciatum</i>	Be.andr	100	-	-	-	rip
<i>Bembidion femoratum</i>	Be.femo	86.8	13.2	-	-	rip
<i>Bembidion laticolle</i>	Be.lati	100	-	-	-	rip
<i>Bembidion litorale</i>	Be.lito	96.5	3.5	-	-	rip
<i>Bembidion ruficolle</i>	Be.rufi	100	-	-	-	rip
<i>Bembidion semipunctatum</i>	Be.semi	66.7	33.3	-	-	rip
<i>Bembidion tenellum</i>	Be.tene	25.0	75.0	-	-	rip
<i>Bembidion tetracolum</i>	Be.tetr	43.4	54.1	-	2.4	rip
<i>Bembidion varium</i>	Be.vari	73.1	27.7	-	0.9	rip
<i>Chlaenius nitidulus</i>	Ch.niti	43.	57	-	-	rip
<i>Cicindela hybrida</i>	Ci.hybr	-	100	-	-	rip
<i>Dyschirius aeneus</i>	Dy.aene	7.3	53.3	39.5	-	rip
<i>Dyschirius arenosus</i>	Dy.aren	82.5	16.7	-	0.8	rip
<i>Dyschirius neresheimeri</i>	Dy.nere	100	-	-	-	rip
<i>Dyschirius nitidus</i>	Dy.niti	72.7	27.3	-	-	rip
<i>Elaphrus riparius</i>	El.ripa	75.6	24.4	-	-	rip
<i>Omophron limbatum</i>	Om.limb	65.4	34.6	-	-	rip
<i>Badister dilatatus</i>	Ba.dila	-	-	-	100	lit
<i>Badister peltatus</i>	Ba.pelt	-	47.3	29.5	23.2	lit
<i>Badister sodalis</i>	Ba.soda	-	-	-	100	lit
<i>Bembidion assimile</i>	Be.assi	1.1	7.1	85.6	6.1	lit
<i>Bembidion biguttatum</i>	Be.bigu	0.7	6.7	-	92.6	lit
<i>Bembidion dentellum</i>	Be.dent	10.6	9.2	-	80.2	lit
<i>Bembidion doris</i>	Be.dori	11.4	13.6	49.2	25.8	lit
<i>Elaphrus cupreus</i>	El.cupr	9.2	6.9	20.6	63.3	lit
<i>Philorhizus spilotus</i>	Ph.spil	-	-	-	100	lit
<i>Stenolophus skrimshirani</i>	St.skri	-	-	66.7	33.3	lit
<i>Abax parallelopipedus</i>	Ab.ater	-	59.0	-	41.0	
<i>Abax parallelus</i>	Ab.para	-	19.4	-	80.6	
<i>Acupalpus flavicollis</i>	Ac.flav	31.0	69.0	-	-	
<i>Agonum duftschmiedi</i>	Ag.duft	-	100	-	-	
<i>Agonum fuliginosum</i>	Ag.fuli	1.8	2.3	19.2	76.7	
<i>Agonum moestum</i>	Ag.moes	-	23.1	-	76.9	
<i>Agonum sexpunctatum</i>	Ag.sexp	-	100	-	-	
<i>Agonum versutum</i>	Ag.vers	100	-	-	-	
<i>Agonum viduum</i>	Ag.vidu	-	100	-	-	
<i>Amara communis</i>	Am.comm	-	48.7	51.3	-	
<i>Amara eurynota</i>	Am.eury	-	100	-	-	
<i>Amara ovata</i>	Am.ovat	-	21.1	-	78.9	

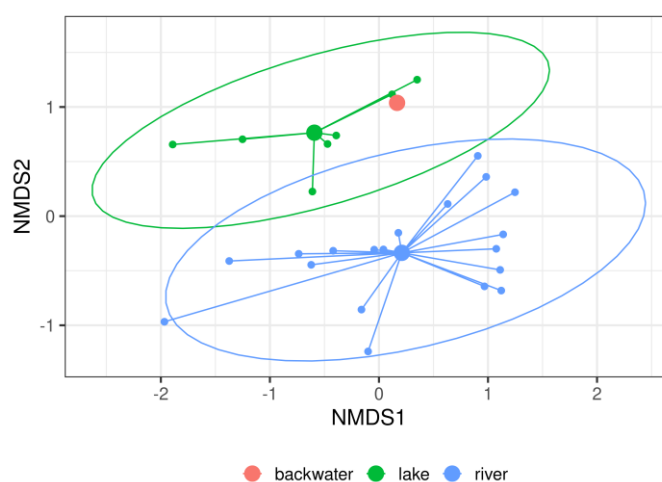
Table 1. Cont.

