Investigating the influence of habitat type and weather conditions on the population dynamics of land snails *Vertigo angustior* Jeffreys, 1830 and *Vertigo moulinsiana* (Dupuy, 1849). A case study from western Poland

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ABSTRACT

The conservation of land snails has become an urgent issue because of the current global decline of this group. Detailed knowledge of population dynamics is needed to develop an appropriate strategy for conservation. We investigated the population dynamics of two threatened European land snail species: *Vertigo angustior* and *Vertigo moulinsiana*. Although the species may be found at the same site, *V. moulinsiana* is more tolerant of wetter conditions than is *V. angustior*. Abundance data for the two species were collected at two sites (one drier and one wetter) in western Poland biweekly during the spring and summer months in 2008 and 2009. In the drier year, snail abundance was similar between the drier and wetter sites. In the wetter year, snail abundances were generally higher than in the dry year, except that the inundation-intolerant *V. angustior* became less abundant at the wetter site. We conclude that weather affects different species differently and therefore should be considered along with the habitat features in interpreting survey results for land snails.

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Introduction

The global decline of land snails has been well documented (Lydeard et al. 2004; Régnier et al. 2009). This fact, combined with their significant role in ecosystem services (e.g. litter decomposition and nutrient cycling; Mason 1970; Graveland et al. 1994; Cook 2001; Bardgett 2005), has meant that the conservation of land snails has become an urgent issue. Species protection however, may only be efficient when the biology and ecology of an organism is well known (Pokryszko 2003). Such data are essential for developing reliable monitoring methods for a particular species, to better understand the factors affecting population dynamics.

As the dispersal abilities of land snails are limited, fluctuations in population densities are shaped mainly by death and birth rates (e.g. Wiktor and Riedel 2002). Furthermore, for limited-dispersal species such as land snails, high life-cycle plasticity greatly increases

the chances of survival. As a result, land snails exhibit significant variability in population dynamics, in response to varying environmental conditions (Madec et al. 2000; Heller 2001; Myzyk 2011; Sulikowska-Drozd 2011).

Two major environmental factors have been recognized as governing land snail activity and hence their reproduction, maturation rates and survival, namely: temperature and moisture (Cameron 1970a, 1970b; Boag 1985; Pokryszko 1990a). It has been shown that frequency of oviposition and number of eggs laid are dependent on moisture levels (Baker 1969; Shirley et al. 2001; Carne-Cavagnaro et al. 2006). Specific levels of moisture and temperatures may, however, affect particular species of land snails differently (Cameron 1970a, 1970b).

Understanding the impact of environmental conditions on population density is essential for the proper interpretation of monitoring results. In this study we track the population dynamics of *Vertigo angustior* Jeffreys 1830 and *Vertigo moulinsiana* (Dupuy 1847–1852). Both species inhabit wetland environments, mainly fens and sedge meadows, however they have slightly different microhabitat requirements (Jankowiak and Bernard 2013; Książkiewicz et al. 2013). *Vertigo angustior* prefers moist but not inundated areas, whereas populations of *V. moulinsiana* flourish in highly humid environments, and may occur in temporarily inundated areas (Pokryszko 1990b; Cameron 2003; Tattersfield and McInnes 2003; Killeen 2003a, 2003b). These two species are threatened across Europe (annex II of the EU Habitat Directive) and their decline is mainly due to habitat disturbances such as eutrophication and drying out (e.g. Pokryszko 2003; Moorkens and Killeen 2011).

In this study we tested the hypothesis that the population dynamics of *V. angustior* and *V. moulinsiana* are asynchronous in sites differing in hydrological conditions; i.e. a locally inundated site and a partially dried out site. We interpreted our results with respect to weather conditions, especially precipitation, because its lack affects water levels. Our research was conducted on two nearby sites with different hydrological conditions in western Poland: one site was locally inundated whereas the second site was partially dried out. Surveys were carried out during spring and summer in 2008 and 2009.

