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INVASION OF THE NORTH AMERICAN AMPHIPOD (*GAMMARUS TIGRINUS* SEXTON, 1939) INTO THE CURONIAN LAGOON, SOUTH-EASTERN BALTIC SEA

Darius DAUNYS[1], Michael L. ZETTLER[2]

[1] Coastal Research and Planning Institute, Klaipėda University, H. Manto 84, LT-92294 Klaipėda, Lithuania. E-mail: darius@corpi.ku.lt
[2] Baltic Sea Research Institute, D-18119 Rostock, Seestrasse 15, Germany

Abstract. The North American amphipod (*Gammarus tigrinus* Sexton, 1939) was found in the Lithuanian part of the Curonian Lagoon in September 2004. In the littoral part, the distribution of the species was restricted to the area of seawater inflows, within a distance of up to 23 km upstream from the sea. The species was present in all types of the habitats sampled (reeds, mixed and soft bottoms) and its distribution showed a continuous rather than fragmented pattern. In most cases, the species was absent in enclosed depositional environments with mixed substrates and the presence of mud. *Obessogammarus crassus* (G. O. Sars) was the only crustacean species always found in the presence of the new invader *G. tigrinus*, whereas other species showed a higher degree of habitat discrimination within the stations. Along with the other two introduced crustaceans *O. crassus* and *Pontogammarus robustoides* (G. O. Sars), *G. tigrinus* showed the highest occurrence (79%) in the salinity range of its recent distribution in the lagoon. As the factors limiting the species establishment are difficult to predict, the rapid spread of *G. tigrinus* into inland Lithuanian waters might be expected.
Key words: Lithuania, Curonian Lagoon, *Gammarus tigrinus*, Crustacea, Malacostraca, invasion

Introduction

The necto-benthic *Gammarus tigrinus* (Amphipoda, Crustacea) is originally a North American species introduced into British waters (Droitwitch district) by ballast waters in 1931 (Sexton 1939; Hynes 1955). Sexton (1939) used specimens from there for description of the species. The spread of this amphipod in European continental waters was accelerated by its intentional release into the tributary of the German River Weser in 1957 (Schmitz 1960; Ruoff 1965; Heuss 1966). In the Netherlands, this species was first recorded from the Ijsselmeer in 1964 (Pinkster 1975; Platvoet & Pinkster 1985; Pinkster *et al.* 1977) and in 1975 reached the south-western part of the Baltic Sea (Schlei Fjord) probably via the 'Nord-Ostsee-Kanal' (Bulnheim 1976; Bulnheim 1980). After two decades, its rapid spread in German waters along the southern Baltic coastline was noticed (Rudolph 1994; Zettler 1995) and soon the species was found in the Szczecin Lagoon (Gruszka 1995; Wawrzyniak-Wydrowska & Gruszka 2005), Puck Bay (Gruszka 2002) and the Vistula Lagoon (Jadzewski & Konopacka 2000; Ezhova *et al.* 2005). The latter water body was the northern limit of the species in the Baltic until its occurrence in the Gulf of Riga (Kotta 2005) and along the Finnish coast in 2003 (harbours of Hamina in the Gulf of Finland and Turku in the northern Baltic) (Pienimäki *et al.* 2004).

The widespread distribution of *G. tigrinus* in Europe was explained by a wide range of salinity (0–25°psu) and temperature (5–35°C) tolerance (Pinkster *et al.* 1977; Wijnhoven *et al.* 2003). In its native range (the Atlantic coast of North America from Labrador in the North to Florida in the South), this euryhaline species lives in both fresh and brackish water (Bousfield 1973), whereas in coastal waters its distribution is restricted to shallow lagoons, bays and estuaries. Being a bottom-dwelling omnivore, *G. tigrinus* is relatively tolerant to pollution and has a much greater reproductive capacity in oligohaline waters than many native gammarid species (Pinkster 1975; Pinkster *et al.* 1977).

The aim of this paper is to provide the first data on the new alien amphipod species *Gammarus tigrinus* in Lithuanian coastal waters. On the basis of collected material, we also describe its association with other malacostracan species and relation to some environmental factors.