Species and Their Codes		River Banks		Shores of Lakes		Habitat Requirements
		Open Bars	Stages 1–3, Backwaters	Open	Closed	
<i>Anisodactylus binotatus</i>	An.bino	-	-	100	-	
<i>Anisodactylus nemorivagus</i>	An.nemo	-	-	100	-	
<i>Anisodactylus signatus</i>	An.sign	-	100	-	-	
<i>Anthracus consputus</i>	An.cons	47.8	52.2	-	-	
<i>Badister bullatus</i>	Ba.bull	-	62.7	-	37.3	
<i>Badister unipustulatus</i>	Ba.unip	-	-	-	100	
<i>Bembidion articulatum</i>	Be.arti	45.1	30.3	23.8	0.7	
<i>Bembidion lampros</i>	Be.lamp	33.9	66.1	-	-	
<i>Bembidion octomaculatum</i>	Be.octo	26.4	73.6	-	-	
<i>Bembidion obliquum</i>	Be.obli	100	-	-	-	
<i>Bembidion properans</i>	Be.prop	-	100	-	-	
<i>Bembidion quadrimaculatum</i>	Be.quad	23.5	76.5	-	-	
<i>Blemus discus</i>	Bl.disc	37.2	62.8	-	-	
<i>Broscus cephalotes</i>	Br.ceph	-	-	-	100	
<i>Carabus cancellatus</i>	Ca.canc	-	100	-	-	
<i>Carabus convexus</i>	Ca.conv	-	100	-	-	
<i>Carabus granulatus</i>	Ca.gran	-	51.6	13.3	35.1	
<i>Carabus menetriesi</i>	Ca.mene	-	100	-	-	
<i>Chlaenius nigricornis</i>	Ch.nigr	89.6	10.4	-	-	
<i>Chlaenius vestitus</i>	Ch.vest	34.7	65.3	-	-	
<i>Clivina collaris</i>	Cl.coll	-	100	-	-	
<i>Clivina fossor</i>	Cl.foss	41.1	38.4	-	20.5	
<i>Cymindis axillaris</i>	Cy.axil	-	-	100	-	
<i>Dyschiriodes globosus</i>	Dy.glob	23.0	23.5	6.0	47.6	
<i>Epaphius secalis</i>	Ep.seca	2.0	10.9	-	87.1	
<i>Harpalus affinis</i>	Ha.affi	50	50	-	-	
<i>Harpalus distinguendus</i>	Ha.dist	-	100	-	-	
<i>Leistus terminatus</i>	Le.term	-	100	-	-	
<i>Loricera pilicornis</i>	Lo.pili	-	18.0	51.3	30.8	
<i>Notiophilus palustris</i>	No.palu	-	100	-	-	
<i>Oodes gracilis</i>	Oo.grac	-	-	-	100	
<i>Oodes helopioides</i>	Oo.helo	1.0	8.3	70.3	20.4	
<i>Oxytelaphus obscurus</i>	Ox.obsc	-	100	-	-	
<i>Panagaeus bipustulatus</i>	Pa.bipu	-	-	-	100	
<i>Panagaeus cruxmajor</i>	Pa.crux	-	30.9	27.6	41.4	
<i>Patrobus atrorufus</i>	Pa.atro	-	-	-	100	
<i>Poecilus cupreus</i>	Po.cupr	100	-	-	-	
<i>Platynus assimile</i>	Pl.assi	4.4	64.0	3.5	32.5	
<i>Pterostichus anthracinus</i>	Pt.anth	8.9	23.0	14.7	53.4	
<i>Pterostichus gracilis</i>	Pt.grac	-	-	-	100	
<i>Pterostichus melanarius</i>	Pt.mela	-	69.2	-	30.8	
<i>Pterostichus minor</i>	Pt.mino	5.0	17.0	52.6	25.3	
<i>Pterostichus niger</i>	Pt.nige	1.7	98.3	-	-	
<i>Pterostichus nigrita</i>	Pt.nigr	1.4	17.2	32.4	50.0	
<i>Pterostichus oblongopunctatus</i>	Pt.oblo	1.8	59.4	-	39.8	
<i>Pterostichus strenuus</i>	Pt.stre	5.8	72.6	-	21.6	

Table 1. Cont.

