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Rapid Communication

"Invasion in progress": first occurrence and spread of river nerite (*Theodoxus fluviatilis* L., 1758) in the largest Central European shallow lake, Lake Balaton, Hungary

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Abstract

This study presents the first occurrence and recent distribution pattern of the river nerite (*Theodoxus fluviatilis* L., 1758) in Lake Balaton. The first appearance of this Prosobranch snail was recorded along the western shore of the Tihany peninsula situated on the middle section of the lake, at 21st of October 2013 during a routine macrozoobenthos sampling. Occurrence of the species was also recorded along the eastern shoreline of the peninsula in 2015, and it became highly abundant in both areas in the following years. Results of a comprehensive survey conducted in the autumn of 2018 in the littoral region of the lake revealed that the river nerite has colonized almost the entire shoreline of Lake Balaton, only the westernmost and easternmost areas were still devoid of this invader, therefore it seems that its spread has not been finished yet. The river nerite appeared in extremely high abundances (up to 4–5000 individuals/m^2) in the middle area of the lake, therefore it is likely that this species will have a significant effect on the biota of Lake Balaton, especially in the littoral zone of the lake.

Key words: snail, oligotrophication, littoral zone, rip-rap

Introduction

The river nerite (*Theodoxus fluviatilis* L., 1758) (Mollusca: Gastropoda) is the most widely distributed member of the Neritidae family; however it has a patchy distribution pattern throughout Europe (Bunje 2005). As phylogenetic studies revealed, this species survived the Pleistocene glacial periods in South European refugia (Northern Italy, Black Sea area), then the species' range started to expand in the Holocene (Bunje 2005). The occurrence of river nerite was reported from the Baltic Sea drainages

(Skoog 1971; Carsson 2000), the Black Sea drainages (Anistratenko et al. 1999), Ireland (Lucey et al. 1992) and Anatolia (Yildirim 1999). Regarding the Danube basin, the species is considered native only in the downstream section of the River Danube (Čejka and Horsák 2002; Bódis et al. 2012). Three congener species are described as native to the Middle Danube section: the black nerite (*Theodoxus prevostianus* Pfeiffer, 1828) can be found in warm springs only; the striped nerite (*Theodoxus transversalis* Pfeiffer, 1828), and Danubian nerite (*Theodoxus danubialis* Pfeiffer, 1828) are distributed mainly in larger rivers. Stock sizes and distribution areas of all these congener species show declining trend (Solymos and Fehér 2011a, b; Marković et al. 2014) while the river nerite is now expanding towards the Black Sea Basin. In the Carpathian Basin this species replaces the native *Theodoxus* species because it can better tolerate more polluted environments (Kebapçi and Van Damme 2012; Mouthon and Charvet 1999).

The expansion of river nerite in the Middle Danubian hydrosystem has begun only at the end of the 20th century. It was first reported from the Hungarian section of the Danube in 1987 (Csányi 1994), and later from the Austrian (Schultz and Schultz 2001) and Slovakian (Čejka and Horsák 2002) section of the river, indicating an upstream colonization. The species appeared in the larger tributaries of the River Danube as well, such as the River Sava (Paunović et al. 2012) and the watershed of River Tisza (Lennert 1997; Varga and Csányi 1997). River nerite has not been previously reported either from smaller rivers/streams, or from lentic waterbodies of this area.

The aims of our study were to (1) present the first occurrence data of a new invader, the river nerite, in Lake Balaton, which is the largest shallow lake in Central Europe, and to (2) describe the current distribution patterns of the river nerite in the littoral zone of the lake.

Materials and methods

Study area

The Lake Balaton is the largest shallow lake in Central Europe and is situated in western Hungary (N46.83; E17.70, Figure 1) with a total area of 596 km^2, and mean depth of 3.25 m. The lake has slightly alkalic (pH 8.4–8.6) calcareous water containing about 400 mg/l Ca^{2+} and $Mg^{2+}(HCO_3)^{2-}$ (Specziár and Bíró 1998). Its watershed was relatively isolated within the Danubian hydrosystem until the end of the 19th century. The water level of the lake has been controlled by the Sió canal since 1863, which provides direct and permanent access to River Danube (Figure 1). Numerous species, especially species of Ponto-Caspic origin—such as Dreissenid mussels (*Dreissena polymorpha* Pallas, 1771 and *Dreissena rostriformis bugensis*, Andrusov, 1897), the Caspian mud shrimp *Chelicorophium curvispinum* GO Sars, 1895) (Sebestyén 1938; Balogh et al. 2008), the killer shrimp (*Dikerogammarus villosus* Sowinsky, 1894) (Muskó 1989), and supposedly

