

A fast snail's pace: colonization of Central Europe by Mediterranean gastropods

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Received: 2 December 2010 / Accepted: 6 October 2011 / Published online: 18 October 2011
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Abstract Central Europe faces an influx of terrestrial invertebrates from more southerly regions, in particular from the Mediterranean. This process is particularly noticeable among terrestrial gastropods. In the last 30 years, the number of non-native land snail species found outdoors in the Czech Republic increased from 5 to 15 (8% of all species); more than half of these have presumed Mediterranean origin. The trend has accelerated recently; seven new alien species (six Mediterranean) have been recorded since 2000. As the most recent example, we report the finding of a large helioid species from the South-East Mediterranean, *Helix lucorum*. A well-established overwintering population was found in Prague, over 400 km from

the nearest known localities of the species. This trend of newly established snails corresponds with increases in average temperatures as well as the intensity of foreign trade in the past six decades, suggesting a synergistic effect of both climatic conditions and socioeconomic factors.

Keywords *Helix lucorum* · New record · Long-range dispersal · Passive transport · Mediterraneanization · Czech Republic

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Central Europe currently faces an influx of expanding terrestrial invertebrates from more southerly regions that are often climate-restricted in their distribution. Due to the mostly Mediterranean geographical origin of such species, the related species composition changes have been fittingly termed “mediterraneanization” (Rabitsch 2008).

This enrichment by southern elements is particularly noticeable among terrestrial gastropods. Although snails are notoriously known for their limited ability for active dispersal, some spectacular range expansions aided by human activities have been recently observed in Europe. A good example is the continental-wide spread of the Lusitanian slug *Arion vulgaris* from its limited native range in Western Europe (Rabitsch 2006). This pest species causes substantial damage in agriculture and horticulture, and has attracted the attention of both researchers and the

public (e.g., Buschmann et al. 2005). Most other terrestrial gastropod colonizers in Europe are less conspicuous than this garden pest; however, even large shelled species can be found among them. We report here the finding of a newly established population of a large Mediterranean helioid species in Central Europe, and summarize the history and present state of the alien snail fauna in the Czech Republic, a region that may be strongly affected by “mediterraneanization” in the near future due to climate change and the increased intensity of transport that facilitates the passive dispersal of terrestrial fauna.

Until recently, the only species of the genus *Helix* (Gastropoda: Helicidae) present in the territory of the Czech Republic was the native Roman snail, *Helix pomatia*, which is the largest shelled terrestrial snail in the region. However, we have found in Prague an established and overwintering population of its congener *Helix lucorum*, which may attain even larger shell sizes (up to 6 cm in diameter). This species, native to the eastern Black Sea region, the Asian part of Turkey, the central Balkans, and parts of the eastern Mediterranean (Yildirim 2004), was discovered on September 22, 2009 close to the centre of Prague, at the former Žižkov freight railway station (50°05'04"N, 14°28'37"E). At the time of discovery, the local population density of *H. lucorum* suggested

successful overwintering and reproduction, and the ability of the species to overwinter was confirmed the following year, in spring 2010.

As the Prague site serves as a transfer area for truck (and previously train) transport, it is likely that the first individuals of *H. lucorum* were introduced with cargo or on vehicles. However, the origin of this population cannot be determined. The locality is almost 400 km from the nearest known populations of this species in Hungary, themselves also introduced (Varga et al. 2010). Several established populations are also known from Western Europe (in France, the Netherlands, and Spain; reviewed by Mienis and Rittner 2010). Thus, the original founders may have reached Prague not only directly from their native range, but also as a secondary introduction from either southeastern or western directions.

