Ecological Indicators 132 (2021) 108289

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Original Articles

Exploring land snails' response to habitat characteristics and their potential as bioindicators of riparian forest quality

Voichița Gheoca [a,*], Ana Maria Benedek [a,*], Erika Schneider [b]

[a] Applied Ecology Research Center, Faculty of Sciences, Lucian Blaga University of Sibiu, 5-7 Dr. Ioan Rațiu Street, 550012, Romania
[b] KIT, Karlsruhe Institute for Technology, University of Land Baden-Württemberg and Research Center of the Helmholtz Society, Institute for Geography and Geoecology, Department Aueninstitut/Institute for Wetlands Ecology, Josefstrasse 1, Rastatt D-76437, Germany

ARTICLE INFO

Keywords:
Land snails
Bioindicators
Riparian forest
Conservation
Habitat fragmentation
Species richness

ABSTRACT

Riparian ecosystems are crucial for landscape-level biodiversity, especially in highly anthropic and agricultural areas. Although the low mobility of snails reduces their dispersal capacity and makes them vulnerable to habitat degradation, they are less commonly used as indicators. We evaluated the potential of land snails as bioindicators of riparian forest quality in central European riparian forests by surveying snail communities in relation to habitat characteristics that characterize its quality. Habitat characteristics were found to affect both snail abundance and species richness. The abundance of snail species increased with the forest continuity, forest width and abundance of leaf litter and decreased with the cover of ruderal plant species and presence of household waste deposits. Snail diversity was positively influenced by habitat continuity, forest width, and abundance of dead wood. The community composition was also sensitive to habitat characteristics, most species having their optimum in habitats with high amounts of decaying dead wood and litter. Many species responded positively to habitat continuity, demonstrating that fragmentation is the main factor affecting abundance of land snail communities. Both total abundance of land snail communities and species richness were good predictors of habitat quality, snail abundance being more powerful than diversity. *Aegopinella epipedostoma, Perforatella bidentata,* and *Helix pomatia* were best at discriminating among high and poor quality forest habitats among individual species. Our study showed that among the parameters describing habitat quality, spatial and temporal continuity of riparian forest are the main factors affecting snail communities. Habitat fragmentation and the absence of suitable microhabitats for snail species preferring decaying wood lead to lower abundance and diversity of land snail communities confirming the potential of land snails as bioindicators of riparian forest quality.

1. Introduction

Riparian zones are complex systems created along river valleys at the interface between terrestrial and freshwater ecosystems. Although riparian ecosystems cover only a small part of a region, they significantly impact both its landscape and biodiversity (González et al., 2017), qualifying them as small natural features (SNFs) with disproportionate ecological importance, known as “Frodo effect” (Primack et al., 2016).

The contribution of the riparian habitats to the biodiversity of a region is remarkable, especially in arid zones and agricultural areas (Hanna et al., 2020), as river valleys generally have higher biodiversity or at least a different array of species than the surrounding areas (Sabo et al., 2005). In agricultural areas, these habitats are often the only natural habitats supporting forest-dependent vertebrate and invertebrate communities (Lees and Peres, 2008). Riparian forests also function as green corridors assuring the connectivity between patches of the remnant forests, enhancing the viability of species in connected habitat patches (Naiman et al., 1993).

Riparian forests are equally crucial for aquatic ecosystems. They can reduce the runoff of sediments and agricultural chemicals into streams, improving water quality and favoring aquatic fauna (Schultz et al., 2004). In addition, large trees can create shade and lower water temperature improving habitat for aquatic species, providing detritus and coarse woody debris for aquatic organisms (Davies and Nelson, 1994).

The riparian habitats have been subject to intense anthropogenic modifications for a long time. Up to 88% of the European floodplain

* Corresponding authors.
E-mail addresses: voichita.gheoca@ulbsibiu.ro (V. Gheoca), ana.benedek@ulbsibiu.ro (A.M. Benedek).

https://doi.org/10.1016/j.ecolind.2021.108289
Received 4 July 2021; Received in revised form 9 October 2021; Accepted 10 October 2021
Available online 14 October 2021

forest has disappeared due to conversion to agriculture and flow regulation (Hughes and Rood, 2003). Other human activities, such as wood exploitation, development of human settlements, industrial areas, and infrastructure, add more anthropic pressure on these habitats (Nilsson and Berggren, 2000; Hughes and Rood, 2003). Because riparian habitats provide major ecosystem services, they represent a great concern for land and water resource management (González et al., 2017).

The quality of riparian habitats has been assessed using different methods. Some of them are based on vegetation, many using remote sensing techniques (Munné et al., 2003; Ward et al., 2003; Booth et al., 2007), while others focus on stream and bank morphology (Petersen, 1992; Jansen et al., 2004). The QBR Index (the abbreviation of the Catalan 'Qualitat del Bosc de Ribera' - Riparian Forest Quality) was developed for Mediterranean rivers and considers the riparian cover, cover structure, number of native tree species, and channel alteration (Munné et al., 2003). One metric that includes vegetation structure and river bank morphology is the Riparian Quality Index (RQI) (Gonzáles del Tánago and de Jalón, 2006). RQI includes the width and longitudinal continuity of the riparian habitat, bank condition, lateral and vertical connectivity, vegetation composition and structure, age structure, and regeneration processes in riparian vegetation.

Vegetation and habitat morphology provide valuable information and help assess the habitat's degree of conservation. In addition, monitoring fauna completes the picture of the way environmental changes affect natural populations. The high diversity and functional importance of many invertebrates in terrestrial ecosystems, their small size, and low mobility make them especially suited as environmental bioindicators (Gerlach et al., 2013).

Terrestrial snails and slugs are widely distributed, and they are an essential food source for many terrestrial animals. Land snails are characterized by low vagility as their annual movement does not exceed more than a few tens of meters (Baur and Baur, 1993; Aubry et al., 2006) so that they are confined to a specific habitat, and their community structure will reflect local conditions. Furthermore, the persistence of snail shells allows a more accurate evaluation of species richness than in most other taxa. Despite these valuable characteristics in bioindication and the fact that mollusks are easy to record and relatively easy to identify, they are less commonly used as indicators (Gerlach et al., 2013). Land snails are known to be bioindicators of heavy metal environmental pollution. Due to the interference of metals with calcium metabolism and their need to prevent water loss, snails have developed strategies for metal immobilization, both at the cellular and molecular level (Dallinger, 1994; Oehlmann and Schulte-Oehlmann, 2003). During the last two decades, numerous studies have demonstrated this ability of terrestrial gastropods and correlated it with the degree of habitat contamination. However, beyond the heavy metal bioaccumulation, the indicator potential of snails in terrestrial ecosystems was less addressed. Due to their affinity for humidity, land snails are among the most important taxa in river floodplains (Cejka and Hamerlik, 2009; Horáčková et al., 2015) and they reflect the changes in their habitat. Among the studies using snails as bioindicators, there are several evaluating the response of snails to habitat characteristics in European floodplains focusing mainly on large rivers, such as the Loire, the Danube and the Elbe (Castella et al., 1994; Foeckler et al., 2006; Čejka et al., 2008; Cejka and Hamerlik, 2009; Ilg et al., 2009) with particularities of the vegetation and the flooding regime that are not transferable to small central European rivers.

To the best of our knowledge, as yet, no studies evaluated the bioindicator potential of land snails in central European riparian forests. We hypothesized that communities of land snails respond in terms of total abundance, diversity, and species composition to habitat characteristics considered by well-established indicators of riparian forest quality (such as RQI and QBR developed for Mediterranean riparian forests), rendering them valuable bioindicators. Therefore, we aimed to find the best parameters of land snail communities and individual species that may be used to predict the habitat quality of riparian forests in Central Europe.