Species and Their Codes		River Banks		Shores of Lakes		Habitat Requirements
		Open Bars	Stages 1–3, Backwaters	Open	Closed	
<i>Pterostichus vernalis</i>	Pt.vern	-	15.6	-	84.4	
<i>Stenolophus mixtus</i>	St.mixt	11.2	13.8	75.0	-	
<i>Stenolophus teutonius</i>	St.teut	54.5	-	-	45.5	
<i>Trechus quadristriatus</i>	Tr.quad	-	-	-	100	
<i>Trichocellus placidus</i>	Di.plac	-	100	-	-	
<i>Trichocellus rufithorax</i>	Di.rufi	-	100	-	-	

The NMDS on the abundances of ground beetles among stations showed major differences between assemblages in the banks of the river and in the shores of the floodplain lakes (Figure 3). It also highlighted that the conditions in the backwaters of the river, where the flow rate is slowed down and the substrate is silted, are close to those on the shores of lakes.



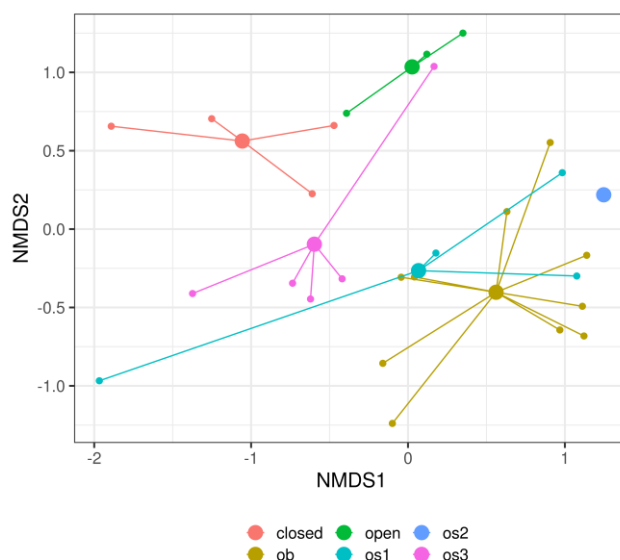
**Figure 3.** Non-metric multidimensional scaling (NMDS) of the Kulczynski distance matrix among ground beetle assemblages on the banks of the Psel River, backwater, and shores of floodplain lakes.

NMDS showed considerable variation between the shores of floodplain lakes (Figure 4, in the upper left quarter of the graph) and the habitats along the riverbanks (in the lower right part of the graph), with riverbanks completely covered by vegetation laying between them (Figure 4, os3). Indeed, the assemblage structure of ground beetles along the banks of the river and floodplain lakes is significantly different (Figure 5).

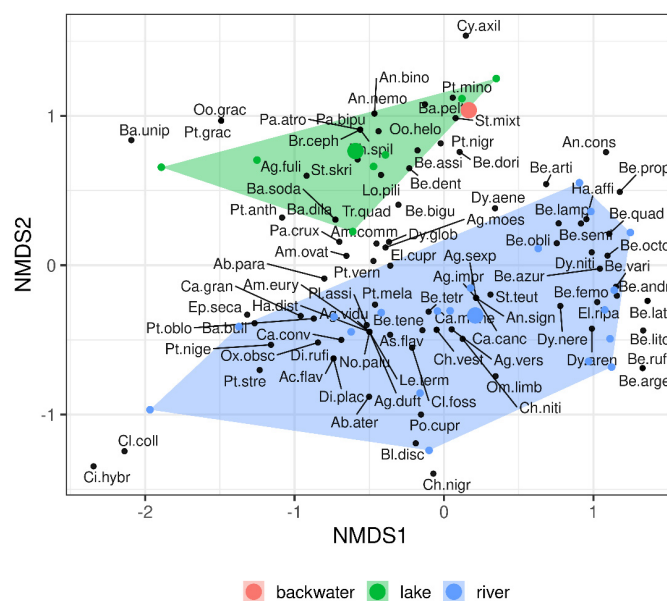
NMDS confirmed that the shores of floodplain lakes clearly differed in the composition of ground beetles from the banks of the channel (Figure 6). Open alluvial banks and sections of the banks with vegetation in the first and second stages of overgrowth were similar in composition. Overgrown riverbanks (stage 3) occupied an intermediate position, while both open and closed habitats on the shores of floodplain lakes are located in the left upper part of the plot (Figure 6).

