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RIPARIAN GROUND BEETLES AS INDICATORS OF THE RIVER ECOSYSTEM STATE – THE HYDROLOGICAL REGIME AND MORPHOLOGY OF THEIR CHANNELS

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Abstract. This paper considers the results of studies on the effect of changes in the hydrological regime of the river on the structure and spatial distribution of riparian ground beetles (Coleoptera, Carabidae). To assess changes in the structure of the riparian community, statistical methods from the R version 4.1.1 program were used. This paper presents the results of studying the spatial distribution of typical riparian ground beetles in the riparian continuum of 180 km of the Psel River section (basin of Dnipro, Ukraine), disturbed by the dam of the power plant and hydrotechnical transformations of the banks. The riparian carabid species are relatively well represented in the studied section of the Psel River, often locally. Riparian arthropods are assumed particularly sensitive to hydrological and morphological river modifications. It is shown that the use of ground beetles as biological indicators is especially important on rivers, where dams form reservoirs not of a lake type, but of a channel type. The structure of riparian assemblages of ground beetles makes it possible to establish the spatial boundaries of channel reservoirs and to assess the degree of disturbance of the hydrological regime. Arthropod abundance within the narrow shoreline strip provides the best indicator of potential trophic linkages between the aquatic and terrestrial systems, as trophic interactions occur predominantly close to the shoreline. The use of statistical methods has demonstrated that typical riparian beetles well reflect changes in the geomorphology of the shoreline; respond with changes in the structure of communities to a decrease in the speed of the current and siltation of the riverbanks.
Keywords: riverbanks, flow regulation, hydroelectric dam, Coleoptera, Carabidae, assemblage structure, diversity

1 INTRODUCTION

The scientific and technological revolution and the rapid growth of cities a decrease put the issue of a shortage of high-quality fresh water on the agenda. The problem of the environmental consequences of river regulation was actively discussed in European countries in the 1990s of the 20th century. Most of the rivers have been transformed, and their flow has been regulated (Tockner and Stanford, 2002; Tockner et al., 2006; Zimmerman et al., 2010). All over the world, the issue of surface water quality control has become acute. At the same time, the quality of the aquatic environment is largely determined not only by the processes in the reservoir but also by the processes and quality of the terrestrial ecosystem, especially the banks of rivers.

Numerous anthropic changes in river floodplains are associated with the construction of dams, channel modifications (straightening, strengthening the banks with dams, erosion protection, etc.). The flow patterns of many rivers are changing as a result of withdrawals for irrigation (Tockner and Stanford, 2002), and an increase in the frequency and severity of droughts in many areas is predicted as a consequence of global climate change (Prather et al., 2013).

Numerous runoffs have changed the quality of the water in the rivers and provoked an increase in trophic levels. An increase in river trophic levels also affected terrestrial communities of both vertebrates and invertebrates (Zulka, 1994; Manderbach and Reich, 1995; Lambeets et al., 2008, 2009; Sinnadurai et al., 2016; Kirichenko-Babko et al., 2019). The regulation of river flow has also led to a reduction in biodiversity and the impact of flood-flood disturbance on terrestrial invertebrates in floodplains (Paetzold et al., 2008; Baiocchi et al., 2012; Moran et al., 2012; Lafage et al., 2015). A decrease in river runoff and a violation of the hydrological regime leads to a decrease in the diversity and abundance of larval stages of aquatic insects (Jesus et al., 2004; Dewson et al., 2007; Death, 2010; Fulan et al., 2010; Hauer et al., 2014). However, most of the studies on the impact of disturbances on the hydrological characteristics of rivers are aimed at studying the responses of aquatic invertebrates and fish (Fjellheim and Raddum, 1996; Bredenhand and Samways, 2009; James et al., 2009; Bruno et al., 2010; García et al., 2011). The question of the influence of small hydropower plants on the fauna of ecotone communities remains insufficiently studied.