2. Material and methods

2.1. Study area and habitat

The study area is located in the southern part of the Transylvanian Plateau, between 45.784°–46.218° N and 24.313°–25.216° E (Fig. 1). The annual mean air temperature is 7–8 °C, and the average precipitation is 700–800 mm/year (Badea, 1983). Most of the selected forests are part of the Natura 2000 European network of protected areas, being included in three sites: ROSCI0227 Sighișoara Târnava Mare, ROSCI0303 Hârtibaciu Sud-Est, and ROSCI0304 Hârtibaciu Sud-Vest. The researched habitats were riparian forests of 91E0 Natura 2000 habitat type, subtype 44.13 Salicion albae, typical for the study area. The field survey was conducted in 2017–2018.

2.2. Description of riparian forests of southern Transylvania

In the southern Transylvanian Plateau, riparian forests follow the river's courses forming primarily compact and well-structured galleries, marking the area's hydrographic network. The riparian willow forests of 91E0 Natura 2000 habitat type are multilayer forests with three, sometimes four, or even five layers. The tree canopy may be single or double layered, dominated by *Salix alba* and *S. fragilis* in various proportions. The shrub layer is well developed and diverse, including mostly *Cornus sanguinea* and *Evonymus europaeus* and the herb layer is tall and diverse, usually dominated by nitrophilous species: *Urtica dioica*, *Aegopodium podagraria*, *Anthriscus sylvestris*, *Rumex obtusifolius*. *Rubus caesius* is often abundant, forming thickets that represent an important microhabitat in these riparian forests. The hygrophilous meadow species, such as *Eupatorium cannabinum*, *Senecio paludosus*, *Filipendula ulmaria*, *Cirsium oleraceum*, *C. canum*, form a belt of tall herbs at the forest edge. The various layers are connected by lianas that form thick covers on trees and shrubs. *Humulus lupulus* is characteristic of most riparian forests, while *Clematis vitalba* is present in the older ones. Besides the native species, the allochthonous invasive *Echinocystis lobata* is also widespread and abundant.

In some short river sectors, with deep valleys and steep slopes that maintain a cooler microclimate, the forests belong to subtype 44.2. (Alnion incanae), with *Alnus incana* and other montane species, such as the tall herb *Telekia speciosa*.

The study area has both well-preserved natural habitats and habitats subjected to high anthropic pressure, most evident near localities, where local people cut wood for heating and deposit household waste on the river banks. In addition, parts of the forests were wholly clear-cut and replaced by crops, altering the continuity of the riparian habitats. The mosaic of natural and modified riparian habitats offers the opportunity to analyze the impact of local anthropic changes on habitat quality and riparian snail communities.

2.3. Study sites and sampling methods

During 2017–2018 we sampled 48 sites (Fig. 1, Appendix A, Table A.1) selected on Târnava Mare, Hârtibaciu, and Olt rivers and their affluents, at least 500 m distance from the nearest human settlement. We chose the sampling sites in habitats differing in their degree of conservation. In two sites, the riparian forest was in contact with the neighboring beech forest. In each sampling site, land snails were visually searched by two persons for one hour in all microhabitats suitable for the animals (Pokryszko and Cameron, 2005). Besides, in each site, a 20 l sample of litter and topsoil was filtered through a 10 mm mesh sieve, the resulting material was bagged and taken to the laboratory. Then, the material was air-dried and sieved into smaller fractions, searched for snails directly or using a binocular microscope, depending on their size. Only live specimens and fresh empty shells with intact periostracum

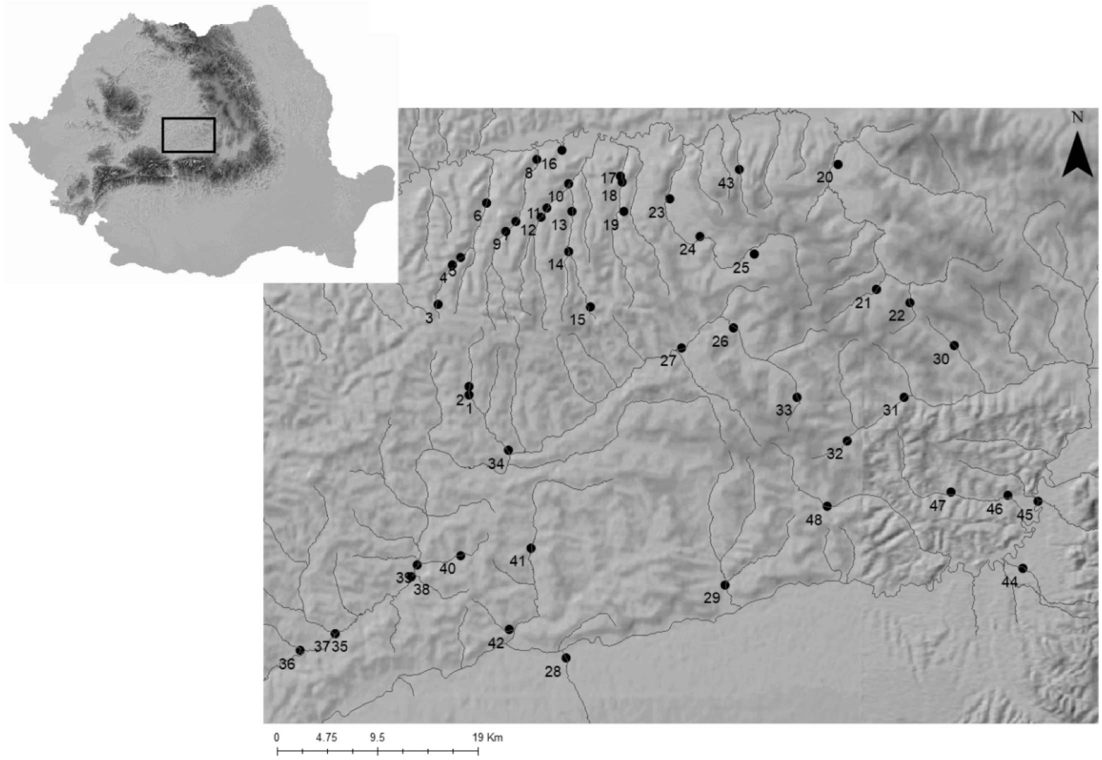

Fig. 1. Map of the study area showing the location of sample sites.

were considered in the analyses to reduce the bias due to floods that can wash away autochthonous shells and redeposit allochthonous shells (Sólymos et al., 2009).

2.4. Habitat characteristics

As habitat characteristics, we included 20 variables – 12 quantitative, 4 ordinal on a four-category scale, and 4 binary (presence-absence) (Appendix A, Table A.1). For this, in each sampling plot, we surveyed the vegetation based on one phytocoenological relevé. For each plant species, we estimated the abundance using cover percentages. Then, we used the collected data to estimate several quantitative parameters: cover of the tree and shrub canopy, herb layer, riparian vegetation, ruderal vegetation, total cover, the abundance of neophytes, lianas, nitrophilous species, aquatic vegetation, and the number of tree species. We also measured forest width, which determines the space available for the riparian communities along the rivers.

The abundance of old trees reflects the temporal continuity of the riparian habitat, potentially affecting land snail communities. We evaluated it as an ordinal variable (Table 1). Trees can be considered old if they have hollows and generate dead branches (a process that begins for the willows in the local conditions at about 30 years). We estimated the abundance of decaying wood by counting the number of dead trees in the sampled area. We noted with 0 sites with no decaying wood, 1 - site with some decaying branches or bark, 2 - site with at least one decaying trunk, and 3 - site with more than one decaying trunk. To estimate the abundance of leaf litter, we selected within the sampling plot four random quadrats of 0.25 m^2 and collected the litter, measuring it using the cylinder of the sieve. The forest longitudinal continuity was also considered as an ordinal variable with four categories (Table 1).