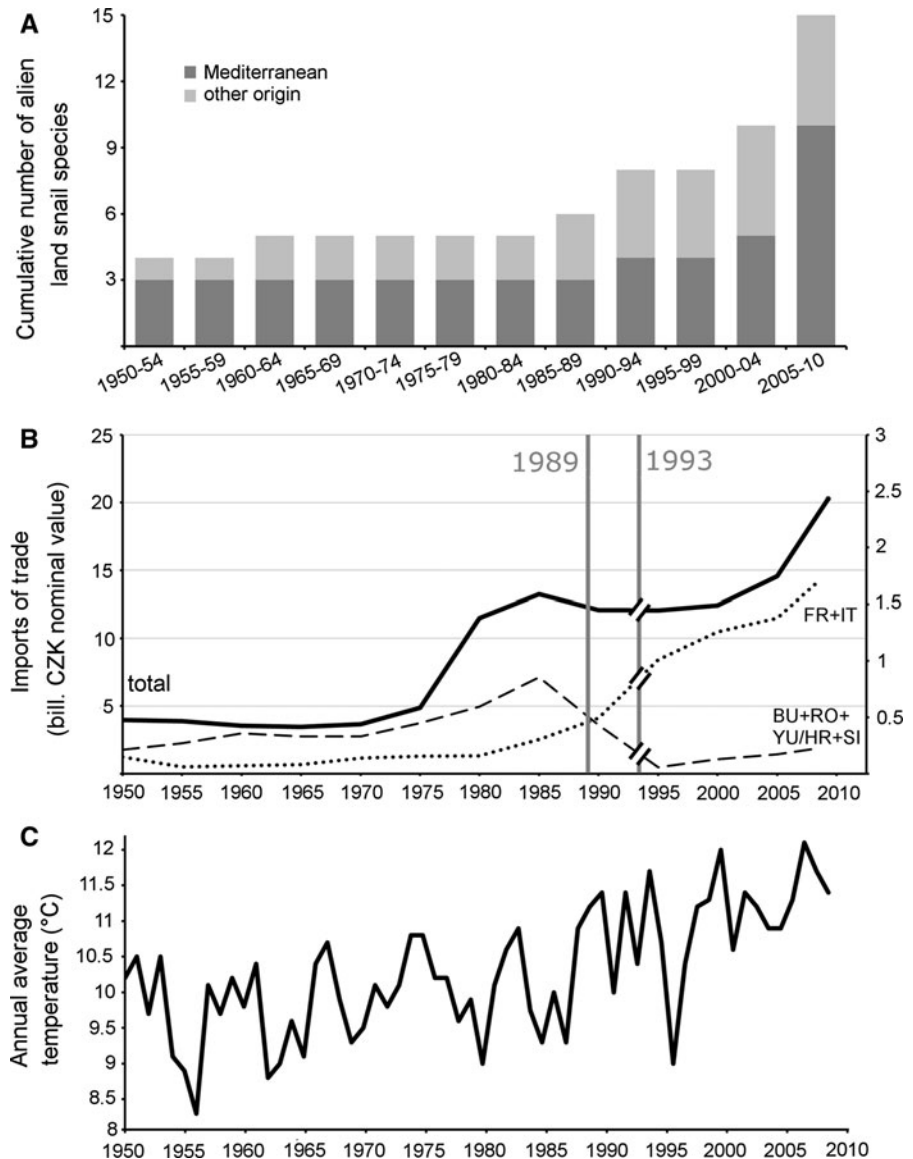
Helix lucorum is just the latest addition to an increasing list of alien terrestrial gastropod species in the Czech Republic (Table 1). Although the first, *Cepaea nemoralis*, was recorded at the end of the 19th century, there was only a slow increase in numbers of new snail species arriving over the next approximately 100 years (Table 1, Fig. 1). At present, over 8% of all land snail species found in the Czech Republic outdoors (as opposed to in greenhouses) are non-indigenous species that have colonized the country

Table 1 List of non-native terrestrial gastropods established outdoors in the Czech Republic (Juříčková 2006; Horsák et al. 2010), with the year an established population was first recorded

| Species name / family | First record | Original range |
|--|--------------|--------------------------------------|
| <i>Cepaea nemoralis</i> (Linnaeus, 1758)/Helicidae* | 1890s | Western Europe |
| <i>Monacha cartusiana</i> (Müller, 1774)/Hygromiidae* | 1935 | Mediterranean |
| <i>Oxychilus draparnaudi</i> (Beck, 1837)/Zonitidae | 1930s | Atlantic-Mediterranean |
| <i>Cermuella neglecta</i> (Draparnaud, 1805)/Hygromiidae* | 1950s | Western Mediterranean |
| <i>Boettgerilla pallens</i> Simroth, 1912/Boettgerillidae | 1960 | Caucasian |
| <i>Lucilla scintilla</i> Lowe, 1852/Helicodiscidae | 1988 | Mediterranean or North America |
| <i>Arion vulgaris</i> (Moquin-Tandon, 1855)/Arionidae* | 1991 | Southwest Europe |
| <i>Oxychilus alliarius</i> (Miller, 1822)/Zonitidae | 1993 | Western Europe |
| <i>Deroceras panormitanum</i> (Lessona & Pollonera, 1882)/Agriolimacidae | 2003 | Probably Mediterranean |
| <i>Limacus flavus</i> (Linnaeus, 1758)/Limacidae | 2004 | Eastern Mediterranean or Asia Minor |
| <i>Zonitoides arboreus</i> (Say, 1816)/Zonitidae | 2006 | North America |
| <i>Cornu aspersum</i> (Müller, 1774)/Helicidae | 2009 | Mediterranean |
| <i>Helix lucorum</i> Linnaeus, 1758/Helicidae | 2009 | Eastern Mediterranean and Asia Minor |
| <i>Monacha cantiana</i> (Montagu, 1803)/Hygromiidae | 2009 | Mediterranean |
| <i>Hygromia cinctella</i> (Draparnaud, 1801)/Hygromiidae | 2010 | Mediterranean |