Material and methods

Study area

The research was conducted on two sites which differ in local hydrological conditions: in the Pliszka site, which was locally inundated (mosaic of moist and locally inundated patches), and in the Ilanka site, which was partially dried out (mosaic of moderately moist and partially dried patches). Surveys were carried out during two growing seasons in 2008 and 2009. These studied sites are located in the valleys of small lowland rivers: Pliszka and Ilanka. Both rivers have similar parameters: their lengths do not exceed 60 km and their catchment areas are approximately 440 km². Both rivers are also tributaries of the Odra River: the Ilanka flows into the Odra at 566.9 km along the river course and the Pliszka enters at 578.7 km (IOŚ 2002).

Annual temperatures in the study area range between 8.0 and 8.4°C (average January temperature ranges from 1.0 to 1.5°C, the average temperature in July is approximately

18°C). Annual precipitation ranges from 550 to 650 mm, with snow cover for about 40–60 days, and the growing season lasts 220–230 days (Prawdź and Koźmiński 1972).

Figure 1(A) and Figure 2(A) show the average monthly temperatures and precipitation levels at the Słubice meteorological station (approximately 35 km from the study area) for the years 2008 and 2009 (data from the Institute of Meteorology and Management, National Research Institute, Poland).

Study sites

The Pliszka site (52°14'46.5" N, 15°10'11.1" E; c. 0.20 ha in area) is treeless and locally inundated (approximately 35% of the site is a permanent marsh wetland). Water levels varied from –20 cm to +5 cm above the land surface during the period of our study, with a pH $\approx$ 7.8. The plant cover was usually lush and the most abundant plant species in the site were *Carex acutiformis*, *Carex paniculata* and *Thelypteris palustris*. However, the central part of the site was predominantly covered with mosses (Książkiewicz et al. 2013).

The site in the Ilanka river valley (52°20'09.7" N, 15°03'07.3" E; c. 0.15 ha in area) is approximately 7 km from the Pliszka site. It is densely covered by *C. acutiformis* and has undergone local eutrophication, indicated by the presence of the nettle species, *Urtica dioica*. The site has not been inundated for the previous 10 years. Groundwater levels varied from –20 cm to –5 cm during the period of our study, with a pH $\approx$ 7.6 (Książkiewicz et al. 2013).

Both of the studied sites had a similar character (i.e. they were calcareous fens) in the past (Stańko and Wołejko 2001; Wołejko et al. 2001).

Data collection

Both sites were sampled biweekly during the spring and summer months in 2008 (nine sampling events in Pliszka, ten in Ilanka) and 2009 (seven in Pliszka; seven in Ilanka). The first sampling was undertaken at the Ilanka site in April 2008 to calibrate the methodology.

At each site, four parallel transects were laid out; along each of the transects, four samples of litter were collected at 10-m intervals using a 0.25 $\times$ 0.25-m Økland frame (0.0625 m² in area) (Økland 1929).

Methodology described by Sharland (according to Cameron 2003) was applied for the collection of material within the frame. All vegetation was collected to ground level, loose litter was harvested and soil and root-mats were cut to a depth of 5 cm. In the laboratory, litter and soil samples were dried and divided into two fractions using a 0.5-mm mesh sieve. Particles passing through the sieve were examined manually for the presence of snails under a stereomicroscope. The retained fraction and cut plants were carefully examined for snails using a magnifying glass. Only living individuals were included for further analysis, which were divided into adults (with apertural barriers fully developed) and juveniles. In some plots, after the heavy rain, collection of material was impossible. To standardize data, population dynamics (i.e. changes in species densities in particular sampling events), are presented as the number of individuals per square metre.

Figure 1. (A) Precipitation in the studied sites in consecutive months of 2008; dashed bars – sampling months. (B) and (C) Abundance of individuals: juveniles (white bars) and adults (black bars) of *Vertigo angustior* (B) and *Vertigo moulinsiana* (C) in each sampling event in the Ilanka and Pliszka sites in 2008.

