The River Odra Estuary as a Gateway for Alien Species Immigration to the Baltic Sea Basin

Das Oderästuar als Pfad für die Einwanderung von Alienspezies in die Ostsee

Dr. Piotr Gruszka
Department of Marine Ecology and Environmental Protection, Agricultural University in Szczecin, ul. Kazimierza Królewicza 4/H, PL 71-550 Szczecin, Poland
E-mail: pgruszka@fish.ar.szczecin.pl

Summary:
The river Odra estuary belongs to those water bodies in the Baltic Sea area which are most exposed to immigration of alien species. Non-indigenous species that have appeared in the Szczecin Lagoon (i.a. Dreissena polymorpha, Potamoichthys antipodarum, Corophium curvispinum) and in the Pomeranian Bay (Cordylophora caspia, Mya arenaria, Balanus improvisus, Acartia tonsa) in historical time and which now are dominant components of animal communities there as well as other and less abundant (or less common) alien species in the estuary (e.g. Branchiura sowerbyi, Eriocheir sinensis, Orconectes limosus) are presented. In addition, other newcomers - Marenzelleria viridis, Gammarus tigrinus, and Pontogammarus robustoides - found in the estuary in the recent ten years are described. The significance of the sea and inland water transport in the region for introduction of non-indigenous species is discussed against the background of the distribution pattern of these recently introduced polychaete and gammarid species.

Keywords: Alien Species, Marenzelleria viridis, Gammarus tigrinus, Pontogammarus robustoides, River Odra Estuary

Zusammenfassung:

1 Introduction
Elimination of environmental pollution and sustaining the environment in a non-polluted state are often referred to as the most important issues of the present times [1]. In many cases, pollution of the environment results in diminishing biological diversity, which leads to disturbance in the ecological
equilibrium. Biodiversity has received much attention since the Rio Declaration of 1992 [2] and is still very important, especially now, during the process of implementing Agenda 21 in the Baltic Sea Region. Among the types of human activities that threaten biodiversity, such as chemical and mechanical pollution, there is another kind of activities which can, through introduction of alien (non-indigenous or exotic) species, cause perturbations, visible as fundamental, irreversible alterations in the structure of communities, by way of predation, competition, disturbance, and the introduction of diseases and parasites [3]. The appearance of exotic species in an area and their subsequent establishment there may bring about effects ranging from the almost undetectable to very profound (e.g. change in dominance structure and displacement of native communities). As seen from several examples around the world, serious economical consequences of such introductions can be expected even though they are not necessarily accompanied by drastic changes in diversity within biota [4-6].

Transport in ships' ballast water is thought to be the main pathway for the transfer of organisms between various seas [7-9]. In addition, organisms attached to ship hulls can be transported over long distances as well [7, 9, 10]. Numerous canals connecting various riverine systems, which evolved in Europe during the last two centuries, are of a great importance for the dispersal of a number of freshwater species [11]. The German inland waterways act as the key canal system for spreading alien species in European inland waters, particularly in Central and Western Europe. The Main-Danube canal, constructed in 1845, connects this part of the continent with the Black Sea catchment area and the Balkan region. Another important system is that in Russia and Eastern Ukraine, which connects the Baltic Sea area with the Caspian and Black Seas (via the Azov Sea) [11]. Species can use artificial waterways for their natural migrations as well [5]. From the Baltic perspective, the risks of introducing non-indigenous species by ships navigating river/canal systems connecting the Baltic with the Black and Caspian Seas should be regarded as very serious and imminent.

Mordukhai-Boltovskoi [12], Jazdzewski [11], and Jansson [5] pointed to another way of man-mediated dispersal of species, i.e. to acclimatization (mainly related to aquaculture), which has been practised in Europe (including the Baltic Sea basin) for more than a hundred years, especially in the former Soviet Union in the 1960s and early 1970s. Associated with acclimatization of numerous fish species are unintentional introductions of e.g. novel parasites. Organisms accidentally released from aquaria must be mentioned here as well [5, 9].

A resolution adopted by the International Maritime Organization (IMO) in 1993 [13] identifies brackish water areas as those offering the highest probability of survival for aquatic organisms and pathogens transferred from elsewhere.

Inland shipping in Poland occurs mainly in the river Odra, the highest ship traffic intensity taking place between Szczecin and the inland ports of Western Europe [14]. Thus, as the effect of both inland and marine shipping converging to the two major river and sea ports of Szczecin and Swinoujscie, and also that of Stralsund, the river Odra estuary belongs to those water bodies in the Baltic Sea area which are most exposed to immigration of alien species.

The aim of this paper is to review data on non-indigenous species introduced to the estuary in the historical time, particular attention being paid to the recent newcomers found in the area over the last ten years, and to follow mechanisms facilitating alien species introduction there.

