

## The first records of the occurrence of a North American invader *Gammarus tigrinus* Sexton, 1939 in the tributaries of the upper Vistula River

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**Abstract** – The amphipod species *Gammarus tigrinus*, Sexton 1939 is native to the Atlantic coast of North America. The native range of its occurrence includes oligo- and mesohaline brackish waters with salinity of up to 14‰. Our survey was carried out in the tributaries of the upper Vistula River in Upper Silesia that is the most urbanised and industrialised region in Poland and constitutes one of the largest coal basins in the world. This survey uncovered the first occurrence of *G. tigrinus* with the maximum density of 1040 individuals m<sup>-2</sup> in the tributaries of the upper Vistula River that have been polluted by coal mine water discharge. The occurrence of the invasive alien gastropod species, *i.e.* *Potamopyrgus antipodarum* (Gray, 1843) was also recorded in such salinised water. Our results showed that the anthropogenically salinised tributaries of the upper Vistula River constitute new habitats for euryhaline species and create new migration routes for alien and invasive species.

**Keywords:** alien species / gammarid / river / salinisation

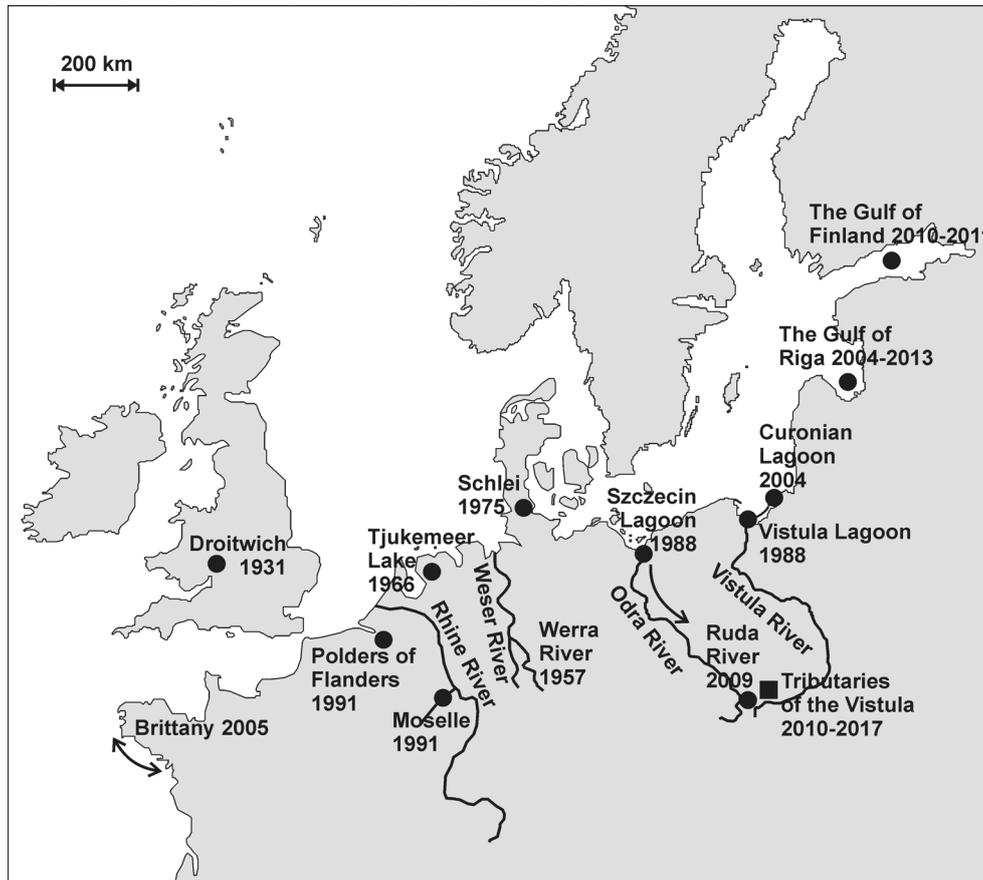
**Résumé** – Les premiers signalements de l'apparition d'un envahisseur nord-américain *Gammarus tigrinus* Sexton, 1939 dans les affluents de la Vistule supérieure. L'espèce d'amphipode *Gammarus tigrinus*, Sexton 1939 est originaire de la côte atlantique de l'Amérique du Nord. L'aire de répartition de sa présence naturelle comprend les eaux saumâtres oligo- et mésohalines d'une salinité allant jusqu'à 14‰. Notre étude a été réalisée dans les affluents de la haute Vistule en Haute Silésie, la région la plus urbanisée et industrialisée de Pologne et qui constitue l'un des plus grands bassins houillers du monde. Ce relevé a mis en évidence la première occurrence de *G. tigrinus* avec une densité maximale de 1040 individus m<sup>-2</sup> dans les affluents de la Vistule supérieure qui ont été pollués par les rejets d'eau des mines de charbon. La présence de l'espèce exotique envahissante de gastéropode, à savoir *Potamopyrgus antipodarum* (Gray, 1843) a également été enregistrée dans ces eaux salinisées. Nos résultats ont montré que les affluents anthropogéniquement salinisés de la haute Vistule constituent de nouveaux habitats pour les espèces euryhalines et créent de nouvelles voies de migration pour les espèces exotiques et envahissantes.