The riparian and littoral species are represented in variable numbers on the banks of the Psel river and the shores of floodplain lakes (Figure 7). On the banks of the river, 21 riparian species were recorded (22% of the total number of species), of which only five species were found on the banks of floodplain lakes: *Asaphidion flavipes*, *Bembidion tetracolum*, *Bembidion varium*, *Dyschirius aeneus*, *Dyschirius arenosus* (Table 1, Figure 7). Of the 10 littoral species found on the littoral of lakes, six were found in the riverbanks, but in a smaller abundance: *Badister peltatus*, *Bembidion assimile*, *Bembidion biguttatum*, *Bembidion dentellum*, *Bembidion doris*, and *Elaphrus cupreus* (Figure 7).





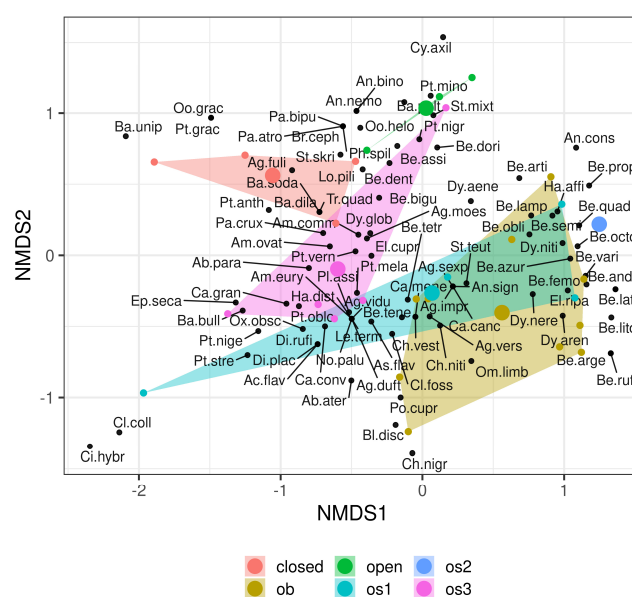
**Figure 4.** NMDS of the Kulczynski distance matrix among habitats located on the Psel riverbanks and oxbow lakes, classified according to plant overgrowth. ob, os1–3: as in Figure 2, open: shores of lakes with meadow vegetation, closed: shores of lakes covered with trees and shrubs.



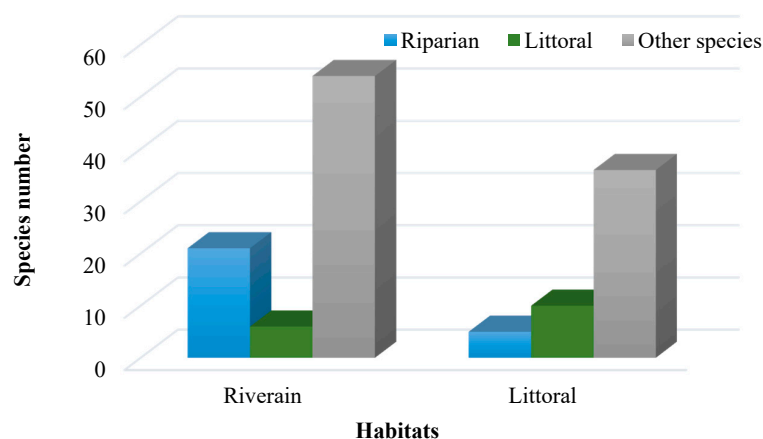
**Figure 5.** Species superimposed on the NMDS plain of the Kulczynski distance matrix among stations located on the riverbanks of the Psel, the shores of lakes, and in backwaters. Code abbreviations of the species are presented in Table 1.

The proportion of riparian and littoral species in the various habitats of riverbanks and shore lakes is significantly different. The proportion of specialized riparian species decreased in succession from the open banks of the river through the three stages of their overgrowth and to the shores of floodplain lakes (Figure 8). Littoral species prevailed in the shores of lakes, but showed tolerance to habitats on the banks of the river (Figure 8). The abundance of riparian species clearly decreased on the shores of floodplain lakes, while that of the littoral species decreased on the open riverbanks (Figure 9).