As binary variables, we considered the presence of recent human impact - recent wood exploitation, recent fires, household waste deposits, and grazing.

Table 1
Variables considered in estimating the habitat's degree of conservation in addition to those included in the QBR index (Munné et al., 2003).

	Value			
Variable	0	5	10	25
Average width	<5m	5–10 m	10–20 m	>20 m
Old trees - temporal continuity	absent	A few old trees	At least 15 % of the tree vegetation	Over15%
Longitudinal connectivity	>100 m distance between the habitat fragments	50–100 m between the habitat fragments	<50 m between the habitat fragments	Continuous habitat

2.5. Evaluation of riparian forest quality

To assess habitat quality, we used a method that combines the QBR index with other synthetic parameters that we considered appropriate in the context of riparian forests in central Romania. The core of the habitat quality assessment was the QBR index, based on four parameters assessing mainly the vegetation: the riparian cover, cover structure, cover quality, and channel alteration (Munné et al., 2003). The riparian cover considers the total vegetation cover excluding annual plants, taking into account the connectivity between the riparian habitat and the forest, the cover structure is based on tree and shrub cover and distribution, as for the cover quality, the number of native tree species and their distribution, according to the riparian geomorphology is quantified. Compared to the original index, in evaluating the cover quality, we considered factors with a negative impact on the quality of the forest, besides the waste deposits and constructions, also two other human activities common in the area - grazing and recent wood exploitation. Although some channel alteration was registered only in two sampling sites, we kept this parameter in the evaluation of habitat quality, as in the original index. However, due to the peculiarities of our study area, besides the four mentioned parameters, we included the average width of the riparian habitat, the longitudinal continuity, and the old tree cover, parameters used in other evaluation methods for forest quality (Gonzáles del Tánago and de Jalón, 2006; Geburek et al., 2010). The last three parameters were also quantified on a scale from 0 to 25, similarly to the classes used by QBR index (Table 1), to maintain the same contribution to the quality index of all the considered parameters. Using this evaluation method, the maximum value for quality was 175 (7 parameters with a maximum of 25 each). The estimated values of the habitat quality in the sampling sites ranged from 25 to 170 (Appendix A, Table A.2).

We also considered snail macrohabitat and microhabitat preferences to characterize the land snail community. The categories for habitat preferences were: woods, shrubs, alluvial forests, tall herbs, grasslands, water edge, and for microhabitat preferences: trees/shrubs, herbs, litter, soil, roots (Falkner et al., 2001).

2.6. Data analysis

We used several community parameters as response variables to evaluate the effect of habitat characteristics on land snails. Abundance was the total number of individuals counted in a sample. Because of the very uneven abundance among sites, to standardize the richness, we included as a measure of diversity the rarefied species richness, estimated for the sample size of the site with least abundant community (48 sampled individuals). However, because the sampling effort was the same in every site, and therefore the observed species richness gives another dimension of diversity, we considered also the observed species richness (i.e., the number of species identified in a sample). In the multivariate analyses, the response variables were the abundances of the various species within the community, referred to as *species composition* hereafter.

Prior to model construction, we performed a Spearman multiple correlation analysis among the quantitative and ordinal habitat variables to test for potential multicollinearity. To test the significance of the relationship between binary predictors and the other variables, we used the non-parametric Wilcoxon test, because the assumption of the normal distribution was not met. None of the correlation coefficients was higher than 0.7, but the Wilcoxon test showed significant differences in the ruderal vegetation cover in the presence and absence of recent fire, and the forest continuity in the presence and absence of recent exploitation. Therefore, we removed the binary variables fire and exploitation from the analyses.

The relationship between diversity and habitat characteristics was analyzed using multiple linear regression. We chose the best model by automatic selection based on Akaike Information Criterion (AIC) using stepAIC function in MASS package (Venables and Ripley, 2002) in R (R Core Team, 2018). In the case of abundance, the assumption of homoscedasticity of residuals was not met; therefore, we accounted for overdispersion using the negative binomial generalized linear model (GLM) function (glm.nb) in MASS package. For the predictors in the best model we evaluated their importance calculating ΔAICc – difference between the value of AIC corrected for small samples of the model without the corresponding predictor and that of the best model.

To evaluate the response of land snail species composition to habitat characteristics, we used the multivariate linear redundancy analysis (RDA), performed in Canoco 5.12 software (ter Braak and Šmilauer, 2018). To find the set of predictors that best explained species composition, we used the interactive forward selection. Probabilities were adjusted to correct for the inflation of type-I error caused by multiple testing, using the false discovery rate values (Šmilauer and Lepš, 2014). We tested the significance of ordination axes by the Monte-Carlo permutation test with 999 unrestricted permutations per test. The significance of species' responses (either positive or negative) to individual predictors was evaluated visually, constructing the t-value biplots with van Dobben circles (Šmilauer and Lepš, 2014).

To evaluate the bioindicator value of land snail communities, we used habitat quality as the response variable and diversity and log-transformed abundance of snail communities as predictors in linear regression models. To identify the snail species that may be used to assess the riparian forest quality, we constructed a regression tree with habitat quality as the response variable and the abundances of individual species as predictors. The regression tree was constructed in rpart package (Therneau and Atkinson, 2019) and illustrated using prp function in rpart.plot package (Milborrow, 2020) in R. To find significant indicators of riparian forest quality, expressed as low (QBR $\leq$ 70) or high (QBR $>$ 70), we applied the indicator analysis in Canoco 5.12, testing the indicator value based on the quantitative data using the Monte Carlo permutation test with 999 permutations (ter Braak and Šmilauer, 2018). We considered as significant indicators snail species with $p < 0.05$.

3. Results

3.1. Habitat characteristics

The selected sampling sites were very heterogeneous concerning the habitat characteristics, including those used in the assessment of habitat quality (Table 2). In 15 of the 48 sampling sites the riparian woodland was <10 m wide (Appendix A, Table A.1), the minimum width required for an appropriate buffer function related to invertebrate diversity (Broadmeadow and Nisbet, 2004).

3.2. Abundance of land snails

We identified 12,570 land snails of 71 species, 49 genera, and 22 families (Appendix B). Four of the species (*Cecilioides acicula*, *Chondrula tridens, Granaria frumentum*, and *Monacha cartusiana*) are xeric, steppe species, represented by shells flushed away, therefore they were not included in the analyses. The abundance of the other species varied between 48 and 947 specimens per sample (mean = 260.5, SE = 31.5) (Appendix B). *Carychium tridentatum* had the highest abundance, but other microsnails such as *Punctum pygmaeum, Truncatellina cylindrica,* and *Vallonia costata* were also abundant. Among the larger species, *Fruticicola fruticum*, *Aegopinella epipedostoma, Laciniaria plicata,* and *Helix pomatia* were found in the largest numbers.

The abundance of land snails in the sampling sites was explained both by positive and negative habitat characteristics. The best negative binomial model included the forest continuity and width and the abundance of litter, which had positive effects on snail abundance, and the presence of waste deposits and cover of ruderal vegetation, with negative effects. The forest continuity and abundance of litter had the

Table 2
Descriptive statistics for the quantitative habitat characteristics evaluated in the study.