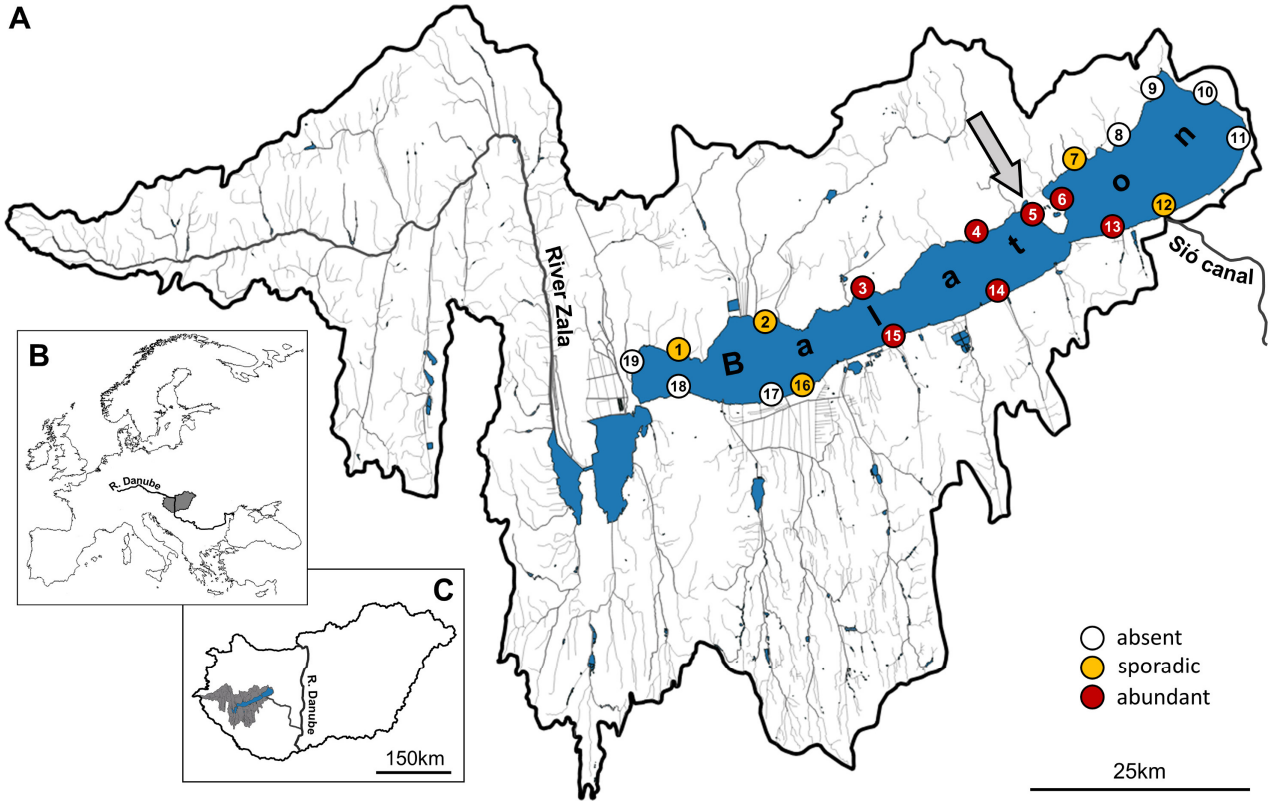

Figure 1. Sampling sites on the shoreline of the Lake Balaton (A). Black solid line is the border of Balaton catchment. Numbered circle: sampling site. The colouration of the circles correspond with the abundance data. (white: absent, yellow: sporadic, red: abundant.) The place of first record is marked by grey arrow. Geographic position of Hungary in Europe, and the Balaton catchment's position in Hungary are indicated in the inserts B and C, respectively. For WGS84 coordinates and other information see Table S1.

the monkey goby (*Neogobius fluviatilis* Pallas, 1814) (Bíró 1972)—conquered this watershed through the Sió canal. Therefore this waterway is identified as the main invasion corridor for the Lake Balaton. Numerous native taxa were displaced by these invaders as the result of these processes, and consequently, these newcomers have become the most characteristic species of the littoral zone of the lake (Sebestyén 1937; Muskó 1989; Balogh et al. 2008, 2018).