Material and methods

In September 2004, 22 littoral stations were visited in the Lithuanian part of the Curonian Lagoon (Fig. 1).

The bottom macrofauna was collected at depths down to 1 m using a hand net. Three types of habitats (reeds, mixed sediment and soft bottoms) were sampled separately spending approximately 10–15 min. A total of 38 samples were taken during the survey. Geographic coordinates, salinity, type of sediment, exposure (sheltered/exposed) and the distance from the shoreline were noted for each sampling site.
Collected fauna was fixed in 4% formaldehyde solution and a standard proceeding of samples was carried out in the laboratory. The species abundance was estimated using a ranking scale: 1 – rare (<10 individuals/sampling), 2 – common (10–50 individuals/sampling), 3 – abundant (>50 individuals/sampling). In order to compare the species abundance, the relative rank abundance was calculated. This measure was estimated by summing up the abundance ranks of the species in different samples and normalising them to the total rank sum of all species involved in comparison.

Results

Gammarus tigrinus was found at seven stations (11 samples collected therein) of the Klaipėda Strait and the northernmost part of the Curonian Lagoon (Fig. 1, Table 1). All these stations are located within a distance of 23 km upstream from the sea and subject to saline water inflows and temporal increase in salinity up to 7 psu. The species distribution in the study area showed a continuous rather than fragmented pattern. It was present in all types of habitats examined (reeds, mixed and soft bottoms), whereas the highest abundance was found at the stations closest to the sea (stations 13 and 14). We did not find any specimens of *G. tigrinus* in enclosed depositional environments at stations 2 and 11 with mixed substrates and the presence of mud. On the other hand, the species occurred in highly polluted Malku Bay (station 3), where the lowest species diversity comprised of mainly oligochaetes during our survey was noted. Only two other alien crustaceans, the mysid (*Paramysis lacustris*) (Czerniavsky) and the amphipod (*Obesogammarus crassus*) (G. O. Sars), were found at this station.
Out of 63 macrofauna species (insects excluded) found along with *G. tigrinus* at the sampling sites, 19 belonged to molluscs (4 bivalves and 15 gastropod species), 17 – to oligochaetes, and 5 – to leeches. The number of mobile benthic or bentho-pelagic crustaceans, potentially exploiting a similar habitat or food source as *G. tigrinus,* was also high (14 species): three mysids (*Praunus flexuosus* (O. F. Müller), *Paramysis lacustris* and *Limnomysis benedeni* (Czerniavsky)), the isopod *Asselus aquaticus* (L.), three corophiids (*Corophium volutator* (Pallas), *Apocorophium lacustre* (Vanhöffen) and the alien *Chelicorophium curvispinum* (G. O. Sars)), six gammarids (*Gammarus zaddachi* (Sexton), *G. oceanicus* (Segerstrale), *G. duebeni* (Lilljeborg) and the introduced *Pontogammarus robustoides* (G. O. Sars), *O. crassus*, *Chaetogammarus warpachowskyi* (G. O. Sars)) and the decapod *Palaemon elegans* (L.). Seven of these species were restricted to the most saline part of the studied area (range of the mean annual salinity between 0.5 and 3.5 psu) (Fig. 2). The rest of species were distributed along the entire Curonian Lagoon and inhabited both permanently fresh and oligohaline waters exposed to temporal Baltic water (~7 psu) inflows. The distribution of *G. tigrinus* was coincident with the spread of another alien *O. crassus* and the latter was the only crustacean species always found in the presence of the new invader. In contrast to *G. tigrinus* and *O. crassus*, found in all types of habitats, in case they were present at the station, the other species showed a higher degree of patchiness (usually found in only one of two station samples).