It is known that disruption of the hydrological regime has a significant impact on the composition of aquatic organisms from protozoa to molluscs and fish (Babko and Kuzmina, 2009). At the same time, the reaction of aquatic organisms to a violation of the hydrological regime is more obvious than the reaction of representatives of the terrestrial fauna. Previously, a response to a change in the hydrological regime under the conditions of run-of-river reservoirs was shown for a population of the stenotopic species, *Omophron limbatum* (Kirichenko and Babko, 2009). Because riparian ground beetles are trophically oriented to the production of aquatic ecosystems, this makes them more dependent on the transformation of hydrobiocenose than is commonly believed.

In 1992, an EU-funded programme was initiated to model the sensitivity of river margin ecosystems to environmental changes at regional and local scales. The European River Margins Programme (ERMAS) established a research network of sites across Europe using clearly defined experimental protocols to develop and test predictive models of important biological processes in relation to hydro-climatic regime (regional scale) and soil: sediment characteristics (patch scale).

All this provoked the development of methods for monitoring the quality of the aquatic environment. In control systems, more attention is paid to the analysis of biological diversity as the most significant criterion. Increasingly diverse groups of organisms are being recruited as bioindicators. The effectiveness of bioindications largely depends on the choice of objects, their sensitivity, and their significance in ecosystem processes. In this context, the quality of the aquatic environment is largely determined not only by the processes in the reservoir but also by the processes and quality of the terrestrial ecosystem, especially the riverbanks.

2 METHODS

2.1 Study area and sampling methods

A segment of the Psel (tributary of river Dnipro), a length of about 180 km, from Myropillia to the Petrenkove (Sumska oblast, Ukraine) was investigated (Figure 1). The first section (about 50 km) is located from the village Myropillia to city Sumy. In this section, the hydrological regime is almost not disturbed and there are no settlements in the river valley. The second section captures the Sumy city and continues to the village Nyzy. This site is a run-of-river reservoir, which have for 40 km. The third section is represented by the run of river reservoir with a total length of about 40 km. We studied the upper section of this reservoir about 15 km below the dam.

The sites on the Psel are large and geomorphologically complex. Morphological categories of riverbank were ranked as following: sandy bars, low banks, and high banks. A total 38 sampling sites were investigated: 20 sandy bars, 5 sites of low banks, 2 high banks, 6 sites of scarp and 4 sites of rampart. These sites were placed randomly within study section upper and lower on the different distances from the hydroelectric power station (HPS, vil. Nyzy). The banks in the studied section of the river had a thin grassy cover.

The beetles were sampled using pitfall traps and direct hand searching techniques using an aspirator. Ground beetles were sampled using plastic pitfall traps that were arranged parallel with the waterline – 15 pitfall traps in each site and filled with drop of detergent. The abundance of the ground beetles was standardized by the number of trap-days.

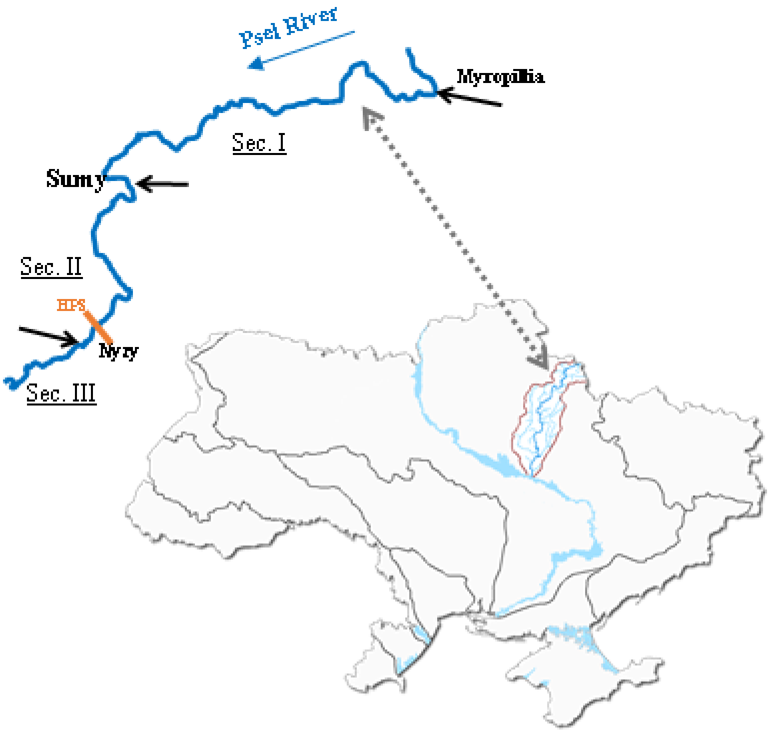


Figure 1. Scheme of the research area and the location of sampling section of Psel River. A dashed arrow indicates the location of the study area on the map. The direction of the river flow is shown by blue arrow. The black arrows show the division of the riverbed into sections with different hydrological regimes: Sec. I – III. HPS – hydroelectric power station that located in the vil. Nyzy