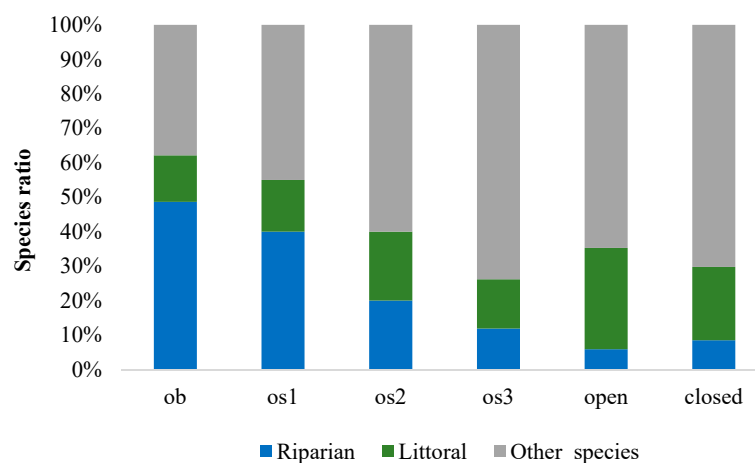




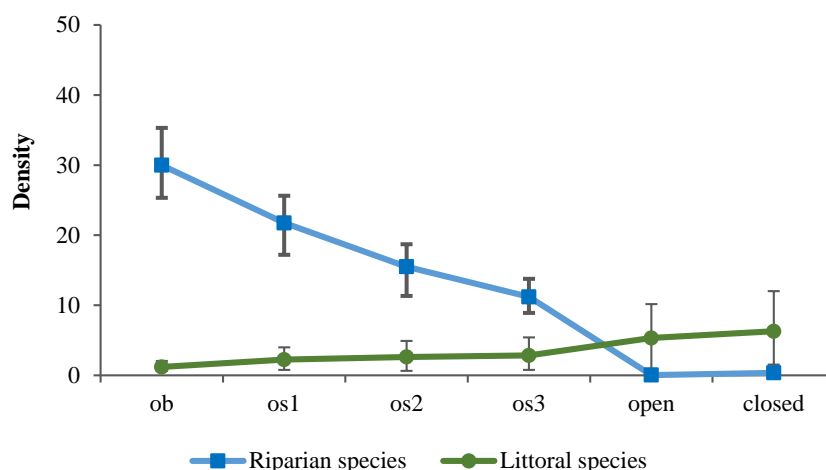
**Figure 6.** Species superimposed on the NMDS plain of the Kulczynski distance matrix among habitats located on the riverbanks of the Psel, oxbow lakes, and backwaters, classified according to vegetation overgrowth (as in Figures 2 and 4). Code abbreviations of the species are given in Table 1.



**Figure 7.** Number of riparian, littoral, and other species on the banks of the Psel River and the shores of floodplain lakes.



**Figure 8.** The proportion of riparian, littoral, and other species in the habitats of the Psel river and floodplain lakes. ob, os1–3, open, closed as in Figures 2 and 4.



**Figure 9.** Density of populations of riparian and littoral species in open bars and the stages of vegetation overgrowth of the Psel riverbanks and the shores of floodplain lakes. ob, os1–3, open, closed as in Figures 2 and 4.

#### 4. Discussion

Due to the constant drift of river channels within their floodplains, the landscape of river valleys is highly dynamic. The main factor determining the dynamics of channel processes and the transformation of shorelines is flood [58,59]. Flooding, regularly repeated on a geological time scale, constantly changes the configuration of the main elements of floodplains. The meanders provide a multitude of habitats that support multiple species with variable life strategies. The diversity of species along riverbanks is associated with a mosaic of habitats [60]. Fragmentation of the habitat also determines the structural organization of beetle assemblages, which usually show a spotted structure [35,61].

Despite the fact that the riparian species are focused on the production of hydroecosystems [13,15,62], and floodplain water bodies, especially shallow ones, are highly productive ecosystems, the structure of the ground beetle assemblages on the banks is determined not so much by the presence of food objects, but by the type (lotic or lentic) and the quality of habitats.

Among the riparian species, a highly specialized group (stenotopic) stands out as adapted to the conditions of river banks [17,20,43,46,63–65]. The riparian species are mainly winged forms that can spread along the river, small in size and with a flattened body [16,66–68].

According to the NMDS results, the banks of the river and the shores of the floodplain lakes clearly differ in the species composition of ground beetles (Figures 5 and 6). The assemblage of ground beetles on the banks of the Psel river contains 21 riparian species (Table 1). Among them, 11 species of the genus *Bembidion* predominate, as also noted by other researchers [36,68,69]. Specifically, in the open banks on the flat Hase River (Germany) 12 stenotopic species were noted [39], nine of which were also recorded on the open banks of the Psel River: *Asaphidion flavipes*, *Elaphrus riparius*, *Bembidion articulatum*, *Bembidion femoratum*, *Bembidion litorale*, *B. varium*, *Dyschirius arenosus*, *D. aeneus*, and *Omophron limbatum*.