Variable (measure units)	Minimum	Maximum	Median	Mean	Standard deviation
Forest width (m)	3	45	13	15.58	8.24
Tree canopy (%)	5	95	40	41.17	21.43
Shrub canopy (%)	2	85	30	35.56	19.19
Herb layer (%)	25	100	60	59.69	20.65
Total cover (%)	82	296	173	171.5	51.42
Riparian vegetation (%)	24	207	92.25	100.6	42.17
Ruderal vegetation (%)	0	25	1	3.34	6.4
Neophytes (%)	0	85	0.5	7.15	15.32
Lianas (%)	0	40	1.5	7.68	10.92
Nitrophilous species (%)	0	139	41	46.79	39.38
Aquatic vegetation (%)	18	180	70.5	76.03	38.14
Tree species (number)	1	6	2	2.43	0.87

strongest effect on abundance (Table 3). The explained deviance of the model was 0.792.

3.3. Diversity of land snails

The observed number of species per sampling station ranged between 10 and 41 (mean = 20.3, SE = 0.99). The best linear model explaining land snail species richness in the sampling sites (R^2_{adj} = 0.516) included abundance of logs (ΔAICc = 12.5), forest continuity (ΔAICc = 3.29) and width (ΔAICc = 4.51). By the increase with one unit of the abundance of logs, mean species richness of land snails per plot increased with 3.75 species. In case of forest continuity, the mean species richness increased with 2.74 species and in case of forest width with 0.19 species.

The rarefied species richness (at 48 individuals) per sampling station ranged between 6.74 and 18 (mean = 13.51, SE = 0.42). The best linear model relating rarefied species richness to habitat characteristics (R^2_{adj} = 0.306) included the abundance of logs (ΔAICc = 9.12), the cover of aquatic vegetation (ΔAICc = 2.35) and that of neophytes (ΔAICc = 0.47). The mean rarefied species richness of the land snail community increased with 1.56 for an increase with one unit of logs abundance, with 0.04 for an increase with one percent of the neophytes cover and 0.02 for an increase with one percent of the aquatic vegetation cover.

3.4. Habitat preference

Considering the habitat preferences, most snails belonged to woodland species (32.09%, SE = 0.41%) such as *Faustina faustina, Perforatella bidentata, Cochlodina laminata, Clausilia cruciata, Bulgarica cana*, and microsnails like *C. tridentatum* and *Vitrea transsylvanica.* Characteristic alluvial forest species (15.39%), dominated by *Monachoides vicinus*, are an important component of the researched land snail assemblages. The snails characteristic for open tall herbs were also well represented (16.41%). This category includes opportunistic species, such as *F. fruticum, Euomphalia strigella*, and *H. pomatia*.

Concerning the microhabitat, snails preferring leaf litter (26.79%) were dominant. Well represented were also those living in the herb layer (21.78%), herb litter (17.23%) and woody debris (21.13%), which have similar ratios in the community. Dominant in the last category were *F. faustina*, *C. cruciata*, and *L. plicata*.

3.5. Species composition

The presence of logs and litter explained 11.8% of the total species variation, the adjusted explained variation being 7.9% (test on all axes pseudo-F = 3, p = 0.001). Abundance of logs explained 8% of the variability in species abundance (pseudo-F = 4, $p_{adjusted}$ = 0.004), while the abundance of litter explained an additional 3.8% (pseudo-F = 1.9, $p_{adjusted}$ = 0.012). The first constrained axis extracted 80.1% of the explained fitted variation, thus being the only significant axis (pseudo-F = 0.2, p = 0.017). This axis was equally defined by the two predictors, which were positively correlated (Fig. 2a). Most species preferred forests with a high abundance of logs and rich litter (Fig. 2a). The t-value biplot showed that the abundance of litter induced two significant positive responses, from *C. tridentatum* and *V. transsylvanica*. Abundances of *L. plicata, Isognomostoma isognomostomos, Macrogastra tumida, Cochlicopa lubrica, Vestia elata*, and *Pomatias rivularis* were significantly affected by the abundance of logs, having a positive response, while *Helix lutescens, Caucasotachea vindobonensis*, and *F. fruticum* had a negative response, marginally significant of the latter.

In the RDA ordination space given by the variables describing the habitat characteristics, species richness showed a gradual and strong decrease along the first constrained axis. The explained variation of the loess smoother model was R^2 = 70.5. The number of identified species increased with both habitat characteristics, especially abundance of logs (Fig. 2b).

Table 3
Coefficients of the best negative binomial GLM model explaining the abundance of land snails in the sampling stations. continuity – degree of forest continuity (ordinal variable), litter – abundance of litter (ordinal variable), width – forest width (in m), ruderal – cover of ruderal vegetation (in percents), waste – presence of waste deposits (binary variable). ΔAICc – difference between the value of Akaike Information Criterion corrected for small samples of the model without the corresponding predictor and that of the best model.

Coefficient	Estimate	Standard error	ΔAICc
Intercept	4.47	0.162	
Continuity	0.43	0.088	16.75
Litter	0.24	0.056	14.23
Width	0.01	0.006	2.96
Ruderal	−0.02	0.009	1.4
Waste	−0.3	0.119	2.9

3.6. The value of land snails as indicators of riparian forest quality

The total abundance of land snail communities was a very good predictor of habitat quality (ΔAICc = 47.99, R^2_{adj} = 0.641). In the model relating habitat quality to the log-transformed number of individuals, when abundance increased two times, quality increased by 22.29 points (Fig. 3). Observed species richness was also a good indicator of habitat quality (ΔAICc = 26.64, R^2_{adj} = 0.44). The increase with one species indicates increased habitat quality with a mean of 2.84 points. Removing from the data the most influential sample (with the maximum number of observed species – 41), the quality of the model increased (ΔAICc = 37.98), but the explained variation decreased (R^2_{adj} = 0.328). However, in the multiple regression, because of the dependence of species richness on the abundance (Cameron and Pokryszko, 2005), the number of observed species did not add significant information to that conveyed by the abundance, its effect being small (ΔAICc = 1.92). On the other hand, riparian forest quality showed only a very weak relationship with the rarefied species richness (ΔAICc = 2.67, R^2_{adj} = 0.078).

Considering the species composition of land snail communities, the abundance of *A. epipedostoma* is the best predictor of habitat quality. In forests where the abundance of *A. epipedostoma* exceeds 29.5 individuals/sampling plot, the estimated mean habitat quality is 117 (10 sites). In sites where *A. epipedostoma* has lower abundances, habitat quality may be predicted by *H. pomatia*. In better habitats with an estimated quality of 77.8 (16 sites), its abundance is higher than 9 individuals/plot. Where *H. pomatia* is less abundant, *P. bidentata* has the best predicting value, with an abundance of 0.5 individuals/plot (Fig. 4). For the first node of the regression tree, *M. vicinus, I. isognomostomos, A. aculeata, P. pygmaeum,* and *C. tridentatum,* can also be used as surrogates for *A. epipedostoma* to distinguish between high and low-quality habitats, with an agreement between 0.85 and 0.9 (Appendix C).

Most species with significant indicator value preferred habitats of high quality, with Q > 70 and among these *Acanthinula aculeata, M. vicinus* and *F. faustina* showed the strongest preference (Table 4). *C. vindobonensis* and *H. lutescens* where the only species showing a significant preference for low-quality forests.

4. Discussion

We surveyed terrestrial snail communities in riparian forests in Central Romania in relation to habitat characteristics, this study being the first to assess the value of land snails as indicators of habitat quality in this type of ecosystem.