**Mots-clés** : espèces exotiques / gammaridé / rivière / salinisation

The amphipod species *Gammarus tigrinus*, Sexton (1939), which is typical of small and large estuaries or creek mouths, is native to the Atlantic coast of North America. The native range of its occurrence includes oligo- and mesohaline brackish waters with salinity of up to 14‰. Its range includes the estuary of the St. Lawrence River, the Chesapeake Bay, the estuary of the Potomac River and Florida (Bousfield, 1969). *G.*

*tigrinus* colonised the Laurentian Great Lakes at density of 283 individuals m<sup>-2</sup> during 2001–2004 (Grigorovich *et al.*, 2005). In Europe, it was found in the brackish waters of the Salwarpe River (the Droitwich district, UK) for the first time in 1931 (Sexton, 1939) (Fig. 1). *G. tigrinus* was deliberately introduced into German rivers, which had been heavily polluted by the potash mining industry, *i.e.* the Weser and the Werra in 1957 from England to compensate for a decrease in the native amphipod species (Bäthe and Coring, 2011; Braukmann and Böhme, 2011). This North American species then began to

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**Fig. 1.** The distribution and possible migration routes of *Gammarus tigrinus*, Sexton 1939 in Europe (Author: Z. Rymarski).

occur in the inland waters of continental Europe. *G. tigrinus* was recorded in the Netherlands at a density up to 24 000 individuals  $m^{-2}$  in 1960 (Chambers, 1977). In 1991, this amphipod was first recorded in the Moselle River, an oligohaline tributary of the Rhine River (north-eastern France) from where it dispersed to the other catchments of the rivers (the Saône, the Rhône, the Loire Rivers) *via* canals. It was first reported along the southern coast of Brittany in 2005 (Piscart *et al.*, 2005; 2008). *G. tigrinus* was first recorded in the Schlei estuary in the Baltic Sea (Germany) in 1975 (Pienimäki *et al.*, 2004). *G. tigrinus* continued its spread to the Szczecin Lagoon (Poland) by 1990 (Gruszka, 1999) and it had reached the Vistula Lagoon by 1998 (Jazdzewski *et al.*, 2004). By 2007, this amphipod species was recorded in the lower and middle courses of the Odra River (Grabowski *et al.*, 2007) and was continuing to spread upstream. Recently, it has been found in the tributaries and catchment of the upper Odra River (Spyra *et al.*, 2015; Sowa *et al.*, 2018). Simultaneously, *G. tigrinus* has successfully continued its spread within the Baltic Sea (Pienimäki *et al.*, 2004; Daunys and Zettler, 2006; Kotta *et al.*, 2013; Strode *et al.*, 2013) (Fig. 1).

Our survey was carried out in the tributaries of the upper Vistula River from 2010 to 2017 (Upper Silesia and adjacent areas, Poland). The Vistula River has a total length of 1047 km and a catchment area of 194 424  $km^2$  (the longest river in Poland). Upper Silesia is the most urbanised and industrialised region in Poland and constitutes one of the largest coal basins in the world. Three tributaries of the upper Vistula River, *i.e.*

the Potok Gromiecki River, the Gostynia River, the Mleczna River as well as the inflow into the Mleczna River from a coal mine dewatering system were investigated. The waters of these tributaries are characterised by high levels of chlorides, sulphates, biogenic elements or conductivity, which is a consequence of the discharge of mine waters from the coal mine dewatering system into the rivers. Samples of the macroinvertebrates were collected according to quantitative methods and the physical and chemical parameters of the water were also analysed (Tab. 1). This survey uncovered the first occurrence of *G. tigrinus* in the tributaries of the upper Vistula River (Fig. 2).