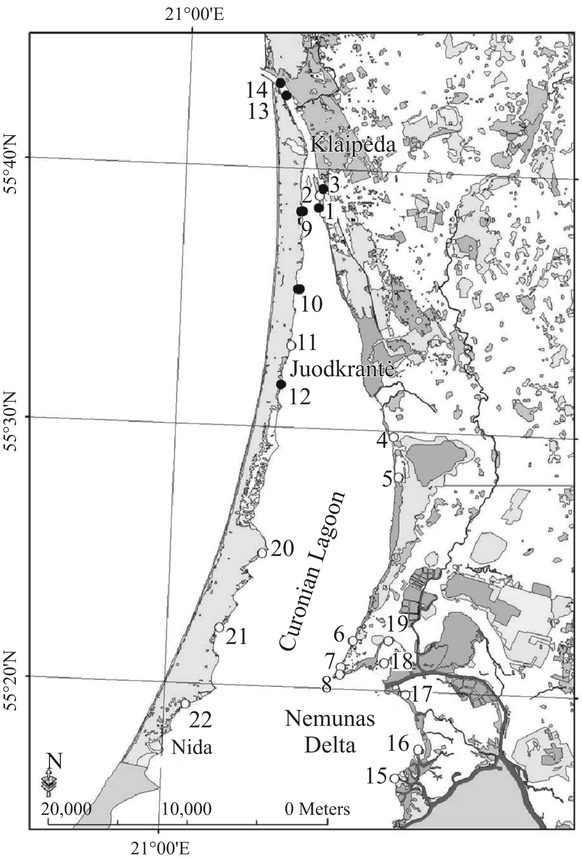

Figure 1. Sampling stations in the Curonian Lagoon. Numbers indicate station numbers used in the text. Filled and open circles denote stations with the presence and absence of *Gammarus tigrinus*, respectively.

Table 1. Geographic positions and environmental conditions at the stations of *Gammarus tigrinus* occurrence. A – relative rank abundance of *G. tigrinus* (see 'Material and methods' for the explanation of the ranking scale); Depth – sampling depth (m); Distance – distance from the shoreline (m).

Station No	Latitude	Longitude	Substrate	A	Depth	Distance
1	55°33.806'	21°09.261'	1. Fine sand with *Potamogeton pectinatus*;	2	1	65
			2. Small stones and gravel	1	0–0.2	0–5
3	55°39.230'	21°09.324'	Stones, reed, *P. pectinatus*, mud	1	0–1	0–2
9	55°38.333'	21°07.980'	1. Soft sediments with stones on sites;	1	0.6	10
			2. Reed	1	0–05	0–5
10	55°35.380'	21°08.013'	Sandy sediments with scarce macrophytes	1	0.6	80
12	55°31.667'	21°07.100'	1. Fine to coarse sand, with scarce *P. pectinatus*;	1	1.0–1.3	20
			2. Reed and wood on sand	1	0–05	0–10
13	55°42.799'	21°06.651'	Stones with Enteromorpha and Cladophora	3	0–1	0–3
14	55°43.287'	21°06.210'	Large boulders and stones with Enteromorpha and Cladophora	3	0–1	0–5