Many researchers have noted that riparian species are good indicators of habitat quality and particularly in the structure and quality of alluvial sediments [70,71]. For example, *E. riparius* and *Bembidion semipunctatum* are indicators for sand bars less covered by vegetation, unvegetated, or with mud; *Dyschirius thoracicus* and *Bembidion litorale* are indicators for open sand bars; and *Bembidion cruciatum* and *B. femoratum* are characteristic of less vegetated or unvegetated cobble, gravel, and sand bars [71].

Hydrotechnical transformations of riverbeds and allochthonous organic and inorganic pollution significantly increased the trophic status of most rivers and triggered plant coverage development on the earlier open river sediments. These phenomena have become global. The above factors and the lack of floods lead to development of monotypic conditions along the river banks, which, in turn, lead to changes in the structure of ground beetle communities [27,72,73]. Most researchers confirm a

significant reduction in the number of riparian species [22,23,39,74], many of which are classified as endangered [20,24–27].

As our results have shown, the expansion of vegetation on the open banks of the river significantly affects the species composition and spatial distribution of the riparian ground beetles (Figure 6). The number and density of riparian species decreases with increasing development of the vegetation cover (Figures 8 and 9).

Among 21 riparian species recorded on the banks of the Psel river, only *A. flavipes*, *D. arenosus*, *D. aeneus*, *B. tetracolum*, and *B. varium* tend to spread to the littoral of floodplain lakes. This ability has also been noted for *E. riparius*, *Bembidion articulatum*, and *O. limbatum*, which actively inhabited the open shores of the floodplain lake after its connection with the river was restored [39]. This is important and confirms the tolerance of these species to the conditions of floodplain water bodies.

Most studies distinguish a group of riparian species, the composition of which varies depending on the quality of the banks and the type of river (plain or mountain). There are few studies on species that prefer stagnant water bodies [38,40,41] and analyzing arthropods of river banks and their floodplain lakes in comparative way [39,42,61]. For example, Šustek [42], studying the banks of the Danube and Morava rivers and their lakes, identified 21 ripal species of ground beetles (pp. 136–138), but analyzed their preference for the banks of standing and flowing water. Indeed, the author exclusively analyzed the banks with thickets of *Phragmites australis*, which predetermined the low number of riparian species recorded [42].

During our research, 51 species of ground beetles were recorded on the banks of the floodplain lakes of the Psel river, among which 10 preferred the banks of floodplain lakes (Table 1). The littoral species identified by us were also noted on different types of shores of the floodplain lakes of the Dnieper [40]. Apparently, the possibilities of riparian and littoral species spreading beyond the floodplain are limited. According to Lott [38], no riparian species were recorded on the shore of the studied ponds in England, with the exception of the littoral species *Badister dilatatus*.

Thus, most riparian species are associated with the open banks of flowing water bodies, which makes them extremely vulnerable in the rivers with channels changed by man and lacking their natural characteristics. Riparian species of riverbanks are as a rule not found on the banks of floodplain lakes. They are also rare in the sections of river where riverbank sediments are covered with vegetation. A number of species tolerant to overgrowth, for example, *A. flavipes*, *E. riparius*, *B. articulatum*, *B. tetracolum*, *B. varium*, *D. arenosus*, and *D. aeneus*, are also found on the banks of lakes, especially if they are situated close to the river bed [39,61,75,76]. Obviously, these species use the shores of floodplain lakes as fodder areas. However, the shores of lakes for them are not fully adequate habitats.

## 5. Conclusions

The banks of rivers and floodplain lakes are different habitats, and different assemblages of ground beetles are formed within them. A total of 95 species of ground beetles were found, of which 81 species were found on the riverbanks of the Psel and 51 species were found on the shores of floodplain lakes. Based on the analysis of their spatial distribution, 21 species that prefer the riverbanks and 10 species that prefer the shores of lakes were identified.

Our findings confirm that typically riparian species are associated with open riverbanks, though some species also occurred on the shores of floodplain lakes. Changes in the quality of banks and overgrowth with vegetation due to river pollution leads to a critical reduction in the habitat of riparian species, making them extremely vulnerable. Moreover, since the shores of the floodplain water bodies are only an optional habitat for a sub-set of species, they cannot be considered as refugia for riparian ground beetles. This should be taken into account when developing measures for the renaturalization of rivers and their banks.

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