We found that land snail assemblages varied strongly among the sampling sites in relation to habitat characteristics. Most of the identified snails were typical woodland species, some of them being characteristic for alluvial forests (e.g., *Pseudotrichia rubiginosa, Monachoides incarnatus, M. vicinus, Vestia gulo*). Others were eurybiotic species (e.g.,

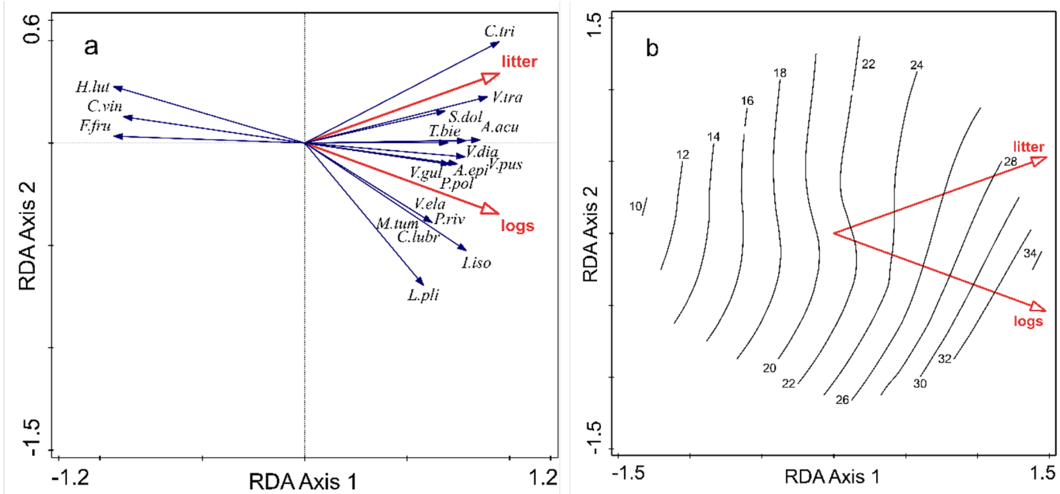

Fig. 2. RDA of land snails and the two habitat characteristics included in the best model: abundance of litter (litter) and dead wood (logs). a. Species-habitat biplot with the 20 best fitting snail species along the first constrained axis are represented (the second axis is not significant). Species are coded using the initial of the genus name and the first three letters of the species name; the only exception is C.lubr – for *C. lubricella*, to avoid confusion with C.lub, for *C. lubrica* (not shown in the graphs). b. Attribute plot illustrating the variation of the species number in the RDA ordination space given by the best predictors describing the habitat characteristics (using the first two axes). Visualization is based on a loess smoother model with $R^2 = 70.5$.

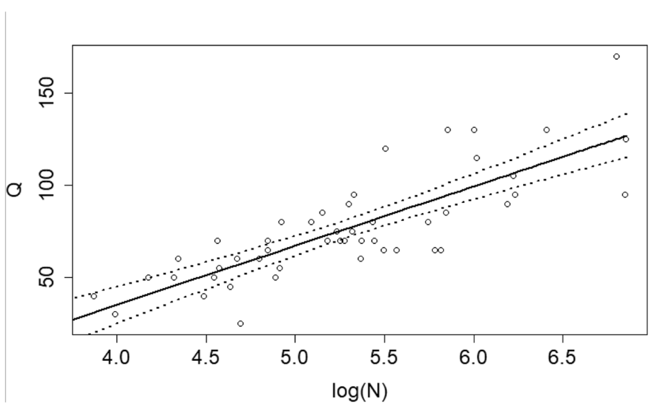

Fig. 3. Linear model illustrating the log-transformed abundance (N) of land snails as the predictor of habitat quality (Q). The 95% confidence interval for the mean estimated value of habitat quality is plotted in dotted lines.

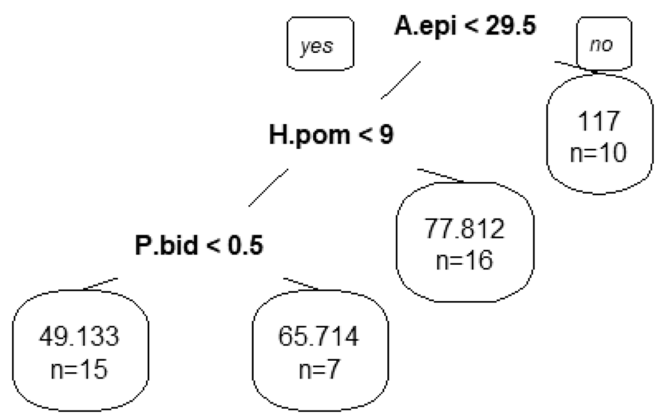

Fig. 4. Regression tree for habitat quality based on the abundance of snail species in riparian forests. A.epi - *A. epipedostoma*, H.pom - *H. pomatia*, P. bid – *P. bidentata*, n is the number of samples (sites) in each terminal node of the regression tree, the number beside each species represents the threshold of its abundance as indicator value, the number in the boxes represents the estimated value of the habitat quality (Q) for each terminal node (for the peculiar combination of the abundances of the three species).

F. fruticum, *H. pomatia*, *E. strigella*) or they have been accidentally carried by the water from the mesophylous meadows located on the slopes, where the configuration of the habitat allows the water flow (e.g., *M. cartusiana*, *C. tridens*, *G. frumentum*). This type of dispersal was recorded by Czógler and Rotarides (1938) in driftwood along two rivers in Hungary, where the majority of the shells belonged to species characteristic for floodplain habitats, but species associated with rocky or dry habitats were also found (e.g., *G. frumentum*, *Xerolenta obvia*). Other authors have demonstrated the water dispersal of land snails and even the establishment of new snail populations (Dörge et al., 1999; Pfenninger and Posada, 2002). However, if the habitat requirements are not fulfilled, these species do not survive in the riparian forest. Therefore, they are typically found only as empty shells, in small numbers, living animals being indicators of a recent passive dispersion process.

Habitat characteristics affected both snail abundance and diversity, habitat continuity, and forest width having a positive effect on the abundance and species richness. The litter positively affected snail abundance, while the abundance of logs had a positive effect on species richness. The presence of deadwood is an important factor determining snail diversity. This was also confirmed by the dominance of snails living in woody debris together with those preferring leaf litter. The old willows and alder trees with hollows and decaying wood generate new microhabitats available for snails. These microhabitats are important for land snails whose distribution is known to be affected by micro-scale variation in the availability of structural elements such as coarse woody debris (Müller et al., 2005; Kappes et al., 2006). The presence of coarse woody debris is known to have a major impact on general biodiversity in terrestrial ecosystems (Harmon et al., 1986; Mac Nally et al., 2001) and to impact both land and aquatic biodiversity in riparian habitats (Czarnecka, 2016), several studies finding positive correlations between deadwood and snails (Müller et al., 2005; Kappes et al., 2006). Decaying wood provides shelter and laying ground for terrestrial mollusks but also a food source, as some species are feeding on the microflora that develops here. On the other hand, under the bark of old trees or in decaying branches and tree trunks, the humidity is kept for longer, favoring species that are sensitive to low humidity (Müller et al., 2005).

The leaf litter represents the microhabitat for fauna living on the forest floor. Many snails are litter-dwelling, most of the snail species being considered consumers of decaying plant material (Locasciulli and

Table 4
Indicator values of land snail species for habitat quality (high or low) based on abundance data, and their significance (p value).

