Acta Oecologica 82 (2017) 16–22

Contents lists available at ScienceDirect

Acta Oecologica

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

Calcareous forest seepages acting as biodiversity hotspots and refugia for woodland snail faunas

Michal Horsák*, Eva Tajovská, Veronika Horsáková

Department of Botany and Zoology, Masaryk University, Brno, Czech Republic

A R T I C L E I N F O

Article history:
Received 16 January 2017
Accepted 13 May 2017
Available online 22 May 2017

Keywords:
Biodiversity hotspots
Conservation
Forest seepages
Land snails
Refugia

A B S T R A C T

Land-snail species richness has repeatedly been found to increase with the increasing site calcium content and humidity. These two factors, reported as the main drivers of land-snail assemblage diversity, are also among the main habitat characteristics of calcareous seepages. Here we explore local species richness and compositional variation of forest spring-fed patches (i.e. seepages), to test the hypothesis that these habitats might act as biodiversity hotspots and refugia of regional snail faunas. In contrast to treeless spring fens, only little is known about land snail faunas inhabiting forest seepages. Studying 25 isolated calcareous forest seepages, evenly distributed across the White Carpathians Protected Landscape Area (SE Czech Republic), we found that these sites, albeit spatially very limited, can harbour up to 66% of the shelled land-snail species known to occur in this well-explored protected area (in total 83 species). By comparing land snail assemblages of the studied seepages with those occurring in the woodland surroundings of each site as well as those previously sampled in 28 preserved forest sites within the study area, we found the seepages to be among the most species rich sites. Although the numbers of species did not statistically differ among these three systems, we found highly significant differences in species composition. Seepage faunas were composed of many species significantly associated with spring sites, in contrast to the assemblages of both surrounding and preserved forest sites. Our results highly support the hypothesis that calcareous forest seepages might serve as refugia and biodiversity hotspots of regional land snail faunas. Protection of these unique habitats challenges both conservation plans and forest management guidelines as they might act as sources for the recolonization and restoration of forest snail assemblages particularly in areas impoverished by harvesting and clearcutting.

1. Introduction

Springs and seepages are unique and spatially limited ecosystems of isolated nature, acting as important biodiversity hotspots, occupied by many highly endangered species and habitat specialists (Hájek et al., 2011; Horsák et al., 2015). Due to a constant source of groundwater, which can further alter a local chemistry of the spring area, spring-fed patches might act as island-like habitats of a high ecological contrast (Watson, 2002; Hubáčková et al., 2016). Biotic communities of spring areas are influenced by various environmental factors, mainly associated with groundwater chemistry (Hájek et al., 2006), but also by dispersal capacities of individual taxa (Rádková et al., 2014), and further modified by biogeographical processes such as historical continuity of the habitats and their historical frequency (Hájek et al., 2007).

There are various types of spring habitats, sharply differing in their water chemistry (from calcareous to acidic; Hájek et al., 2006), spring area (from only few square meters to several hectares; Horsák et al., 2012) and community age (from tens to thousands years; Horsák et al., 2012). Last, but not least, the presence of trees and shrubs highly influences the composition of herb-layer vegetation and mosses, as well as various groups of invertebrates (e.g. Hájek et al., 2006). While there is a growing body of literature dealing with treeless spring communities (e.g. Horsák, 2006; Hájek et al., 2007; Horsák et al., 2015), only little is known about forest spring-fed areas, though they represent a contrasting type of spring habitats. Several studies dealt with the vegetation of acid springs (Strohbach et al., 2009; Schweiger and Beierkuhnlein, 2014), showing that the vegetation of spring-fed areas is mainly controlled by local conditions (Pielech et al., 2015), and is more species rich than the other riparian forest habitats (Kuglerová et al., 2014). However, we have only very limited data on soil-dwelling

* Corresponding author.
E-mail address: horsak@sci.muni.cz (M. Horsák).

http://dx.doi.org/10.1016/j.actao.2017.05.006
1146-609X/

invertebrates such as molluscs, although they are likely to develop species rich assemblages in spring-fed forest habitats, mainly in the calcareous types (Horsák, 2006).

Four minute land-snail species of the genus *Vertigo*, mostly having a tight affinity to spring habitats, have become protected under Annex II of the European Union's Habitat Directive (92/43/EEC). This triggered an intensive regional research of land snail assemblages at treeless spring habitats, mainly fens, across Europe under the NATURA 2000 mapping program. Fen mollusc communities were found to be driven mainly by water chemistry (Horsák and Hájek, 2003), climate and geographical isolation (Horsák and Cernohorsky, 2008), hydrology (Schenková et al., 2014) and habitat size (Horsák et al., 2012). Treeless spring fens have been proven as biodiversity hotspots and important refugia harbouring many highly endangered species including several Late Glacial relicts (Hájek et al., 2011; Schenková and Horsák, 2013). However, no study has dealt with forest springs so far, to investigate diversity and variation of local land snail assemblages. Thus, it is not known whether these ecologically specific habitats harbour any exclusive species or assemblages of unique species composition, which cannot be found elsewhere in the surroundings matrix. If so, they can be considered refugia (Pielou, 1979; Nekola, 1999), also acting as important regional biodiversity hotspots.