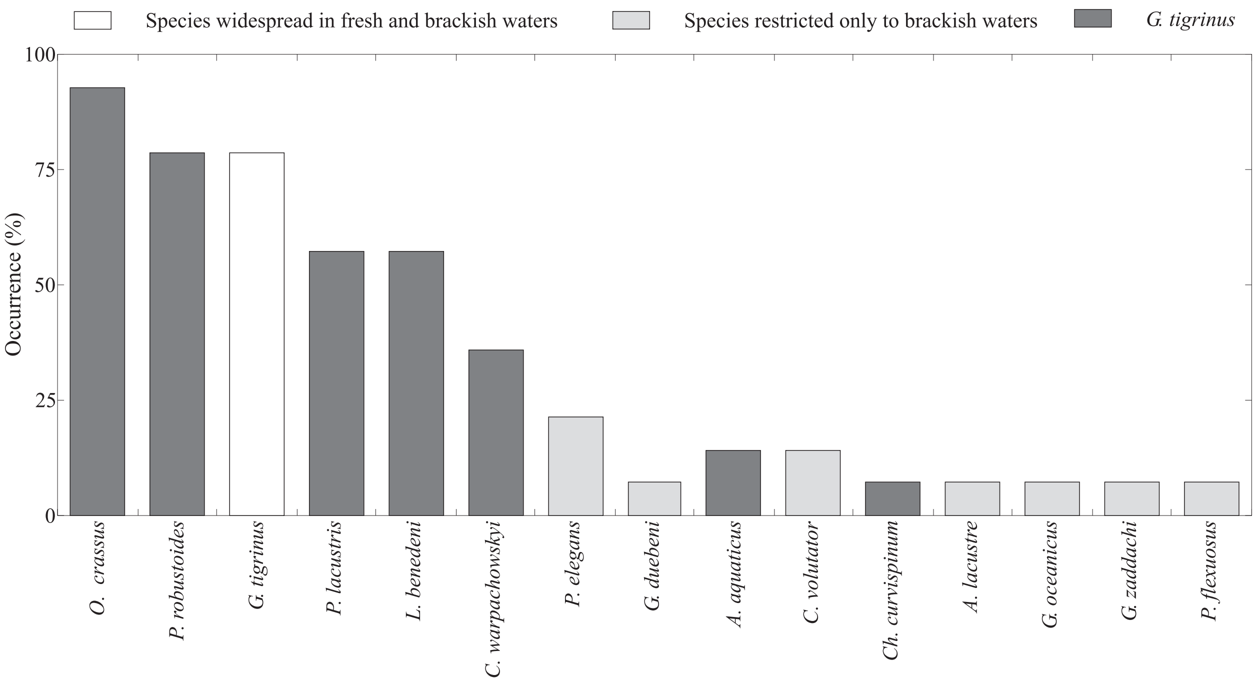

Figure 2. Occurrence of crustacean species in the area of *Gammarus tigrinus* spread in the Curonian Lagoon.

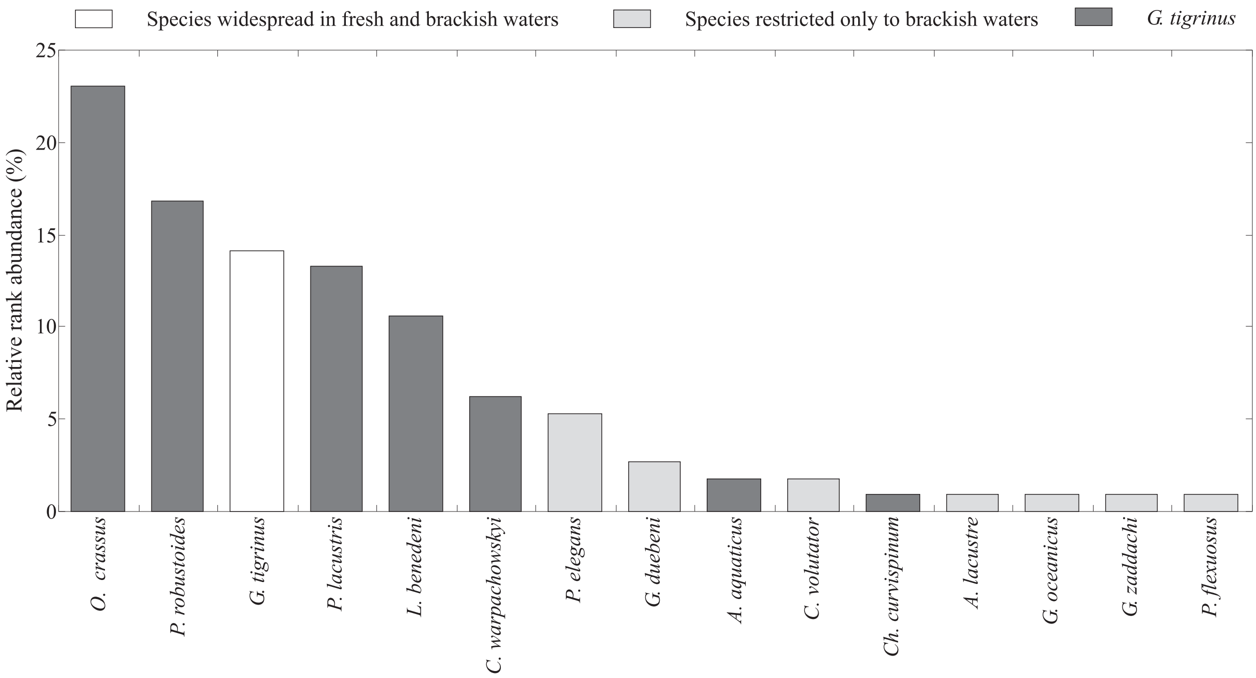

Figure 3. Relative rank abundance of crustaceans in the area of *Gammarus tigrinus* spread in the Curonian Lagoon.