Species	Low	High	Preferred group	p value
Acanthinula aculeata	0.01725	0.4827	High	0.001
Monachoides vicinus	0.04492	0.66926	High	0.001
Faustina faustina	0.05215	0.57061	High	0.001
Vertigo pusilla	0.11918	0.5576	High	0.003
Carychium tridentatum	0.20489	0.59195	High	0.004
Isognomostoma isognomostomos	0	0.28571	High	0.004
Cochlicopa lubrica	0.19603	0.5736	High	0.006
Laciniaria plicata	0.287	0.60096	High	0.008
Vitrea transsilvanica	0.07476	0.44054	High	0.009
Vallonia costata	0.1436	0.52419	High	0.01
Helix lutescens	0.52869	0.10906	Low	0.011
Aegopinella epipedostoma	0.22868	0.53184	High	0.028
Merdigera obscura	0.00615	0.2383	High	0.032
Caucasotachea vindobonensis	0.4688	0.14306	Low	0.038
Vitrea crystalina	0.07915	0.3639	High	0.044

Boag, 1987). Therefore, forests with rich litter shelter abundant land snail communities.

The width and continuity of habitat, reflecting the size of habitat fragments, were two of the main factors affecting snail abundance in our study. At a larger scale, fragmentation was found determinant in land snail assemblages of tropical rainforests (Raheem et al., 2009) and lowland forests in Germany (Kappes et al., 2009), although snails have also shown high resilience to habitat fragmentation (Raheem et al., 2009). In their study, Raheem et al. (2009) found that 72% of the native land-snail species present in the study area have survived extensive habitat fragmentation. In the riparian forests we studied, habitat continuity was related to snail abundance and diversity, having an important role in shaping land snail communities, making fragmentation the main factor affecting the land snail community.

The presence of household waste and the cover of ruderal species had a negative impact on snail abundance. Waste deposits are located mainly in the vicinity of human settlements. Even if they usually cover only a small part of the habitat, sometimes the resulted pollution affects a considerable area. In most cases, the waste deposits do not modify the habitat structure and composition; therefore, they primarily affect the snail abundance by limiting the available area without affecting species richness. Furthermore, the forest exploitation and the replacement of the natural riparian habitat with cultivated land allow the penetration of ruderal species, indicating a degraded habitat.

Other human activities, such as wood exploitation and grazing, had no significant effect on land snail abundance and diversity in our study. We considered as wood exploitation only recent tree cuts identified during the sampling. These were sporadic and limited in terms of extracted wood. However, the effect of older exploitations was reflected in the continuity and width of the riparian forest and the reduced number or even absence of old trees, which are the major source of dead wood, affecting both abundance and diversity. Studies on clear-cutting in boreal riparian forests (Ström et al., 2009) suggest that this practice leads to an initial decline in abundance of many snail species, an effect that is transient for most species, with recovery from clear-cutting within 40–60 years. In their study on Mediterranean secondary forests, Barbato et al. (2020) concluded that the forest age was not determinant for land snail species richness and abundance. Instead, they singled out the habitat structure as the key factor modeling land snail communities.

Livestock (mainly sheep and goats, and fewer cattle) grazing is common in the study area. The herds usually graze on the nearby pastures and cross the riparian area for watering or resting in the shade, rarely effectively grazing there. Although the intensity of grazing influences land snail communities in grasslands (Boschi and Baur, 2007), its impact on the studied riparian forest is limited to watering places and adjacent areas and does not affect the land snails.

The species composition was also sensitive to habitat characteristics, most species having their optimum in habitats with high amounts of logs and litter. Microhabitat preferences were illustrated by the species responses to the presence of logs and litter; *I. isognomostomos,* and *L. plicata* showed the highest positive response to the abundance of dead wood, while microsnails like *C. tridentatum* and *V. transsylvanica,* preferred a high amount of leaf litter. Among the species with a negative response to the presence of logs and litter were *H. lutescens* and *C. vindobonensis*, two open habitat land snails, which also showed significant preference for degraded habitats. This preference is probably related to changes in forest structure that allow the penetration of tall grasses from the edge into the riparian forest.

Different vertebrate and invertebrate taxa have proved their quality as indicators of riparian habitat conditions. Among them are birds (Bryce et al., 2002), bats (López-Baucells et al., 2017), butterflies (An and Choi, 2021), ants (Jiménez-Carmona et al., 2020), social wasps (de Souza et al., 2010), and terrestrial arthropods (Williams, 1993).

The available data confirm that habitat degradation has a negative impact on land snails. Limestone prosobranchs were found to respond to habitat degradation in Borneo (Schilthuizen et al., 2005). The highly degraded karst forest has shown an overall downward shift in the relative abundance of the prosobranchs, with a corresponding upward shift of pulmonates, raising the issue of the possible replacement of autochtonous prosobranch snails by invasive pulmonates. Forest microsnails were proved to be sensitive to changes associated with human disturbance, which supports the conclusion that microsnails can be useful indicators of old-growth forests in the US (Douglas et al., 2013). The analysis of some Czech urban areas, including protected natural ecosystems, displayed decreased anthropophobic snail species with the increase of human disturbance (Horsák et al., 2009). Land snails have also been suggested as indicating long-term stability within woodland (Norden and Appelqvist, 2001). All these findings support the idea that land snails may be used as ecological indicators.

Our findings confirm our hypothesis that land snails may also be valuable indicators of riparian forest quality. Both the total abundance of land snail communities and species richness are good predictors of habitat quality described as the sum of individual parameters, snail abundance being more powerful than diversity. Among individual species, *A. epipedostoma* and *P. bidentata* prefer wet woodlands, and their abundance in the area explains their value as quality predictors, in contrast to other less abundant species. *H. pomatia*, an open forest and shrubland species, is generally abundant on river valleys, especially in agricultural areas, where the riparian habitats act as refuges for many species. The response of *H. pomatia* to high-quality habitat could be enhanced by its exploitation. The intensity of human impact on the riparian forest by wood exploitation in the studied area is generally related to the poverty of the local population. Local people without stable income use alternative means to ensure their subsistence, such as cutting wood for heating and collecting snails for selling. In fact, there are unusually numerous collection centers in the studied area that buy snails from the local population for export (Gheoca, 2013) since the Romanian legislation allows the species' exploitation. Therefore, the potential of *H. pomatia* for discriminating between low and high-quality habitats could be the effect of more intense exploitation of its populations in degraded forests.

In conclusion, snail abundance, species richness, and community composition responded to habitat parameters describing the presence of suitable microhabitats (logs and litter) and to those assessing the spatial (longitudinal) and temporal continuity (abundance of old trees). Habitat fragmentation and the absence of suitable microhabitats for snail species preferring decaying wood lead to lower abundance and diversity of land snail communities. Although a complex vertical structure with herbs, shrubs, and lianas can contribute to preserving humidity, a limiting factor for land snails, this was not found to affect snail communities significantly.

Conservation of riparian habitats is a global priority due to the multitude of ecosystem services they offer. Therefore, assessing the condition of alluvial forests in central Romania to preserve remnant natural habitats and implement reconstruction programs should be a priority. This goal can be achieved by using appropriate tools for assessing the condition of riparian forests, and land snails proved to be effective in monitoring their quality.

CRediT authorship contribution statement

Voichița Gheoca: Conceptualization, Methodology, Investigation, Formal analysis, Data curation, Writing – original draft. **Ana Maria Benedek-Sîrbu:** Formal analysis, Writing – original draft. **Erika Schneider:** Investigation, Writing – original draft.

Declaration of Competing Interest

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

Acknowledgments

This study was funded by a research grant from Lucian Blaga University of Sibiu (LBUS-IRG-2018-04). We are very grateful to Robert Cameron for the valuable feedback on our work. The authors thank the two anonymous reviewers for their constructive comments and suggestions that helped improve the article.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolind.2021.108289.