Species currently expanding are indicated by asterisks

Fig. 1 a Changes in the alien land-snail species recorded outdoors in the Czech Republic (1950–2010, 5-year periods, cumulative species numbers). In 2010, there were 169 land snail species recorded (excluding species reported exclusively from indoor habitats such as greenhouses; Horsák et al. 2010). **b** Total trade imports (normalized to nominal prices in 2000) to Czechoslovakia (1950–1992)/Czech Republic (1993–2009). To illustrate changes in importance of different regions for international trade, summaries are provided for selected Western Mediterranean (Italy, France) and southeastern European countries (Bulgaria, Romania and Yugoslavia, or Slovenia and Croatia, respectively). Adapted from data provided by the Czech Statistical Office. *BU* Bulgaria, *FR* France, *HR* Croatia, *IT* Italy, *RO* Romania, *SI* Slovenia, *YU* Yugoslavia. **c** Average annual temperatures in the Czech Republic (1950–2009), based on data from the Czech Hydrometeorological Institute



since 1900 (Fig. 1a). In addition to *H. lucorum*, three species new to the country were recorded in Prague in 2009 and 2010: *Cornu aspersum* (Juříčková and Kapounek 2009), *Monacha cantiana* (Hlaváč and Peltanová 2010), and *Hygromia cinctella* (Říhová and Juříčková 2011). Many records of new snail invaders (including those mentioned above) are from cities. This is not an artefact of the higher concentration or work intensity of malacologists, but rather due to increased local traffic (and therefore, the likelihood of dispersal), the abundance of disturbed sites enriched with nutrients (especially calcium), and microclimatic

conditions that facilitate invader survival. It is not surprising that the localities of the four new invaders found in Prague are situated in the proximity of important transport channels: railways, highways, and river port (Juříčková and Kapounek 2009; Hlaváč and Peltanová 2010; Říhová and Juříčková 2011).

Global environmental changes influence the distribution of native species and facilitate invasions of alien species all over the world. Generally, two major driving forces accelerating the global trend of biological invasions are discussed—global climate change (Walther et al. 2009), and human pressure through

various socioeconomic activities (Pyšek et al. 2010). To try to disentangle these influences in the recent increase of the number of Mediterranean terrestrial snails in the Czech Republic (Fig. 1a), we compared our data with available information on annual average temperatures between 1950 and 2009 (Fig. 1b) as well as data on imports (in normalized prices), as a rough proxy of the intensity of transport (Fig. 1c). The climatic data show an unequivocal trend of an increase in annual average temperatures, which is most pronounced in the last decade.

The amount of imported goods also shows a substantial increase throughout most of the second half of the twentieth century (due to data availability, Fig. 1b shows imports for the whole of Czechoslovakia before 1993, and subsequently just for the Czech Republic). A short period of stagnation in the late 1980s and early 1990s, reflecting major socioeconomic changes in eastern Europe, was followed by a dramatic increase in imports, and also in transit traffic (which is not reflected in import statistics) in the last 15 years. This may have increased the propagule pressure of passively transported invertebrates, including gastropods. In addition, not only the volume but also the main countries from which goods were imported changed substantially in the 1990s (see the marked decrease of imports from the Balkans and southeastern Europe, and an increase from the western European Mediterranean countries in Fig. 1c). However, opportunities for the import of invasive species from the Balkans or Turkey remained high, as opening of the western borders of the former Czechoslovakia made it a major transit country between western and southeastern Europe.

The effects of political isolation and subsequent changes in 1989 on gastropod dispersal can be illustrated by the expansion of *Arion vulgaris* in the Czech Republic. The Lusitanian slug has been expanding in western and northern Europe since the 1960s, but was only recorded in the Czech Republic for the first time in 1991 (Juříčková 2006; Rabitsch 2006). East European species, including *H. lucorum*, could possibly have dispersed within the “Soviet bloc” countries before 1989 with the aid of humans, but only one alien species found in the Czech Republic between 1950 and 1990, *Boettgerilla pallens*, was of such origin (Table 1).