SEASON 2

Figure 2. Precipitation in the studied sites in consecutive months of 2009; dashed bars – sampling months. (B) and (C) Abundance of individuals: juveniles (white bars) and adults (black bars) of *Vertigo angustior* (B) and *Vertigo moulinsiana* (C) in each sampling event in the Ilanka and Pliszka sites in 2009.

Statistical analyses

We used Rndom Pro 3.14 software for statistical analyses. A one-way analysis of covariance (ANCOVA) test was used to compare abundances of *V. angustior* and *V. moulinsiana* between the two studied sites in particular seasons. Sites (i.e. Ilanka – 1; Pliszka – 2) was the grouping variable, sampling event was a covariable and the dependent variable was the log-transformed number of individuals of *V. angustior* or *V. moulinsiana* collected in each sampling event.

Results

During the study, a total of 6585 individual vertiginids were collected: 6430 *V. angustior* (Ilanka 2008, 2012 individuals and 2009, 3578 individuals; Pliszka 2008, 671 individuals and 2009, 169 individuals) and 155 *V. moulinsiana* (Ilanka 2008, 20 individuals and 2009, 42 individuals; Pliszka 2008, 13 individuals and 2009, 80 individuals).

In 2008, the abundance of *V. angustior* was not significantly different in the Ilanka and Pliszka sites (one-way ANCOVA: $F = 2.665$; $p = 0.104$; Ilanka: mean = 1.74, SD = 1.40; log-transformed number of individuals; Pliszka: mean = 1.40, SD = 1.06), the same for *V. moulinsiana* ($F = 0.036$; $p = 0.850$; Ilanka: mean = 0.1, SD = 0.28; log-transformed number of individuals; Pliszka: mean = 0.04, SD = 0.26). The mean density of *V. angustior*, however, was higher in the non-inundated Ilanka site (129 individuals/m²) than in the locally inundated Pliszka site (48 individuals/m²). The lowest recorded density of *V. angustior* in the Ilanka site was detected in the test sampling (28 April, 42 individuals/m²) (Figure 1B). After April, the density gradually increased till the end of the season (reaching a maximum in September: 1224 individuals/m²) with one slight decline at the end of June (30 June). In the case of the Pliszka site, the lowest abundance (53 individuals/m²) was noted on 22 July, whereas the highest (146 individuals/m²) was on 29 September.

Mean density of *V. moulinsiana* was 1.3 individuals/m² in the Ilanka site and 1 individual/m² in the Pliszka site (Figure 1C). The number of individuals of the species was very low in the season so we did not analyse abundance in regard to weather conditions.

In contrast to 2008, abundance differences between sites were statistically significant in 2009 for both *V. angustior* (one-way ANCOVA: $F = 92.16$; $p < 0.01$; Ilanka: mean = 1.48, SD = 2.62 log-transformed number of individuals; Pliszka: mean = 0.76, SD = 0.75) and *V. moulinsiana* ($F = 8.165$; $p < 0.01$; Ilanka: mean = 0.30, SD = 0.60; log-transformed number of individuals; Pliszka: mean = 0.37, SD = 0.74) in the study sites in 2009 (Figure 3). In accordance with weather conditions (i.e. higher precipitation in 2009 than in 2008), the inundation-intolerant species *V. angustior* had higher mean density the drier Ilanka site (266 individuals/m²) than in the locally inundated Pliszka site (14 individuals/m²). Among years, mean density of this species was higher in the Ilanka site and lower in the Pliszka site in the wetter season 2 in comparison with the drier season 1. In the Ilanka site, the lowest abundance of *V. angustior* was recorded in April (the first sampling event 28 April; 128 individuals/m²), whereas the highest was recorded on 3 August (1110 individuals/m²) (Figure 2B). In the Pliszka site the lowest abundance (16 individuals/m²) was recorded on 2 June, and the highest (54 individuals/m²) was on 13 September.

Figure 3. Diagram of one-way analysis of covariance test comparing a logarithmized number of individuals of *Vertigo angustior* ($F = 92.16$; $p < 0.01$) and *Vertigo moulinsiana* ($F = 8.165$; $p < 0.01$) in the Ilanka and Pliszka sites in 2009. Middle line: mean; box range: standard error; whiskers: standard deviation.