It this study, we aim to explore land-snail assemblages of spatially-limited calcareous forest seepages in a protected landscape area, characterized by a frequent occurrence of these habitats (Dvořáková et al., 2011). As land snails are known to favour sites of high amounts of calcium (Juřičková et al., 2008) and mostly also of a high humidity (Hettenbergerová et al., 2013), calcareous spring-fed areas might provide very favourable conditions for land snails. Therefore, we explored and analysed species richness and composition variation at 25 isolated spring-fed forest areas, evenly distributed across the study area. We tried to cover the highest possible variation in habitat size, elevation, tufa (i.e. calcium carbonate) formation, and water table level across the area. To assess possible ecological contrast and potential refugial nature of these spring-fed patches, we also explored woodland land-snail faunas in the surroundings of each study site. We then compared the assemblages of spring-fed patches with those of the surrounding woodland areas, and in addition, with the 28 preserved and species-rich forest sites in the region. We hypothesized that if the spring-fed patches serve as refugia of forest snail fauna, they should express significantly higher species richness and/or significantly different composition from that of the surrounding woodland habitats. They should also host a set of species preferentially inhabiting these spring-fed areas.

2. Material and methods

2.1. Study sites and area

In August and September 2009–2012 we quantitatively sampled land snails in 25 isolated and preserved forest spring sites, located in areas of preserved deciduous forest stands and being evenly distributed across the White Carpathians Protected Landscape Area (Fig. 1). The bedrock of the study area is composed of calcium rich flysch sediments, which supports a high frequency of calcareous springs and seepages (Hájek et al., 2011). All study sites have a strong calcium carbonate precipitation (i.e. tufa formation).

2.2. Measuring environmental variables

For each site, characterized by geographical coordinates measured with a GPS in the field, we established following eight environmental variables. Water pH and electric conductivity were measured at three places within each plot, using portable instruments (CM 101 and PH 119, Snail Instruments, Beroun, Czech Republic); the mean value was calculated and used in the analyses. Elevation was measured with a GPS in the field, and checked against 1:50,000 topographic maps. The area of each spring-fed patch was determined in the field. Amount of fallen wood, representation of tufa, and water table level were estimated in the field at relative four-grade (water table) or five-grade (wood and tufa) scales, with 1 representing the category of the lowest value and 4 or 5 of the highest values, respectively. These variables were expected to be the most important drivers of snail assemblages based on literature data (e.g. Horsák and Cernohorsky, 2008), and to be describing well the environmental variation of the study system. We also calculated total transmitted solar radiation (on average 12.56 mol m^{-2} d^{-1}) by taking canopy photographs at each spring area. As there was no effect on both snail species richness and composition detected ($P \gg 0.05$; data not shown), we excluded this variable from final analyses and used only seven out of these eight variables.

2.3. Snail sampling and sample processing

At each site, snails were searched by eye for 90 min interval over the entire seepage area as the sites were of comparable sizes (varied between 30 and 60 m^2). In the central part of each site, a litter sample was collected from four quadrates of 25 × 25 cm to the depth of 5 cm. These samples were air dried and all snail shells were sorted out in the laboratory. All shells collected at the site were identified to the species level based on Horsák et al. (2013) and sorted to fresh shells with the entire periostracum (including snails alive in the time of sampling and dead within approx. the same year) and the rest, representing shells of variable age. The latter were not used in the analyses as they might include also species not living at the site any longer. For each of the 25 spring sites, snail assemblages of the surrounding forest habitats were sampled, in the area defined within the circles of 10 and 30 m distances from the edge of a spring patch. The samples were processed using the same protocol as described above. For further comparison we also used data about snail assemblages of 28 preserved forest sites across the study area, collected within an extensive survey of land-snail fauna at more than 430 sites in the White Carpathians (Dvořáková et al., 2011). The choice of samples was constrained to sites (i) explored by using both hand picking and litter sampling, (ii) evenly distributed across the entire study area and if possible also located close to the study spring sites each, and (iii) covering the same range of species richness as found at the spring sites from the minimum to the maximum number of species within the whole dataset (Dvořáková et al., 2011).

2.4. Statistical analyses

Prior the analyses we excluded all shell fragments and shells with a damaged periostracum, suggesting that these snail individuals died more than 1–2 years ago (Davies and Grimes, 1999). We also excluded all slugs, represented by only few species and individuals of rather accidental records, as the sampling method was not appropriate for their sufficient detection (Cameron and Pokryszko, 2005), especially at the surrounding habitats, as these were mostly drier than spring areas. We also excluded five species of freshwater molluscs as they were mostly restricted to the spring areas, thus they would promote a trivial contrast between spring areas and surrounding forest environments. Differences in the species richness among habitat types and relationships between the number of species recorded at spring areas and seven environmental variables were analysed using Generalized Linear