2.2 Statistical analysis

The multidimensional scaling method was used to describe patterns of changes in the spatial distribution of coastal ground beetles in relation to the studied sections of the river channel. We used non-metric multivariate scaling (nMDS) because it is particularly suitable for environmental data and provides a stress factor that indicates ordination stability (Krijthe, 2015). NMDS was applied with measures of similarity: Bray Curtis to assess why sample areas were split. The Bray-Curtis measure is the most popular abundance indicator used in biological and environmental applications.

In addition, a hierarchical cluster analysis was performed. All sampling sites were grouped based on their similarity in ground beetle occurrence using the following similarity indices: Bray-Curtis and Ward's method. Hierarchical cluster analysis with Ward's agglomeration method is often used with Euclidean metrics. Grouping individuals using this method tends to minimize intra-group variance (Maechler et al., 2021). The above mentioned analysis were performed using the R-core (https://www.R-project.org).

3 RESULTS AND DISCUSSION

In total, 21 species of riparian ground beetles were collected on the site of the Psel River. These species are widespread on the banks of the plain rivers of Europe (Gerisch, 2011; Gerisch et al., 2012a, 2012b; Royan et al., 2015; Jachertz et al., 2019; Kirichenko 2000; Kirichenko and Babko, 2009; Kirichenko-Babko et al., 2020).

The studied sections of the river differ significantly in hydrological conditions, that it can be assumed that the structure of riparian ground beetles may also differ. As a primary hypothesis, we assume the presence of at least three different configurations in the structure of the assemblage of riparian ground beetles. The Gap statistic method quite confidently showed agreement with the primary hypothesis about the possible division of the data array into three groups of habitats in accordance with the characteristics of the hydrological conditions in the studied sections of the river: a segment with undisturbed hydrological conditions, the upper reaches of the first and second reservoirs, respectively (Figure 2).

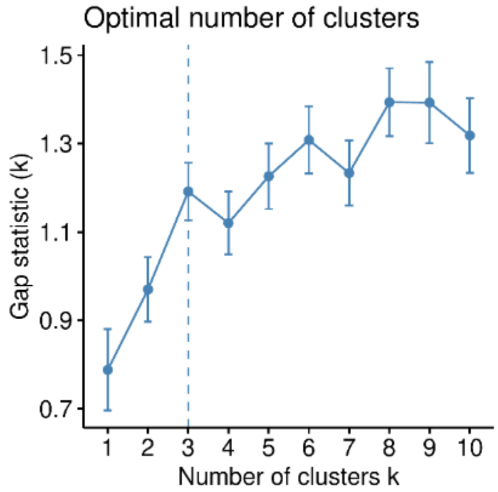
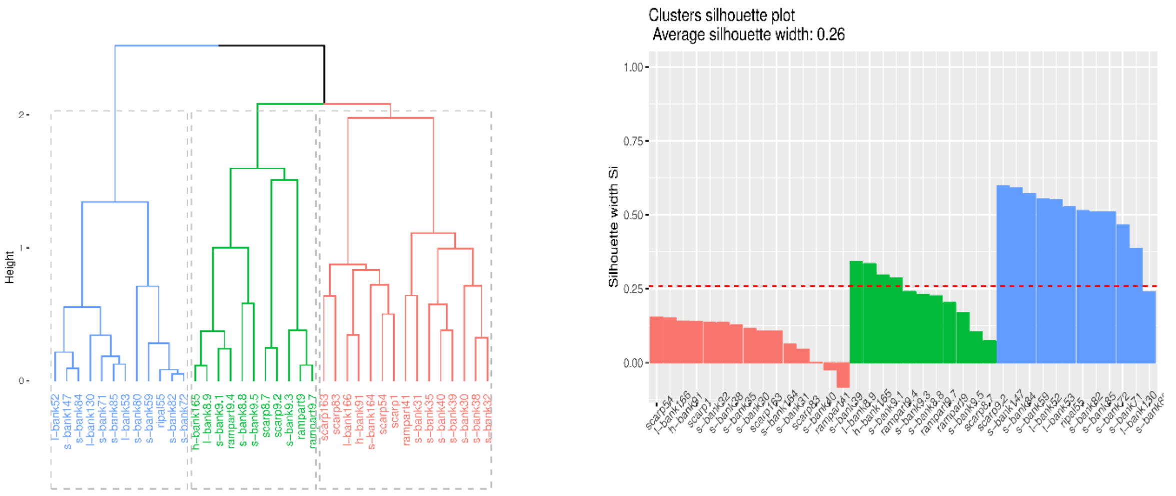