References

An, J.S., Choi, S.W., 2021. Butterflies as an indicator group of riparian ecosystem assessment. J. Asia Pac. Entomol. 24, 195–200. https://doi.org/10.1016/j.aspen.2020.12.017.
Aubry, S., Labaune, C., Magnin, F., Roche, P., Kiss, L., 2006. Active and passive dispersal of an invading land snail in Mediterranean France. J. Anim. Ecol. 75, 802–813. https://doi.org/10.1111/j.1365-2656.2006.01100.x.
Badea, L., 1983. Geografia României T. 1: Geografia fizica, ed. Academiei RSR, Bucuresti.
Barbato, D., Benocci, A., Manganelli, G., 2020. Does forest age affect soil biodiversity? Case study of land snails in Mediterranean secondary forests. For. Ecol. Manage. 20, 919–931. https://doi.org/10.1016/j.foreco.2019.117693.
Baur, A., Baur, B., 1993. Daily movement patterns and dispersal in the land snail Arianta arbustorum. Malacologia 35, 89–98.
Booth, D.T., Cox, S.E., Simonds, G., 2007. Riparian monitoring using 2-cm GSD aerial photography. Ecol. Indicat. 7, 636–648. https://doi.org/10.1016/j.ecolind.2006.07.005.
Boschi, C., Baur, B., 2007. The effect of horse, cattle and sheep grazing on the diversity and abundance of land snails in nutrient-poor calcareous grasslands. Basic Appl. Ecol. 8, 55–65. https://doi.org/10.1016/j.baae.2006.02.003.
Broadmeadow, S., Nisbet, T.R., 2004. The effects of riparian forest management on the freshwater environment: a literature review of best management practice. Hydrol. Earth Syst. Sci. 8, 286–305. https://doi.org/10.5194/hess-8-286-2004.
Bryce, S.A., Hughes, R.M., Kaufmann, P.R., 2002. Development of a bird integrity index: using bird assemblages as indicators of riparian condition. Environ. Manage. 30, 294–310. https://doi.org/10.1007/s00267-002-2702-y.
Cameron, R.A.D., Pokryszko, B.M., 2005. Estimating the species richness and composition of land mollusc communities: problems, consequences and practical advice. J. Conchol. 38, 529–547.
Castella, E., Speight, M., Obrdlik, P., Schneider, E., Lavery, T., 1994. A methodological approach to the use of terrestrial invertebrates for the assessment of alluvial wetlands. Wetl. Ecol. Manage. 3, 17–36.
Cejka, T., Hamerlik, L., 2009. Land snails as indicators of soil humidity in Danubian woodland (SW Slovakia). Pol. J. Ecol. 57, 741–747.
Čejka, T., Horsák, M., Némethová, D., 2008. The composition and richness of Danubian floodplain forest land snail faunas in relation to forest type and flood frequency. J. Molluscan Stud. 74, 37–45. https://doi.org/10.1093/mollus/eym041.
Czarnecka, M., 2016. Coarse woody debris in temperate littoral zones: implications for biodiversity, food webs and lake management. Hydrobiologia 767, 13–25. https://doi.org/10.1007/s10750-015-2502-z.
Czógler, K., Rotarides, M., 1938. Analyse einer vom Wasser angeschwemmten Molluskenfauna. Arb. Ungar. Biol. Forsch. Inst. 10, 8–43.
Dallinger, R., 1994. Invertebrate organisms as biological indicators of heavy metal pollution. Appl. Biochem. Biotechnol. 48, 27–31.
Davies, P.E., Nelson, M., 1994. Relationships between riparian buffer widths and the effects of logging on stream habitat, invertebrate community composition and fish abundance. Mar. Freshw. Res. 45, 1289–1305.
De Souza, M.M., Louzada, J., Eduardo Serráo, J., Cola Zanuncio, J., 2010. Social wasps (Hymenoptera: Vespidae) as indicators of conservation degree of riparian forests in Southeast Brazil. Sociobiology 56, 387.
Dörge, N., Walther, C., Beinlich, B., Plachter, H., 1999. The significance of passive transport for dispersal in terrestrial snails. Z. Ökologie u Naturschutz. 8, 1–10.
Douglas, D.D., Brown, D.R., Pederson, N., 2013. Land snail diversity can reflect degrees of anthropogenic disturbance. Ecosphere 4, 1–14. https://doi.org/10.1890/ES12-00361.1.
Falkner, G., Obrdlík, P., Castella, E., Speight, C.C., 2001. Shelled gastropoda of western Europe. Friedrich-Held-Gesellschaft, München.
Foeckler, F., Deichner, O., Schmidt, H., Castella, E., 2006. Suitability of molluscs as bioindicators for meadow- and flood-channels of the Elbe-Floodplains. Int. Rev. Hydrobiol. 91, 314–325. https://doi.org/10.1002/iroh.200610887.
Geburek, T., Milasowszky, N., Frank, G., Konrad, H., Schadauer, K., 2010. The Austrian forest biodiversity index: all in one. Ecol. Indic.10, 753-761. https://doi.org/10.1016/j.ecolind.2009.10.003.
Gerlach, J., Samways, M., Pryke, J., 2013. Terrestrial invertebrates as bioindicators: an overview of available taxonomic groups. J. Insect Conserv. 17, 831–850. https://doi.org/10.1007/s10841-013-9565-9.
Gheoca, V., 2013. Factors affecting *Helix pomatia* edible landsnail's populations in Southern Transylvania. Acta Oecol. Carp. VI 85–94.
Gonzáles del Tánago, M.G., de Jalón, D.G., 2006. Attributes for assessing the environmental quality of riparian zones. Limnetica 25, 389–402. https://doi.org/10.23818/limn.25.27.
González, E., Felipe-Lucia, M., Bourgeois, B., Boz, B., Nilsson, C., Palmer, G., Sher, A.A., 2017. Integrative conservation of riparian zones. Biol. Conserv. 211, 20–29. https://doi.org/10.1016/j.biocon.2016.10.035.
Hanna, D.E., Raudsepp-Hearne, C., Bennett, E.M., 2020. Effects of land use, cover, and protection on stream and riparian ecosystem services and biodiversity. Conserv. Biol. 34, 244–255. https://doi.org/10.1111/cobi.13348.
Harmon, M.E., Franklin, J.F., Swanson, F.J., Sollins, P., Gregory, S.V., Lattin, J.D., Cummins, K.W., 1986. Ecology of coarse woody debris in temperate ecosystems. Adv. Ecol. Res. 15, 133–302. https://doi.org/10.1016/S0065-2504(08)60121-X.
Horáčková, J., Podroužková, Š., Juřičková, L., 2015. River floodplains as habitat and bio-corridors for distribution of land snails: their past and present. J. Landsc. Ecol. 8, 23–39. https://doi.org/10.1515/jlecol-2015-0012.
Horsák, M., Juřičková, L., Kintrová, K., Hájek, O., 2009. Patterns of land snail diversity over a gradient of habitat degradation: a comparison of three Czech cities. Biodiv, Conserv. 18, 3453–3466. https://doi.org/10.1007/s10531-009-9654-y.
Hughes, F.M., Rood, S.B., 2003. Allocation of river flows for restoration of floodplain forest ecosystems: a review of approaches and their applicability in Europe. Env. Manage. 32, 12–33. https://doi.org/10.1007/s00267-003-2834-8.
Ilg, C., Foeckler, F., Deichner, O., Henle, K., 2009. Extreme flood events favour floodplain mollusc diversity. Hydrobiologia 621, 63–73. https://doi.org/10.1007/s10750-008-9632-5.
Jansen, A., Robertson, A., Thompson, L., Wilson, A., 2004. Development and application of a method for the rapid appraisal of riparian condition, River Management Technical Guideline no. 4. Land and Water Australia, Canberra.
Jiménez-Carmona, F., Heredia-Arévalo, A.M., Reyes-López, J.L., 2020. Ants (Hymenoptera: Formicidae) as an indicator group of human environmental impact in the riparian forests of the Guadalquivir river (Andalusia, Spain). Ecol. Indic. 118, 106762 https://doi.org/10.1016/j.ecolind.2020.106762.
Kappes, H., Topp, W., Zach, P., Kulfan, J., 2006. Coarse woody debris, soil properties and snails (Mollusca: Gastropoda) in European primeval forests of different environmental conditions. Eur. J. Soil Biol. 42, 139–146. https://doi.org/10.1016/j.ejsobi.2005.12.003.
Kappes, H., Jordaens, K., Hendrickx, F., Maelfait, J.P., Lens, L., 2009. Response of snails and slugs to fragmentation of lowland forests in NW Germany. Landsc Ecol. 24, 685–697. https://doi.org/10.1007/s10980-009-9342-z.
Lees, A.C., Peres, C.A., 2008. Conservation value of remnant riparian forest corridors of varying quality for Amazonian birds and mammals. Conserv. Biol. 22, 439–449. https://doi.org/10.1111/j.1523-1739.2007.00870.x.
Locasciulli, O., Boag, D.A., 1987. Microdistribution of terrestrial snails (Stylommatophora) in forest litter. Can. Field-Nat. 101, 76–81.
López-Baucells, A., Casanova, L., Puig-Montserrat, X., Espinal, A., Páramo, F., Flaquer, C., 2017. Evaluating the use of Myotis daubentonii as an ecological indicator in Mediterranean riparian habitats. Ecol. Indic. 74, 19–27. https://doi.org/10.1016/j.ecolind.2016.11.012.
Mac Nally, R., Parkinson, A., Horrocks, G., Conole, L., Tzaros, C., 2001. Relationships between terrestrial vertebrate diversity, abundance and availability of coarse woody debris on south-eastern Australian floodplains. Biol. Conserv. 99, 191–205. https://doi.org/10.1016/S0006-3207(00)00180-4.
Milborrow, S., 2020. rpart.plot: Plot 'rpart' Models: An Enhanced Version of 'plot.rpart'. R package version 3.0.9. https://CRAN.R-project.org/package=rpart.plot.
Müller, J., Strätz, C., Hothorn, T., 2005. Habitat factors for land snails in European beech forests with a special focus on coarse woody debris. Eur. J. For. Res. 124, 233–242. https://doi.org/10.1007/s10342-005-0071-9.
Munné, A., Prat, N., Sola, C., Bonada, N., Rieradevell, M., 2003. A simple field method for assessing the ecological quality of riparian habitat in rivers and streams: QBR

