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Research Article

New records and distribution patterns of the invasive snail *Potamopyrgus antipodarum* (Gray, 1843) in Lithuanian inland waters

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Abstract

This paper presents new records of *P. antipodarum* in inland waters of Lithuania, along with its distribution patterns in the country and within particular lakes. In the period 2014–2018, seven new records sites were found. The current distribution pattern of the snail suggests secondary dispersion vectors are accelerating the spread of the species between distant ecosystems. It was found that most initial records of the invader were in parts of the lakes with intensive water recreation activities. Additionally, analysis at the level of individual lakes indicated high population densities (on average (± SD) from 106.7 ± 45 to 1966.7 ± 1315.8 ind. m^{-2}) in the parts of lakes with recreation activities, thereafter decreasing to zero with distance from these sites. Such results imply the possible role of overland movement of watercraft in the rapid dispersion of *P. antipodarum* over considerable distances.

Key words: boating, rapid spread, watercraft transportation, secondary dispersion, distant spread

Introduction

Potamopyrgus antipodarum (Gray, 1843) is an aquatic snail native to New Zealand, which has become one of the most successful invasive species worldwide. Its high phenotypic plasticity, small hard shell (shell length up to 6 mm) with an operculum, obligate parthenogenesis and lack of natural enemies in its invasive range (Alonso and Castro-Diez 2008) have allowed the species to survive and rapidly colonize distant ecosystems using various secondary dispersion vectors common to aquatic invaders. These include various floating materials, animals (zoochory) and various forms of human activities such as organism translocation, angling, boating and the overland movement of water vehicles (Bossenbroek et al. 2001; Johnson et al. 2001; Richards et al. 2004; Hosea and Finlayson 2005; Leung et al. 2006; Levri et al. 2007; Loo et al. 2007; Davidson et al. 2008; Green 2016).

In Lithuania, *P. antipodarum* was firstly recorded in the Curonian Lagoon near the marine port in 1954 (Gasiūnas 1959). In later years, the species was recorded in various different sites across the lagoon and in the Nemunas

Delta in 2004 (Zettler et al. 2005). Such a gradual spread of the species allows natural dispersion to be supposed. In 2010, however, the species was detected in several lakes and rivers in southern Lithuania, but was not found in the largest rivers (Butkus et al. 2012, 2014). Secondary dispersion vectors, such as water birds or human activities, were assumed to have acted in these cases of such distant and rapid translocation of *P. antipodarum* (Butkus et al. 2014).

The rapid increase in the number of new distant record sites of *P. antipodarum* in Lithuanian inland waters is of concern. In order to understand the pattern, mechanisms and pathways in which *P. antipodarum* spreads between distant ecosystems and to prevent or minimize additional introductions, every new record is important. Thus, the purpose of this paper is to present the new records of *P. antipodarum* in Lithuanian lakes and, additionally, to discuss the distribution patterns of *P. antipodarum* in lake ecosystems.

Materials and methods

Current distribution in Lithuanian inland waters

Newly recorded localities for *P. antipodarum* were obtained in the period 2014–2018 during periodic investigations of various water bodies. Samples were collected using a standard dip-net (25 × 25 cm opening, 0.5 mm mesh size). Additional information was obtained by visual inspection of stones, wooden debris, macrophytes and leaves lying on the bottom. The number of sampling sites per water body and the number of samples collected from each site varied from one to five.

Distribution pattern in lakes

This study was performed in order to evaluate the extent of distribution of *P. antipodarum* within lakes, as well as to identify probable introduction zones. The identification of the introduction zones was based on the assumption that snails would occur at their highest density at the introduction site, thereafter gradually decreasing with increasing distance. The research was carried out in 13 lakes, these selected according to one of two main criteria: either the first record of *P. antipodarum* had occurred in the lake recently (within the previous four years) or the snail had not been recorded in the lake, but the lake was located in a zone of high risk of introduction as it was near other occupied lakes and was characterized by intensive water recreation activities.