Along with the two introduced species, *O. crassus* and *P. robustoides*, *G. tigrinus* showed the highest occurrence (79%) in the salinity range of its recent distribution in the Curonian Lagoon (Fig. 2). Assuming equal sampling efficiency of species, relative rank abundance of the recent invader was either similar or higher (14%) than that of the other alien crustaceans *Paramysis lacustris* (13%), *Limnomysis benedeni* (11%), *Chaetogammarus warpachowskyi* (6%) and *Ch. curvispinum* (1%) (Fig. 3).

Discussion

Despite the fact that *Gammarus tigrinus* has only recently been found in the Curonian Lagoon, its relatively wide distribution may imply an earlier date of its invasion. This is mainly because the species is difficult to collect by standard grab sampling methods used in routine monitoring. Additionally, stations visited once or twice a year during monitoring surveys in the Curonian Lagoon and Klaipėda Strait are located at depths greater than 3 m. Therefore, the probability to find such a mobile species is rather low at the initial stages of species invasion when its abundance is frequently low.

It is difficult to predict the means by which *G. tigrinus* expanded its recent range to Lithuanian waters. The pattern of its distribution in the Curonian Lagoon favours the hypothesis that most likely the species first invaded the Klaipėda Port area and then expanded its range southwards. So far the species has not been found close to another possible route of invasion, the Nemunas River Delta, therefore the possibility of its invasion from inland waters is less likely.

Our results indicate that the species is found in numerous habitats in the lagoon, though its recent occurrence is restricted to the zone of seawater inflows. This part of the lagoon is critical for many other species due to both high anthropogenic pressure and a wide range of salinity fluctuations. Enclosed bays of limited water exchange with the open lagoon tend to be less exposed to invasion at least in its initial stages, however taking into account the tolerance limits of the species, we can conclude that it has a high chance to survive, reproduce and establish in the lagoon as it did in similar conditions in the other Baltic lagoons and coastal waters (Gruszka 1999; Jazdzewski *et al*. 2004; Zettler 2001). In the Szczecin Lagoon, *G. tigrinus* has a long reproduction period, from April to November, forming at least two generations within a year (Wawrzyniak-Wydrowska & Gruszka 2005).

The new alien *G. tigrinus* can affect the native fauna in numerous ways. In the inland waters of Holland and in the Vistula Lagoon (the Baltic Sea), *G. tigrinus* eliminated or outnumbered several amphipod species including *G. zaddachi* and *G. duebeni* (Nijssen & Stock 1966; Chambers 1987; Platvoet *et al*. 1989; Pinkster *et al*. 1992) which are also present in the Curonian Lagoon.

Vulnerability of gammarids at moult may also allow predation of *G. tigrinus* on equally sized or even larger amphipod species (Dick 1996; Dick & Platvoet 1996). Considering a relatively high diversity of mobile benthic species and their high densities in the littoral part in summer, invasion of ecosystem by a new aggressive species may increase competition and modify their distribution in the shallow habitats of the Curonian Lagoon. Roos (1979) reported that the freshwater amphipod *G. tigrinus* also feeds on the polyps of *Cordylophora caspia* (Pallas) in the river system of low and variable salinity in the western part of the Netherlands. In the Curonian Lagoon, the distribution of *C. caspia* is restricted to the habitats where the highest densities of *G. tigrinus* were noticed during our survey and therefore this hydroid species may become one of the food sources of the alien. On the other hand, *G. tigrinus* may successfully enter a local food web becoming a prey for several fish species. The perch (*Perca fluviatilis* L.) diet shifted from chironomid larvae to *Ch. curvispinum* and *G. tigrinus* after their introduction, whereas the dietary overlap of perch and eel (*Anguilla anguilla* L.) has decreased (Kelleher *et al.* 1998). In the Lithuanian coastal zone, the amphipods were found to contribute up to 40% of the perch diet (Bubinas 1994). However, the European eel and other species, such as the pollan (*Coregonus autumnalis* (Pallas)) and the three-spined stickleback (*Gasterosteus aculeatus* L.), may also feed on the alien gammarid (MacNeil *et al.* 1999). Hynes (1956) also noted dragon-fly nymphs consuming very large numbers of juvenile *G. tigrinus* under laboratory conditions.