Amphipods were identified to the species level according to Eggers and Martens (2001). The maximum density of *G. tigrinus* was 1040 individuals  $m^{-2}$  in the tributaries of the upper Vistula River. The occurrence of the invasive alien gastropod species, *i.e.* *Potamopyrgus antipodarum* (Gray, 1843) and alien species *Physa acuta* Draparnaud, 1805 were also recorded in such salinised water. The density of *G. tigrinus* decreased to only a few specimens in the Potok Gromiecki River when the conductivity of the water increased to 40 900 ( $\mu S cm^{-1}$ ) as a consequence of coal mine water discharge into the river. Our survey showed the first occurrence of *G. tigrinus* in rivers with a relatively high conductivity (salinity) (Tab. 2).

This euryhaline gammarid species tolerates salinity of up to 25 PSU (Pienimäki *et al.*, 2004). According to the surveys of Jazdzewski *et al.* (2004) and Grabowski *et al.* (2009), *G.*

**Table 1.** Density (individuals m<sup>-2</sup>) of *Gammarus tigrinus* and *Potamopyrgus antipodarum* in relation to the physical and chemical parameters of the water (ranges) in the tributaries of the upper Vistula River.

| Species   | The Potok Gromiecki River    |                 | The Gostynia River           | The Mleczna River            | Inflow to the Mleczna River from the coal mine dewatering system |
|---|------------------------------|-----------------|------------------------------|------------------------------|--|
| Geographic coordinates  | N 50°03.418'<br>E 19°18.260' |                 | N 50°05.319'<br>E 18°58.885' | N 50°09.701'<br>E 19°00.317' | N 50°09.799'<br>E 19°00.338'                                     |
| Years of the surveys  | 2010                         | 2017            | 2015–2017                    | 2014–2017                    | 2014–2017  |
| <i>Gammarus tigrinus</i>  | 91                           | a few specimens | 28–261                       | 120–1040                     | 2–176  |
| <i>Potamopyrgus antipodarum</i>                                 | 190                          | 0               | 205–4461                     | 23–62                        | 290–7257   |
| Conductivity (μS cm <sup>-1</sup> )                             | 9740                         | 40 900          | 2290–3370                    | 2030–3090                    | 2130–3540  |
| Chlorides (mg Cl <sup>-</sup> dm <sup>-3</sup> )                | 2980                         | 28 700          | 560–590                      | 332–810                      | 388–860  |
| Ammonium (mg NH <sub>4</sub> <sup>+</sup> dm <sup>-3</sup> )    | 0.89                         | 2.99            | 0.61–0.97                    | 0.24–0.91                    | 0.16–2.82  |
| Phosphates (mg PO <sub>4</sub> <sup>3-</sup> dm <sup>-3</sup> ) | 0.26                         | 0.21            | 0.19–0.24                    | 0.04–0.32                    | 0.01–0.14  |
| Hardness (mg CaCO <sub>3</sub> dm <sup>-3</sup> )               | 495                          | 4498            | 450–485                      | 480–570                      | 485–645  |
| Salinity (‰)  | 6.2                          | 25.8            | 1.1–2.1                      | 1.3–2.0                      | 1.1–2.3  |

**Fig. 2.** Male and female *Gammarus tigrinus* Sexton, 1939 in a tributary of the upper Vistula River (The Mleczna River) (Author: D. Halabowski).

*tigrinus* thrives especially well in oligohaline waters of conductivity ranged from 1000 to 8000 μS cm<sup>-1</sup> (0.5–4.0 PSU) and is a very successful invader in the Dead Vistula and in the Vistula Lagoon.