Probable introduction locations in the selected lakes were assumed to be those areas with intensive water recreation activities. At these sites, samples were taken by a stovepipe sampler (cross-sectional area 0.1 m^2) at a depth of about 1.5 m. Three replicates were made at each site. The extent of snail distribution in each lake was evaluated by sampling at all sites that the lake

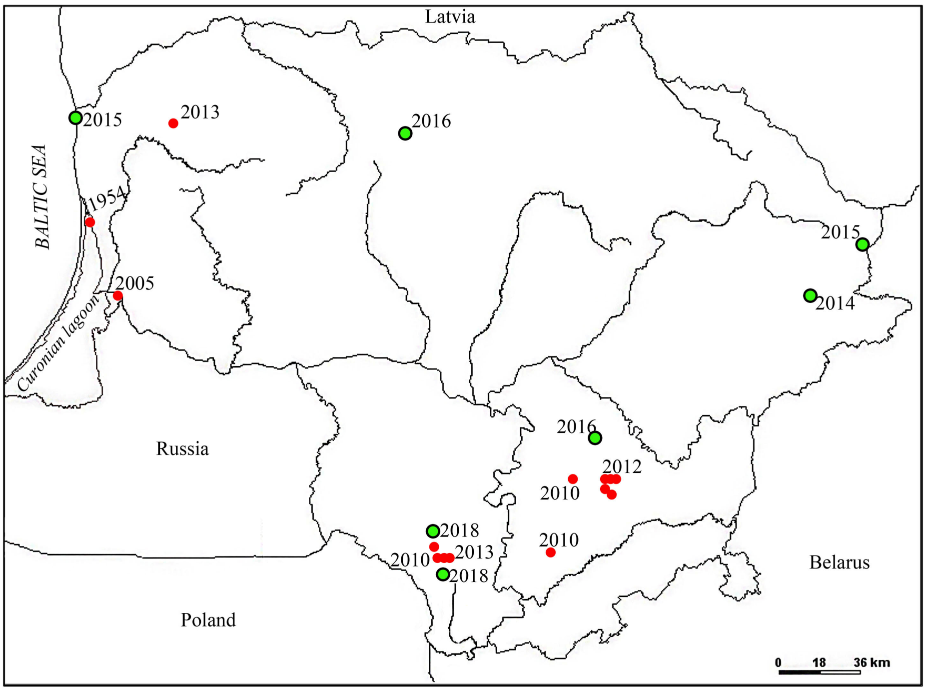

Figure 1. Current distribution of *P. antipodarum* with the indicated year of first record. Red circles indicate published data (more information, Butkus et al. 2014), green circles relate to data of the current study (georeferenced data are presented in Supplementary material Table S1).

was freely accessible (i.e. where there was an absence of fences and reeds). Semi-quantitative samples (~ 2 min) were collected using a standard dip-net by sweeping the benthic macroinvertebrates and checking for the presence of *P. antipodarum*. At sites where the snail was not found, additional samples were collected using the same dip-net in order to confirm the absence of the snail.

Results

During the four year study period, *P. antipodarum* was recorded in seven ecosystems in which the snail had not been present previously (Figure 1, Supplementary material Table S1). These ecosystems included the River Šventoji outflow into the Baltic Sea (next to Šventoji seaport), Elektrėnai water reservoir and five lakes – Lūšiai, Prūtas, Talkša, Seirijis and Gilutis. Interestingly, *P. antipodarum* was recorded in two lakes in northern Lithuania at a distance of more than 100 kilometres from the nearest previously-known invasive population. It was also observed that in 11 out of the 14 invaded lakes, the first records of the snail were at sites with intensive water recreation. In Lake Plateliai and Elektrėnai reservoir, the first records of the snail were found adjacent to yacht clubs – at sites where the overland movement of boats is very intensive.

Distribution pattern in lakes

This was evaluated in 13 lakes (Figure 2). Results indicated a density gradient in the *P. antipodarum* population distribution in five of the 13