In spite of wider food spectra for some fish species, impacts that potentially may have influence on the local economy were also noted. Massive populations of *G. tigrinus* in German rivers have been blamed for destroying fishing gears and injuring fish caught in nets (Pinkster *et al.* 1977). Along with *G. tigrinus*, the parasite (*Paratenuisentis ambiguous*) has been introduced into Europe (Gollasch & Zander 1995; Rolbiecki & Normant 2005). However, highly specific host requirements of this parasite species did not allow its rapid spread in Europe (Taraschewski *et al.* 1987; Rolbiecki & Normant 2005).

At present, it is difficult to foresee natural pressures which may limit the spread or establishment of the new alien *G. tigrinus* in the Curonian Lagoon and other European water bodies. The species is better adapted to withstand the predation between species that potentially exploit the same class of environmental resources (Dick & Platvoet 1996). However, another amphipod *Dikerogammarus villosus* (Sowinski), which rapidly colonises European waters and is capable of eliminating *G. tigrinus* in competition for space (Dick & Platvoet 2001; Devin 2003), may also invade Lithuanian waters soon. In northern Germany, *Ch. curvispinum* arrived at the beginning of the 20th century. In the mid-1990s, *G. tigrinus* and *Echinogammarus ischnus* (Stebbing) reached the highest abundances, whereas later *Pontogammarus robustoides* and afterwards *D. villosus* seem to have displaced the former amphipods. The most recent newcomers *Dikerogammarus haemobaphes* (Eichwald) and *O. crassus* also affected the existing amphipod communities. It seems that each new amphipod species was able to change local fauna interactions, however species extinctions at the ecosystem scale due to invasions of amphipods are poorly recorded in the Northern Europe.

In the Curonian Lagoon *Gammarus lacustris* (G. O. Sars) and *G. pulex* (L.) were mentioned before introduction of four new Ponto-Caspian amphipods in the early 1960s (Gasiūnas 1959; Gasiūnas 1963), while later on both species have not been found. Causal relationships of these changes have not been studied and possible trends in species diversity of the Lagoon's communities remain uncertain, however changes in relative species abundances over time are very likely.

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Šiaurės Amerikos šoniplaukos (*Gammarus tigrinus* Sexton, 1939) invazija į Kuršių marias

D. Daunys, M. L. Zettler

Santrauka

Šiaurės Amerikos kilmės šoniplauka (*Gammarus tigrinus* Sexton, 1939) Kuršių marių Lietuvos dalyje buvo rasta 2004 m. rugsėjo mėnesį. Tyrimų metu ši rūšis buvo paplitusi jūrinio vandens poveikio zonoje, 23 km atstumu nuo jūros vartų iki Juodkrantės įvairiose litoralės buveinėse: nendrynuose, smėlėtame dugne su makrofitais bei tarp akmenų, išskyrus uždaras įlankas, kur dugno nuosėdose vyravo dumblai. Kita vertus, *G. tigrinus* individai buvo rasti Malkų įlankoje, kur nustatyta mažiausia dugno faunos rūšių įvairovė. Kartu su kitomis dviejų rūšių introdukuotomis šoniplaukomis *Obesogammarus crassus* (G. O. Sars) ir *Pontogammarus robustoides* (G. O. Sars), *G. tigrinus* sutinkamumas rūšies arealo ribose (79%) buvo didžiausias lyginant su kitomis tyrimų metu rastomis judrių vėžiagyvių rūšimis. Remiantis *G. tigrinus* plitimo tendencijomis Europoje galima laukti greito šios rūšies plitimo Lietuvos vidaus vandenyse.

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