Figure 2. Diagram for data species on the base method Gap statistic

The hierarchical clustering method demonstrated three groups of stations, which is consistent with the initial hypothesis and the partitioning clustering method (Fig. 3a, b). The separation of stations can be considered logical, since the first cluster (Fig. 3a, blue) united stations in the river section, where the hydrological conditions remained undisturbed. In addition, the silhouette plot showed that this cluster was selected with a high probability (Fig. 3b blue). The second cluster identified with less confidence (Fig. 3a, b, green). The third cluster was identified with low confidence according to the silhouette plot (Fig. 3a, b, pink) and united stations both from the river and from the upper reaches of the first reservoir. Thus, we can state that the studied section of the river is reliably divided into two sections: riverbanks on undisturbed section of the and the s of reservoirs.

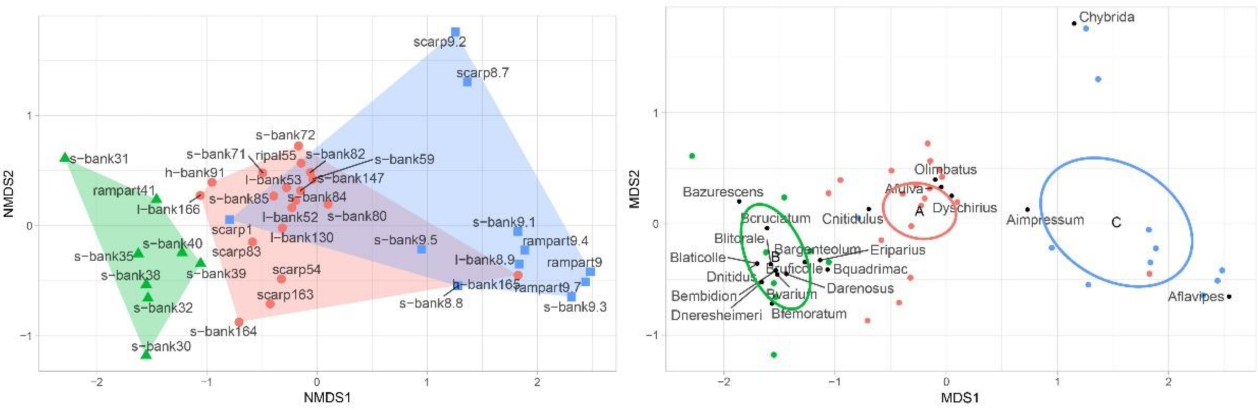


a b

Figure 3. Results of hierarchical clustering: a – dendrogram of the stations in riverbanks used Bray-Curtis distance and Ward's method, b – silhouette plot of the stations in riverbanks

According to the initial hypothesis, the studied stations at three sites along the banks of the Psel River were divided into three groups according to their location, based on nMDS analysis (Kulczynski index) (Fig. 4a). The headwaters of the first reservoir (Fig. 4a, green), the second reservoir (Fig. 3a, blue) and the undisturbed section of the river (Fig. 4a, pink) are quite clearly distinguished.