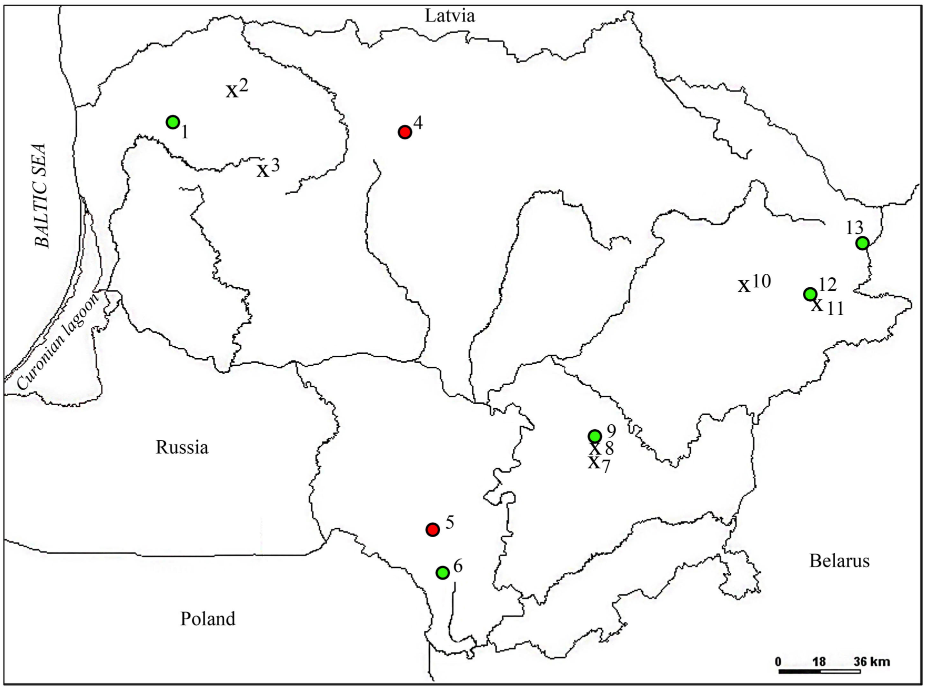

Figure 2. Lakes selected for *P. antipodarum* distribution pattern analysis. Symbols: green circles – snail was present only in part of the lake, red circles – snail was present in the whole lake, x – snail was not found. Numbers indicate lakes: 1. Plateliai, 2. Lūkstas, 3. Mastis, 4. Talkša, 5. Gilutis, 6. Seirijis, 7. Verniejus, 8. Nestrėvantys, 9. Elektrėnai water reservoir, 10. Siesartis, 11. Šakarvai, 12. Lūšiai, 13. Prūtas.

studied ecosystems. In two lakes however, Gilutis and Talša, the snail was present in most parts of the lakes. Despite the snail having been only recently recorded in these two lakes, such results probably indicate that the populations in these lakes are actually older than previously thought. In six lakes, Mastis, Lūkstas, Labanoras, Siesartis, Nestrėvantys and Verniejus, *P. antipodarum* was not found.

In the five lakes with a density gradient, the study found the highest densities of the snails in the parts of the lakes with intensive movements of watercraft (Figure 3). The density thereafter decreased to zero with increasing distance, this indicating the recreation zones as the probable introduction sites. The performed analysis in Lake Plateliai revealed that *P. antipodarum* is distributed across the whole of the south-west part of the lake and even in the first stretches of the outflowing River Babrungas (Figure 3A). As the snail was not found in river samples further downstream (at a distance of 2 km from the lake), it is highly probable that the presence of snails in the river is due to the downstream spread from Lake Plateliai, rather than vice versa (whereby the snails had invaded the lake from the river). In Plateliai, the average density of the snail adjacent to the yacht club was 1966.7 ± 1315.8 (SD) ind. m^{-2}. At Elektrėnai, the reservoir is directly associated with the River Strėva, suggesting a very high probability of future natural spread of *P. antipodarum* (Figure 3B). However, the current study indicated that the snail was currently recorded only near the yacht club, where the average density was 583.3 ± 236.7 ind. m^{-2}. It was absent in other parts of the Elektrėnai