Lake Balaton is one of the most important tourist destinations in Hungary. For this reason, environmental characteristics of its littoral zone have been highly modified in the last decades; 43% of the 236 km long shoreline of the lake has been more or less modified (Sass 1979; Paulovits et al. 2007). The increased nutrient load and the overexploitation of the catchment's environmental resources (e.g. effects of mass tourism, habitat degradation) caused massive eutrophication of the lake since the end of the 1970s (Herodek 1977; Puczkó and Rátz 2000). Due to water quality restoration interventions implemented in the last decades – e.g. rehabilitation of a protecting wetland system, and chemical phosphorus precipitation in the larger sewage treatment plants (for more details see: Herodek et al. 1988; Tátrai et al. 2000; Hatvani et al. 2011) the lake has slowly recovered to oligo-mesothrophic stage (Istvánovics et al. 2007; Somogyi et al. 2016; Blix et al. 2018).

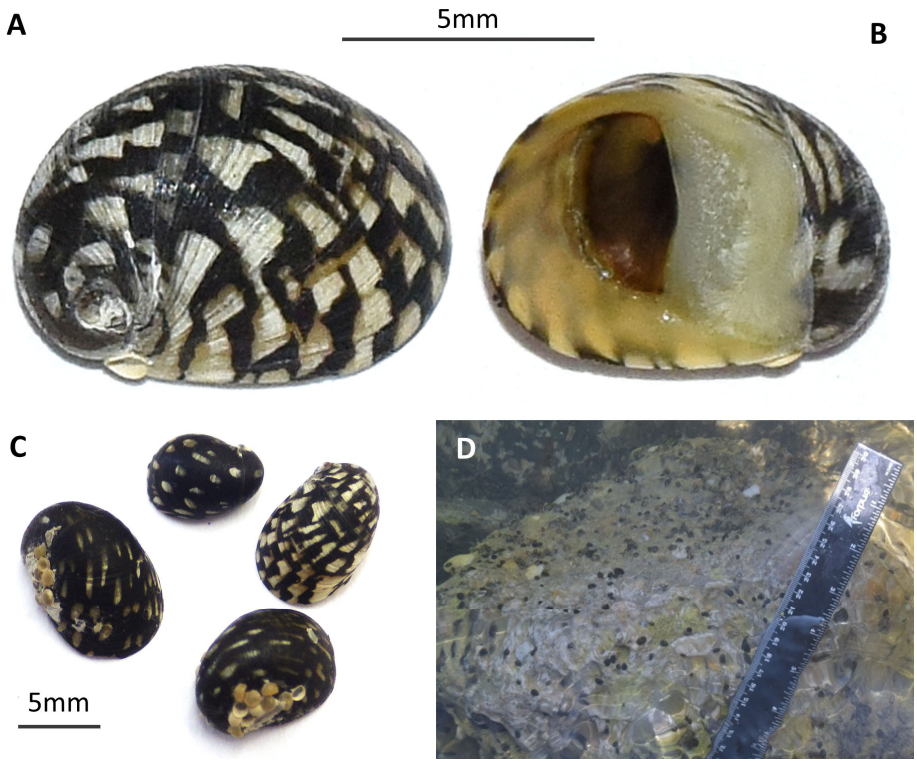

Figure 2. River nerite *Theodoxus fluviatilis* L. 1758 collected from the Lake Balaton. Lateral (A), ventral (B), and dorsal (C) view of the collected individuals. Stock density of the river nerite on a stone at site 15 (D). Photographs by Péter Takács.

The studied species

River nerite can be characterized by solid hemispherical glossy shell with low spire. The pattern and color of the shell is highly variable (Anistratenko 2005), but usually it is dark colored with a pattern of yellow-white streaks. It is a relatively small species; shell length up to 12 mm, height up to 8 mm (Figure 2). It mainly occurs in large calcium-rich rivers, but occasionally it can be found in streams and the littoral zones of lakes with sufficient water movement. It grazes on hard benthic substrates, feeding on benthic algae (e.g. Bacillariophyceae) and detritus (Graham 1988).