index. Aquat. Conserv. Mar. Freshw. Ecosyst. 13, 147–163. https://doi.org/10.1002/aqc.529.

Naiman, R.J., Decamps, H., Pollock, M., 1993. The role of riparian corridors in maintaining regional biodiversity. Ecol. Appl. 3, 209–212. https://doi.org/10.2307/1941822.

Nilsson, C., Berggren, K., 2000. Alterations of riparian ecosystems caused by river regulation: Dam operations have caused global-scale ecological changes in riparian ecosystems. How to protect river environments and human needs of rivers remains one of the most important questions of our time. BioScience 50, 783–792. https://doi.org/10.1641/0006-3568(2000)050[0783:AORECB]2.0.CO;2.

Norden, B., Appelqvist, T., 2001. Conceptual problems of ecological continuity and its bioindicators. Biodivers. Conserv. 10, 779–791. https://doi.org/10.1023/A:1016675103935.

Oehlmann, J., Schulte-Oehlmann, U., 2003. Molluscs as bioindicators. Trace Metals other Contam. Environ. Elsevier 6, 577–635.

Petersen Jr, R.C., 1992. The RCE: a riparian, channel, and environmental inventory for small streams in the agricultural landscape. Freshw. Biol. 27, 295–306. https://doi.org/10.1111/j.1365-2427.1992.tb00541.x.

Pfenninger, M., Posada, D., 2002. Phylogeographic history of the land snail Candidula unifasciata (Helicellinae, Stylommatophora): fragmentation, corridor migration, and secondary contact. Evolution 56, 1776–1788. https://doi.org/10.1111/j.0014-3820.2002.tb00191.x.

Pokryszko, B.M., Cameron, R.A.D., 2005. Geographical variation in the composition and richness of forest snail faunas in northern Europe. Rec. West. Aust. Mus. Suppl. 68, 115–132. https://doi.org/10.18195/issn.0313-122x.68.2005.115-132.

Primack, R.B., Sher, A., Sher, A.A., 2016. Introduction to conservation biology. Sinauer Associates, Incorporated, Publishers.

R Core Team, 2018. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna. https://www.R-project.org.

Raheem, D.C., Naggs, F., James Chimonides, P.D., Preece, R.C., Eggleton, P., 2009. Fragmentation and pre-existing species turnover determine land-snail assemblages of tropical rain forest. J. Biogeogr. 36, 1923–1938. https://doi.org/10.1111/j.1365-2699.2009.02136.x.

Sabo, J.L., Sponseller, R., Dixon, M., Gade, K., Harms, T., Heffernan, J., Welter, J., 2005. Riparian zones increase regional species richness by harboring different, not more, species. Ecology. 86, 56–62. https://doi.org/10.1890/04-0668.

Schilthuizen, M., Liew, T.S., Elahan, B.B., Lackman-Ancrenaz, I., 2005. Effects of karst forest degradation on pulmonate and prosobranch land snail communities in Sabah, Malaysian Borneo. Conserv. Biol. 19, 949–954. https://doi.org/10.1111/j.1523-1739.2005.00209.x.

Schultz, R.C., Isenhart, T.M., Simpkins, W.W., Colletti, J.P., 2004. Riparian forest buffers in agroecosystems–lessons learned from the Bear Creek Watershed, central Iowa. USA. Agrofor. Syst. 61, 35–50. https://doi.org/10.1023/B:AGFO.0000028988.67721.4d.

Šmilauer, P., Lepš, J., 2014. Multivariate analysis of Ecological Data Using CANOCO 5. Cambridge University Press.

Sólymos, P., Kemencei, Z., Páll-Gergely, B., Farkas, R., Vilisics, F., Hornung, E., 2009. Does shell accumulation matter in micro-scale land snail surveys? Malacologia 51, 389–393. https://doi.org/10.4002/040.051.0211.

Ström, L., Hylander, K., Dynesius, M., 2009. Different long-term and short-term responses of land snails to clear-cutting of boreal stream-side forests. Biol. Conserv. 142, 1580–1587. https://doi.org/10.1016/j.biocon.2009.02.028.

Ter Braak C.J.F., Šmilauer P., 2018. Canoco for Windows Version 5.10. Biometris – Plant Research International, Wageningen.

Therneau, T., Atkinson, B., 2019. rpart: Recursive Partitioning and Regression Trees. R package version 4.1-15. https://CRAN.R-project.org/package=rpart.

Venables, W.N., Ripley, B.D., 2002. Modern Applied Statistics with S, Fourth Edition. Springer, New York.

Ward, T.A., Tate, K.W., Atwill, E.R., 2003. Visual Assessment of Riparian Health. University of California, Rangeland Monitoring Series.

Williams, K.S., 1993. Use of terrestrial arthropods to evaluate restored riparian woodlands. Restor. Ecol. 1, 107–116. https://doi.org/10.1111/j.1526-100X.1993.tb00016.x.