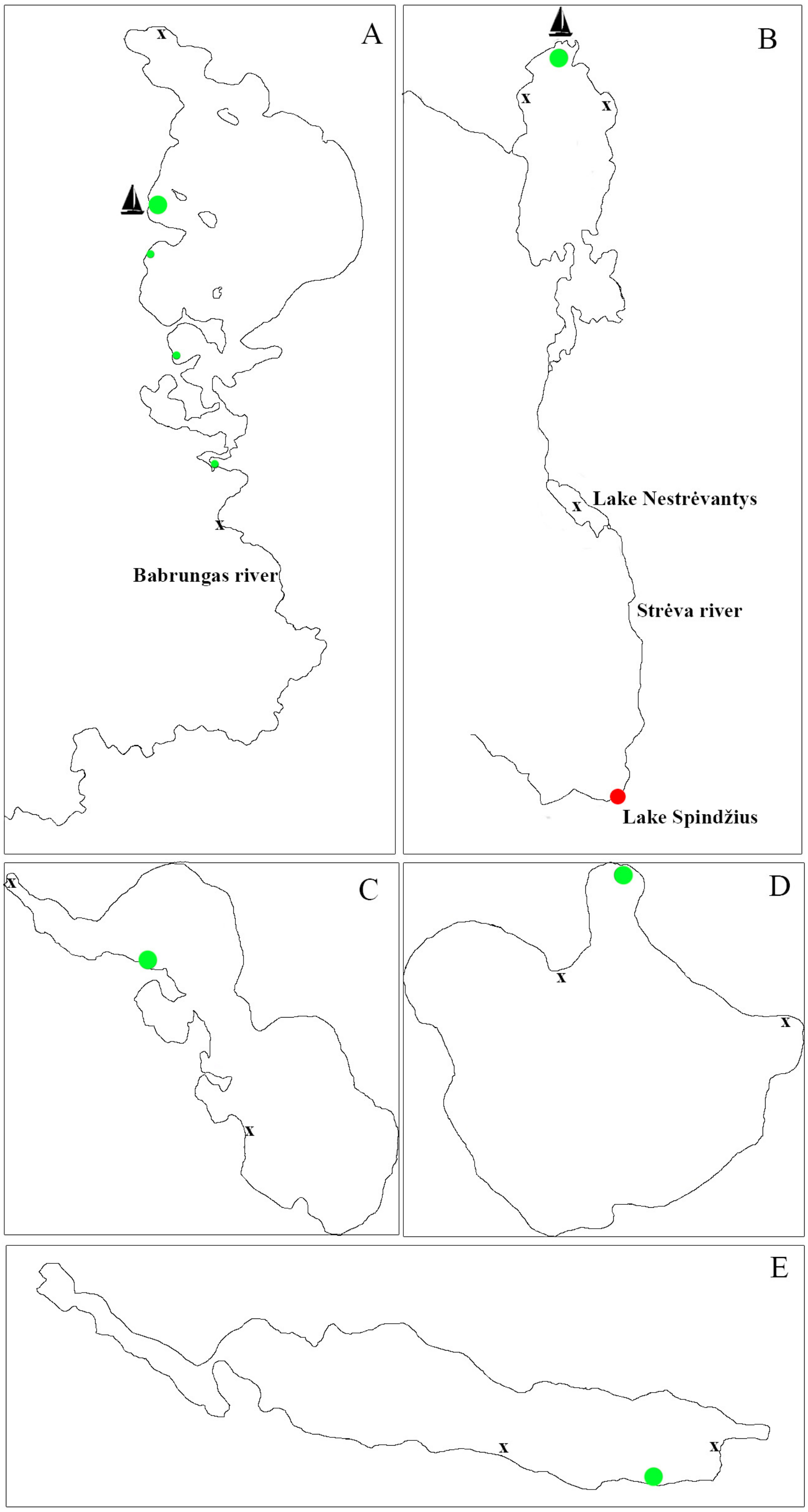

Figure 3. Distribution pattern of *P. antipodarum* in studied ecosystems. Letters indicate: Lake Plateliai (A), Elektrėnai reservoir (B), Lake Prūtas (C), Lake Seirijis (D), Lake Lūšiai (E). Symbols: x – snail was not found; large green dots – zones with intensive water recreation (localities for estimated densities of the snails); small green dots – additional checking sites where the snail was found; black sail boats – yacht clubs.

reservoir and in Lake Nestrėvantys. This latter site is located above the reservoir and is much closer to Lake Spindžius, where the snail had already been recorded in 2011. Such a distribution pattern implies that *P. antipodarum* did not disperse naturally into Elektrėnai reservoir via the River Strėva, but was introduced unintentionally. In the southern part of Lithuania, there is also a high probability that the snail was introduced unintentionally into Lake Seirijis, which is located adjacent to the already invaded Lakes Obelija, Dusia and Metelys. Though it was expected that *P. antipodarum* would be dispersed across the whole ecosystem, our results indicated that it is present only in the north-eastern part of the lake (Figure 3D). The average density of the snail at the boat translocation site was 140.0 ± 115.3 ind. m^{-2}. A similar pattern of high density in watercraft activity zones decreasing to zero with increasing distance was also observed in Lakes Prūtas and Lūšiai (Figure 3C, E). The density in these lakes were respectively 106.7 ± 45.1 ind. m^{-2} and 316.7 ± 198.6 ind. m^{-2}.