Sampling

The occurrence and abundance of river nerite were examined at 19 sites along the lake's shoreline (Figure 1, Supplementary material Table S1). Collection of epilithic macrofauna has been carried out with upturning 5–6 randomly selected stones at each sampling site in the littoral rip-rap zone of Lake Balaton. Voucher individuals were removed and preserved in 96% ethyl-alcohol at each site where the river nerite had been found. We used the following abundance categories: "absent": we did not find the river nerite on the site; "sporadic": if only a few (less than 20); and "abundant": more than 20 individuals were detected per site.

Results

The first occurrence of river nerite was detected in Lake Balaton at the western side of the Tihany peninsula (Sajkod bay) (N46.906440; E17.849460) on 21 October, 2013. During a routine macrozoobenthos sampling in the littoral zone one living juvenile and one living adult specimen were identified. Additionally, on 26 June, 2014, 11 more living juvenile and 33 living adult river nerites were collected from the same site. The species appeared on the eastern shoreline of the Tihany peninsula in 2015 (Cs. Balogh, *pers. comm.*), and became highly abundant in the following years in both areas. Results of comprehensive survey made along the littoral region of the lake showed that the river nerite has colonized almost the entire shoreline except for the westernmost and easternmost areas of the lake (Figure 1, Table S1). Moreover it has been locally abundant (app. 4–5000 individuals/m^2, Figure 1D) in sampling sites located in the middle basins of Lake Balaton.

Discussion

Its rapid spread and the differences in its local abundances indicated that the river nerite may not only established in but invaded the watershed of Lake Balaton. Moreover the recent distribution data show that its invasion is still in progress.

Several notes show (see e.g.: Coelho et al. 2018; Gouillieux 2018) that the exact determination of the circumstances (first locality, invasion route and vector) of establishment is challenging when the invasion has not been finished yet. There are several possible alternative pathways in case of river nerites in Lake Balaton, of which many are reasonable candidates, considering the current distribution pattern of the species. Supposedly it might have been introduced accidentally to the lake, attached to the bottom of a vessel raised from the River Danube through the Sió canal, as it happened with the zebra mussel (Sebestyén 1938). The accidental or deliberate release by amateur aquarists is also possible, because this species is very popular among aquarists in Hungary. Moreover it might have been introduced via carp (*Cyprinus carpio* L., 1758) stockings, similarly to the amur sleeper (*Perccottus glenii* Dybowski, 1877) (Erős et al. 2008), or the spiny cheek crayfish (*Orconectes limosus* Rafinesque, 1817) (Ferincz et al. 2014). As the first known locality of the river nerite in the lake is in a nature conservation area with no sailing ports nearby, nor fish stockings were carried out in the vicinity of the location, therefore it is also plausible that an avian vector introduced the species into this watershed.

Although the basic hydro-chemical characteristics of Lake Balaton seem to be highly appropriate for this species and it has a vast shoreline of rip-raps and concrete walls forming a highly suitable substrate for this gastropod (Kirkegaard 2006); the river nerite occurred in the lake 26 years

after only it had been found in the Hungarian section of River Danube (Csányi 1994). The aerial distance of the lake from the Danube is approximately 60 km, and the length of Sió Canal is 120 km. Its rapid expansion in River Danube suggest that this species would have been capable to overcome such distances in a relatively shorter period, therefore we believe this delay in its first occurrence in the lake cannot be explained solely by hydro-geographical reasons. We argue that recent environmental changes (e.g oligotrophication, and changes in water transparency) in Lake Balaton (Istvánovics et al. 2007; Blix et al. 2018) might also be responsible for the recent establishment and spread of this species.

Although the role of this invader is still unclear in the lake's ecosystem, it might have serious detrimental effects on the macroinvertebrate fauna of the littoral zone of Lake Balaton similarly to other non-native macroinvertebrates (Sebestyén 1937; Muskó 1992; Muskó and Bakó 2005; Balogh et al. 2008, 2018). On the other hand, similarly to Dreissenid mussels, this species might also become an important food item for some abundant fish species (Lappalainen et al. 2001; Specziár and Rezsu 2009) living in the littoral zone. Further monitoring of the distribution patterns of the species is crucial to understand the dynamic ecological changes of a vulnerable lake such as Lake Balaton, and to support preventive and mitigation measures implemented to protect the lake and similar ecosystems.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Localities, geographic coordinates and date of samplings of the surveyed 19 sites.

This material is available as part of online article from:
http://www.reabic.net/journals/bir/2019/Supplements/BIR_2019_Takacs_etal_Table_S1.xlsx