Original Articles

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

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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 (Gonzalez 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...
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 (Münné et al., 2003; Ward et al., 2003; Booth et al., 2007), while others focus on stream and bank morphology (Peterson, 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 (Münné et al., 2003). One metric that includes vegetation structure and river bank morphology is the Riparian Quality Index (RQI) (González 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 complements 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 Hamerlík, 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; Cejka et al., 2008; Cejka and Hamerlík, 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 Hartibaciu Sud-Est, and ROSCI0304 Hartibaciu 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, Anthiscus sylvester, Rumex oblongifolius. 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 Telkia 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, Hartibaciu, 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
were considered in the analyses to reduce the bias due to floods that can wash away autochthonous shells and redeposit allochthonous shells (Sólomos 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 m² 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.

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

![Fig. 1. Map of the study area showing the location of sample sites.](image-url)
the old tree cover, parameters used in other evaluation methods for forest quality (González 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 Smilauer, 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 (Smilauer and Leps, 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 (Smilauer and Leps, 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 < 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 Smilauer, 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). Carychiium tridentatum had the highest abundance, but other microsnails such as Punctum pygmaeum, Truncatellina cylindrica, and Vollandia costata were also abundant. Among the larger species, Fruticula fruticula, Aegopinella epipedostoma, Lacinaria 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.

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

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 (R² 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 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.

3.3. Diversity of land snails

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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, Cochlidia lamiata, Clausilia cruciata, Bulgarica cana, and microsnails like C. tridentatum and V. 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, Macrosogastra tamida, Cochlicopa lubrca, Vestia elata, and Pomatias rivialaris were significantly affected by the abundance of logs, having a positive response, while Helix lutescens, Causacotachea 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 loss smoother model was R² = 70.5. The number of identified species increased with both habitat characteristics, especially abundance of logs (Fig. 2b).

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, R² 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, R² 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 (R² 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 = 26.7, R² 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/sampling 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 species were typical woodland species, some of them being characteristic for alluvial forests (e.g., Pseudotrichia rubiginosa, Monachoides incarnatus, M. vicinus, Vestia sulo). Others were eurybiotic species (e.g.,...
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 Czögler 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 (Dörgé et al., 1999; Plenninger 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). 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...
Boog, 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 major 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 (Storm 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.

Livyatan (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 autochthonous 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 anthropophilic snail species with the increase of human disturbance (Horská 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

Voichia Gheoca: Conceptualization, Methodology, Investigation, Formal analysis, Data curation, Writing – original draft. Ana Maria Benedek-Sirbu: 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.

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Appendix A. Supplementary data

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References