The distribution of riparian ground beetle species shows a similar result (Fig. 4b). Group A (Fig. 4b, red ellipse) included species belonging to burrowing forms with a negative attitude towards silting and overgrowing from beaches. Group B (Fig. 3b, green ellipse) is represented by species that predominate in the undisturbed section of the river, but are tolerant of beach silting. The species grouped in-group C (Fig. 4b, blue ellipse) prefer shaded shores.



a **b**

Figure 4. Ordination to the first two nMDS axes using method Kulczynsky for (a) the sampling stations along 180 km of the river Psel and (b) the carabid species composition. The ellipses emphasize the groups of species within the riverbank sections

Our results confirm the findings of other researchers studying rivers in Germany, Italy, the Netherlands, Ukraine and England (Boscaini et al., 2000; Lambeets et al., 2008; Bruno et al., 2010; Gerisch et al., 2012a, 2012b; Baiocchi et al., 2012; Jachertz et al., 2019; Kirichenko-Babko et al., 2020). It is know that riparian carabid species are adapted to flooding and are able to quickly leave the coastal strip due to their high mobility (Bates, Sadler & Fowles 2006; Lambeets et al. 2008). Moreover, stenotopic species of open riverbanks are able to actively colonize sections of rivers after restoration of their flow (Günter and Assmann, 2005; Bates et al., 2006).

According to our results, the diversity of typical riparian species along the shores of the reservoirs decreased from the upper reaches to the middle section, and they completely disappear towards the dam. In the upper reaches of the second reservoir of the Psel River, downstream of the HPP dam, where the flow resumes, typical riparian species reappear in assemblages, and have been found up to 10 km downstream of the dam.

It has been established that as a result of anthropogenic changes in the hydrological regime of rivers, moisture-loving ground beetles with smaller body sizes are more vulnerable (Von Manderbach and Reich, 1995; Günter and Assmann, 2005; Lambeets et al., 2008). Since the end of the 1980s, there has been a significant reduction in the number of species typical of open riverbanks, as well as their classification as endangered in many European countries, because of river regulation and straightening of their channels (Marggi, 1992; Trautner et al., 1996; Kirichenko, 1998; Bräunicke and Trautner, 1999; Günter and Assmann, 2005).

According to Antvogel and Bonn (2001) and Lambeets et al. (2008) flood duration and habitat management are the main factors influencing the occurrence of ground beetles in floodplains. During the flood season, habitat homogenization leads to a more homogeneous and less specialized riparian species composition. At the same time, Gerisch (2011, 2014) indicates that the coexistence of functionally similar riparian species is observed only for very short time scales – during floods and high waters. Our study provides evidence, following other researchers (Andersen and Hanssen, 2005), that habitat homogenization due to the absence of floods also leads to a more uniform and less specialized of riparian species composition.

Thus, on the continuum of riverbanks, the populations of riparian ground beetles are characterized by a dotted distribution. Changes in the hydrological regime and morphology of rivers are of decisive importance for the distribution of riparian ground beetles. On reservoirs of the river type, without high waters and floods, riparian ground beetles disappear from the assemblages. Fragments of such populations are retained in areas of refuge where conditions are close to natural, which is consistent with the dotted distribution of their populations. According to the composition of riparian ground beetles, river sections with disturbed hydrological conditions can be well marked.

4 CONCLUSION

Typical riparian carabids are highly sensitive to changes in the hydrological regime of rivers, which is manifested both in the species and in quantitative structure of their assemblages. The use of open riparian species as bioindicators is important in monitoring the state of river ecosystems; and it is especially important on rivers, where dams form reservoirs not of a lake type, but of a channel type, where changes in the hydrological regime do not change abruptly. The structure of riparian carabid assemblages makes it possible to establish the spatial boundaries of channel reservoirs and assess the scale of disturbances in the hydrological regime, which is associated with changes in the hydroecosystems of rivers.

The changes in the hydrological regime and channel morphology are of decisive importance for the distribution of riparian ground beetles. The use of statistical methods also made it possible to abandon one of the initial hypotheses: that the type of riverbanks is the determining factor for riparian ground beetles. We underline that dynamic riparian areas play crucial roles for the ground beetles. Riparian species are relatively well presented along the Psel, often locally, and have been shown to closely reflect changes in hydrogeomorphic dynamics.

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