Two different possible patterns of *G. tigrinus* migration to the tributaries of the upper Vistula River can be considered. The first one is the dispersal of *G. tigrinus* from the upper course of the Odra River to the tributaries of the upper Vistula River by the local inland canal-river systems. *G. tigrinus* spreads within the riverine habitats in the Odra River that are well connected to other European waterways (Szlauer-Lukaszewska *et al.*, 2018). *G. tigrinus* is often found in ecosystems disturbed by anthropogenic pollution including salinisation. Such ecosystems are typical of Upper Silesia. It

was also shown that specimens of amphipods are able to attach to invertebrates (molluscs, rotifers or infusorians) that can be considered as possible vectors of their accidental introduction (Berezina, 2007). The upstream migration of *G. tigrinus* from the Vistula Lagoon may be considered as the second possible path of the dispersion. However, the result of Grabowski *et al.* (2007) showed that the distribution of *G. tigrinus* was limited exclusively to the brackish parts of the Vistula Lagoon or the Vistula River mouth and that the gammarid had not dispersed upstream. Therefore, the possible migration route of *G. tigrinus* into the tributaries of the upper Vistula River is not known and this requires further research.

According to Grabowski *et al.* (2007), *G. tigrinus* had replaced the native invertebrates, including other gammarid species in most of the colonised habitats. The high degree of invasive potential and its capacity for further expansion is related to its higher fecundity, smaller size at breeding and an earlier start of the breeding season, significant predation pressure as well as its ability to tolerate a broader range of environmental conditions compared to the native gammarids (Jänes *et al.*, 2015). Grabowski *et al.* (2009) revealed that the small, natural tributaries of large rivers (the Odra, the Vistula Rivers) may function as refugia for the native amphipod fauna. In contrast, our results showed that the anthropogenically salinised tributaries (coal mine water discharge) of a large river (the upper Vistula River) constitute new habitats for euryhaline species and create new migration routes for alien and invasive species, *e.g.* for *G. tigrinus* and *P. antipodarum*.

**Acknowledgements.** The authors are deeply indebted to the Editor-in-Chief and to the anonymous reviewers for their valuable suggestions and comments which significantly improved the quality of this manuscript.

The authors are also grateful to Ms. Michele L. Simmons, B.A., University of Silesia, Faculty of Biology and Environmental Protection, Katowice, Poland, for improving the English style.

**Table 2.** Examples of the occurrence of *Gammarus tigrinus* in relation to the conductivity, concentration of chlorides in the water and salinity in inland and coastal habitats.

| Conductivity<br>( $\mu\text{S cm}^{-1}$ ) | Chlorides<br>( $\text{mg Cl}^{-} \text{dm}^{-3}$ ) | Salinity<br>(PSU) | Density<br>(individuals $\text{m}^{-2}$ ) | Area of occurrence, country                                   | References   |
|---|--|-------------------|---|---|--|
| 15 500                                    |  |                   |   | Watch Lane Flash (lake) England                               | Savage (1982)  |
| 3422                                      |  |                   |   | The Meurthe River, France                                     | Piscart <i>et al.</i> (2005)   |
| 2800                                      |  |                   |   | Bivet, Brittany, France                                       | Piscart <i>et al.</i> (2008)   |
|   | 5860   |                   |   | Brackish polder in Flanders (Belgium)                         | Boets <i>et al.</i> (2011)   |
| 8500                                      | 2500   | 4.6               | 3500                                      | The Werra River (Germany)                                     | Braukmann and Böhme (2011);<br>Bäthe and Coring (2011);<br>Arle and Wagner (2013)                            |
| 2870                                      |  |                   |   | The Odra River (Poland)                                       | Rachalewski <i>et al.</i> (2013)   |
|   |  | 1.4–3.5           | 1520                                      | The Vistula Lagoon  | Jazdzewski <i>et al.</i> (2004);<br>Grabowski <i>et al.</i> (2006);<br>Dobrzycka-Krahel <i>et al.</i> (2013) |
|   |  | 0.2–4.9           | 74<br>6399                                | The Vistula Delta<br>Puck Bay                                 | Dobrzycka-Krahel <i>et al.</i> (2013)<br>Janas and Kedzierska (2014)   |
|   |  | 0–10.0            | 10 767<br>1–70                            | The Gulf of Finland<br>The Latvian waters of the Gulf of Riga | Kotta <i>et al.</i> (2013)<br>Strode <i>et al.</i> (2013)  |
|   |  | 4.5–6.0           | 110–508; maximum 4700                     | The Gulf of Riga  | Reisalu <i>et al.</i> (2016)   |

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**Cite this article as:** Lewin I, Halabowski D, Rymarski Z. 2018. The first records of the occurrence of a North American invader *Gammarus tigrinus* Sexton, 1939 in the tributaries of the upper Vistula River. *Knowl. Manag. Aquat. Ecosyst.*, 419, 31.