Vertigo moulinsiana had higher densities in the wetter season 2 than in season 1 in both the Ilanka and Pliszka sites. Mean density of the species in 2009 was higher in the locally inundated Pliszka site (7 individuals/m²) than in the non-inundated Ilanka site (3 individuals/m²). This vertiginid reached its lowest density on 29 June in both the Ilanka and Pliszka sites (Figure 2C). The highest density in the Ilanka site (16 individuals/m²) was recorded on 13 September and in the Pliszka site on 12 May (27 individuals/m²). In the Pliszka site no individuals of *V. moulinsiana* were found on 28 April.

Discussion

This study showed that population dynamics of the studied species was different (asynchronous) between the studied sites and this difference was associated with different hydrological conditions at the two sites. The population dynamics also varied when comparing changes in the densities of *V. angustior* and *V. moulinsiana*. In the first season of study, neither species differed in abundance between the two studied sites. In the second year, however, the density of *V. angustior* was significantly higher in the Ilanka site than in the Pliszka site and, conversely, the density of *V. moulinsiana* was significantly higher in the Pliszka site than in the Ilanka site.

Total precipitation was much higher in 2009 (season 2) than in 2008 (compare Figure 1A with Figure 2A), whereas the mean temperatures were similar across both seasons. In the Pliszka site, where water levels were relatively high (see Study sites section), heavy rains in season 2 contributed to extensive local inundation. In the partially dried out Ilanka site, however, such conditions contributed to the higher levels of substrate moisture, but without local inundation. *Vertigo angustior* prefers highly moist environments but avoids inundated areas (Cameron et al. 2003; Killeen 2003b), so season 2 in the Pliszka site was probably too wet for this species to

survive, which resulted in a lower mean abundance, in comparison with season 1. In the Ilanka site, the situation was the reverse – higher precipitation levels increased the litter moisture, resulting in a probable increase in the numbers of eggs laid by *V. angustior* (Myzyk 2011). In the case of *V. moulinsiana*, high water levels seem to be beneficial for its survival and can greatly affect population density (Tattersfield and McInnes 2003; Killeen 2003a). In this way, the high precipitation levels recorded in season 2 ‘improved’ habitat conditions in both sites for *V. moulinsiana*. In summary, the higher rainfall in season 2 apparently made the Pliszka site more inhospitable for *V. angustior*; however, the site became more hospitable for *V. moulinsiana*. At the same time, in the Ilanka site, environmental conditions improved for both species; considerably for *V. angustior* and slightly for *V. moulinsiana*. This led to statistically significant differences between the abundances of these two species in the studied sites in season 2.

Our study indicates that population dynamics of *V. angustior* and *V. moulinsiana* may be associated with weather conditions; for example in season 2, the highest abundance of *V. angustior* was recorded in August, after a wet July. At the same time, in the Pliszka site *V. angustior* reached the highest density in September, after 2 months of low precipitation. In the second season, abundances of *V. moulinsiana* in both the Ilanka and Pliszka sites were lowest at the end of June. The main loss of individuals was recorded in the juveniles, which are more prone to loss in unfavourable conditions (Pokryszko 1990a) such as high temperatures and low precipitation (see Figure 2A).

We found that the interaction of habitat characteristics and weather impacts snail populations and that both factors should be considered when interpreting monitoring results. In this study we tracked the population dynamics of two vertiginid species, which have differing optimum and tolerance ranges of hydrological conditions. These conditions, however, may change as weather changes. The habitat that promotes maintenance of both species populations is a mosaic of microhabitats (Cameron et al. 2003; Moorkens and Killeen 2011; Jankowiak and Bernard 2013), such mosaic habitats, however, are dynamic systems that may promote different species when particular weather conditions occur. Our results indicate that weather affects different species differently and therefore weather should be considered when interpreting survey results on land snails along with habitat characteristics. To maintain and promote the conservation of land snails, it is vital to sustain the variability of microhabitats within the site and so ensure refugia for species with different requirements.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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