Both *H. lucorum* and *Cornu aspersum*, widespread around the Black Sea and in the Balkan peninsula,

arrived only in 2009 (see Table 1), within the period characterized by increasing average annual temperatures in Central Europe. Thus, it seems that the rate of new invasions after 1989 may have also been facilitated by climatic factors. This period has had milder winters (especially in large cities) and a decreasing number of frosty days (Dobrovolný et al. 2010). After 2000, the interaction of socioeconomic factors and climate change apparently created particularly favourable conditions for the spread of alien species originating from the Mediterranean region. Climatic and socioeconomic factors separately would not lead to such a high number of successful land snail expansions, but together constitute suitable conditions for spreading (Pyšek et al. 2010)—intensified trade results in higher propagule pressure, while milder climate increases the likelihood of survival and establishment.

Both different traffic modes and increasing traffic density facilitate snail expansion; more than 90% of alien invertebrate species are introduced unintentionally by transport (Roques et al. 2009). Human-mediated transport is faster and often encompasses a much larger geographical scale than active species migration or colonization through natural vectors (Lockwood et al. 2007; Godan 1983). This is particularly important for species lacking the ability to overcome physical migration barriers, such as obligate aquatic taxa or slow-moving terrestrial invertebrates, including land snails.

Most gastropod species presently spreading in Europe possess at least one of three crucial features of successful snail travellers: climbing behaviour, aestivation, and hibernation (Godan 1983; Tilling 1986). A number of open habitat snail species, often with Mediterranean or Atlantic-Mediterranean distributions, have developed climbing behaviour to make aestivation possible above warm rocky ground (Jaremovic and Rollo 1979; Cowie 1985). The habit of a snail climbing vertically and remaining firmly attached to a surface seems to be important for successful dispersal: it allows attachment and the ability to hold on to a long-range vector (a vehicle). Subsequent aestivation or hibernation facilitates survival during dry periods or harsh winters in the colonized area. The relationship between snail climbing behaviour, traffic intensity, and snail dispersal is now well-documented (Benke and Renker 2005; Aubry et al. 2006). Such a dispersal mode may result in successful colonization by numerous individuals of

even relatively large-shelled species in a single event, as observed in a case of nearly 50 *Cepaea nemoralis* (shell diameter ca. 2 cm) travelling on the outer surface of a car boot in Prague (L. Juříčková, pers. observ.).

The numbers of records of non-indigenous terrestrial invertebrate species originally restricted to warmer and drier Atlantic and/or Mediterranean regions are increasing in Central Europe, as the boundaries of their ranges are shifting. Consequently, the faunal composition of many European countries is changing (Roques et al. 2009). There have been two major peaks in the range expansions of European terrestrial invertebrates in the last century. The first peak occurred in the 1950s and coincided with a period of warmer climatic conditions. The second peak after 1990, which is also apparent in the increased snail invasions described here, has occurred along with climate change and habitat degradation (Rabitsch 2008).

The range expansion of certain gastropod taxa is often correlated with the loss or retreat of many native species. General habitat degradation, fragmentation and the loss of habitat connectivity have endangered some native taxa (Horsák et al. 2010). In particular, sensitive native elements of semi-natural grasslands and steppes are disappearing (Schutysen et al. 2009). One example is the land snail *Helicopsis striata*, an indigenous inhabitant of primarily forest-free areas, which has been continuously present in Central Europe since the Last Glacial (Ložek 1964), but which has retreated significantly in recent decades and became extinct in the eastern part of the Czech Republic (Horsák et al. 2010). However, other gastropod species, including ubiquitous species from more southerly European regions, benefit from the ruderalization of open areas and replace sensitive species. In the near future, we may expect a further increase in the number of alien snail species well-adapted to human-impacted environments. Several such gastropod species, e.g., *Cerņuella virgata*, are expected to expand northwards across Central Europe, as they are currently well established in the Vienna Basin, Austria (Fischer and Duda 2004). Thus, the increasing number of alien gastropod species found in the Czech Republic (Fig. 1a) and the proportion of Mediterranean elements in Central European gastropod fauna is not likely to decelerate.

Acknowledgments This study was supported by projects of the Czech Ministry of Education (MSM0021620828 and MSM6293359101) and the Czech Ministry of Culture (MK00002327201). The first author thanks her husband Tomáš Peltan, who, despite being an architect, first recognized that the snail population in question is exceptional. Two anonymous referees provided comments that improved the previous version of the manuscript.

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