Discussion

Currently, *P. antipodarum* is the only rapidly spreading invasive mollusc species in freshwater ecosystems in Lithuania (Butkus 2017). From the first records of the snail in five different ecosystems in 2010 (Butkus et al. 2012), the number of invaded ecosystems increased to 17 in 2013 (Butkus et al. 2014). The current study indicates that by 2018, there were 22 different water bodies where the invader had established. It is important to note that previous studies of non-indigenous macroinvertebrates in the largest Lithuanian rivers did not detect *P. antipodarum* (Butkus et al. 2014; Butkus, *unpubl. results*). This latter fact, together with the rapidly increasing number of record sites and the large distances between the invaded ecosystems, implies that secondary dispersion is not active, but associated with particular dispersion vectors.

Despite the fact that additional ecosystems invaded by *P. antipodarum* are being recorded nearly every year in Lithuania, the snail may still be overlooked during studies. In some cases, this is very probably due to a lack of advanced research and to the low densities of the snails during the initial stages of invasion. However, such cases are probably rare and, in our case, thought likely only in two lakes – Talkša and Gilutis. Although a recent invasion event had previously been assumed for these two lakes, our more detailed study indicated that *P. antipodarum* is distributed across the entire lakes, implying a much earlier introduction. Meanwhile, in five of the other lakes studied, *P. antipodarum* was present only in small sections of the ecosystems, where the highest densities of the snails were recorded in recreational areas with intense watercraft translocation. This implies the probable role of human activities, such as overland watercraft transportation, as a secondary dispersion vector for *P. antipodarum*. It is well documented that the overland movement of watercraft is an important secondary dispersion vector in the spread of aquatic non-indigenous organisms (Buchan and Padilla 2000; Johnson et al. 2001; Muirhead and MacIsaac 2005; Puth and Post 2005; Keller and Lodge 2007; Rothlisberger et al. 2010 and others). The study of the Watershed Stewards Program found 2038 organisms during the course of almost 17000 watercraft inspections (Holmlund 2014), indicating the high importance of trailered water transport in the secondary dispersion of aquatic invasive species. Concern about the translocation of invasive species via watercraft has prompted an increased number of studies relating to decontamination of such watercraft. Numerous methods, including the effective check, clean, dry system, have been suggested to minimise the risk of introducing of aquatic nonindigenous species into noninvaded ecosystems via transported watercraft, trailers and recreational equipment (Morse 2009; Zook and Phillips 2009; Rothlisberger et al. 2010; Comeau et al. 2011; Johnstone et al. 2014).

According to current data, several main directions of *P. antipodarum* spread can be identified in Lithuanian inland waters. The largest “hotspot” is located in the southern part of Lithuania, this region containing the highest number of invaded ecosystems. The probability of further dispersion from this donor zone to neighbouring lakes is very high due to both the presence of numerous rivers flowing out from the lakes and to intense overland movements of watercraft. As *P. antipodarum* is already present in Elektrėnai reservoir, dispersion towards the River Nemunas is highly probable. A second, relatively recent “hotspot” is located in the northern part of Lithuania. Currently, there are two known lakes—Prūtas and Lūšiai—where the snail is present. However, given the high concentration of lakes which have direct connections and the relatively short distances between them, such ecosystems are very favourable for the spread of the aquatic invaders. Both natural dispersion of *P. antipodarum* via active movement and spread through secondary dispersion vectors, particularly boat transportation, can be expected. In general, it can be expected that there will be a dramatic increase in the number of Lithuanian inland freshwater ecosystems that will have been invaded by *P. antipodarum* in the near future.

Concluding remarks

This study has indicated a rapid spread of *P. antipodarum* in Lithuanian inland waters over considerable distances, a process that is still ongoing. The distribution pattern of the species in Lithuanian lakes suggests secondary dispersion vectors are accelerating the spread of the invader. The results of the current analysis also reveal that most new records of *P. antipodarum* in lakes were in watercraft translocation sites. It was also found that the highest densities of the snails were present at such sites, thereafter decreasing to zero with increased distance. Despite the lack of direct evidence for secondary *P. antipodarum* dispersion via human activities such as boating or overland watercraft transportation, indirect evidence suggests its importance. To confirm such an assumption, however, additional research is needed.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Location of lakes and river study sites where *Potamopyrgus antipodarum* was recorded.

This material is available as part of online article from:
http://www.reabic.net/journals/bir/2019/Supplements/BIR_2019_Butkus_Vaitonis_Table_S1.xlsx