### 2 Materials and Methods

#### Area of interest

The river Odra estuary consists of three components (Fig. 1): 1) the Pomeranian Bay with Greifswalder Bodden; it is the northernmost, brackish (salinity of about 6..7 PSU) area affected usually by oligohaline (about 1 PSU) to fresh water from 2) the Szczecin Lagoon, the mid-part of the estuary, in which riverine and Baltic Sea water mix throughout most of the year, and 3) downstream section of the river Odra with the adjacent Lake Dabie where salinity rarely exceeds 0.4 PSU. Out of the three straits leading from the Szczecin Lagoon to the Pomeranian Bay: the Peenestrom (via Greifswalder Bodden), Swina and Dziwna, the second one forms the most important connection as it intercepts about 75 % of the water exchange between the Lagoon and the Baltic [15]. The river Odra estuary bottom is covered by muddy and sandy sediments. Sands dominate in the Pomeranian Bay and the littoral zone in the rest of the estuary, while more fine-grained sediments occur in the central parts of the Szczecin Lagoon, Greifswalder Bodden, and the Bay area off the river Swina mouth [16, 17].
**Database**

Research done in the second half of the 19th century by Mobius [18] and Brandt (1896), as quoted by Neubaur [19], provided the initial faunistic observations in certain parts of the river Odra estuary. The species are not native to the estuary are known from the reports printed in this century [e.g. 19-25], and the reviews on alien species from the worlds and European perspective [4-7, 11, 26, 27]. Data on the presence of benthic and planktonic species new for the river Odra estuary were obtained from the samples collected within 1988-1997 and extracted from reports and papers by the author and by other scientists based in Szczecin (Mrs. M. Bak, Dr J. Maslowski, Dr Z. Piesik, Mrs. A. Skarbek, Dr A. Torz, Dr B. Wawrzyniak-Wydrowska, and Mrs. M.-K. Wegielnik). Included in this review are also data reported by German authors working in the estuary [17, 28-31].

Benthos samples were taken either with Van Veen, Petersen, and Ekman-Birge grabs (sampling surfaces ranging from 225 to 1 000 cm²) or with a hand operated tube corer (28 cm² sampling surface). Modified Reineck box corers were used by the German authors [17] in the Pomeranian Bay and the Szczecin Lagoon (sampling surface of 225 and 60 cm², respectively). The samples were washed over 0.5 mm or 1 mm mesh size sieves. Littoral infauna From very shallow sandy bottom was sampled with hand operated sieves of 1 or 2 mm mesh size, depending on the sediment coarseness. Zooplankton was collected with 80 to 100 urn mesh size plankton nets. The animals were preserved in 10% formalin, identified, and counted in the laboratory.

**3 Results and Discussion**

### 3.1 Non-indigenous Species Recorded Prior to 1980

The estuary houses a number of non-native species, most of them being introduced in historical times. At present, some of them are dominating the animal communities, usually in the littoral or shallow sublittoral.

The following non-native species are common and numerous mostly on shallow, sandy, and sandy-muddy bottom of the Szczecin Lagoon, lower Odra, and Lake Dabie:

- *Dreissena polymorpha* (Pallas. 1771), the freshwater or zebra mussel, a filter-feeding epifaunal bivalve of Ponto-Caspian origin (introduced in the 19th century) [5, 26, 32], common also in lakes and reservoirs in northern Poland [32];
- *Potamopyrgus antipodarum* (Gray, 1843), a prosobranch gastropod native to New Zealand, brought to Europe (the Thames estuary) from Australia or Tasmania in the 19th century [6];
- *Comphium curvispinum* G. O. Sars, 1895, a most widely distributed amphipod of Ponto-Caspian origin which appeared in Central Europe, including the river Odra system, in the beginning of the 20th century [11]; in the Szczecin Lagoon the species inhabits mainly coastal bulrushes [33, 34].

The following non-native species are very common at present in the Pomeranian Bay:

- *Balanus improvisus* Darwin, 1854, a native of North America, the only barnacle species in the Baltic Proper and the dominant member of biofouling community there; accord ing to Luther (cited in [26]) recorded in the Baltic for the first time in 1844;
- *Cordylophora caspia* (Pallas, 1771), an epifaunal Ponto-Caspian hydrozoan, brought to the Baltic in the 19th century [5, 26];
- *Mya arenaria* (Linnaeus, 1758), the largest Baltic bivalve, a dominant infaunal species near river mouths; in the Pomeranian Bay it is particularly abundant in the western coastal part influenced by the Odra discharge [35]; it is thought to have become extinct in Europe during a series of Pleistocene glaciations and has become re-established after its transfer from North America during the 16th or 17th century - according to some sources - as early as in the 13th century [5, 6];
- *Acartia tonsa* Dana, 1848, a copepod common in the Baltic zooplankton that appeared in Europe in the first half of the 20th century, possibly transferred from North America [5, 6]; at present, it co-dominates the Pomeranian Bay coastal planktonic community along with the native *A. bifilosa* [36].

With regard to pathways of their introduction, most of the above species (*D. polymorpha*, *C. curvispinum*, *B. improvisus*, and *C. caspia*) are thought to have been transferred attached to ships' hulls, while the other three (*P. antipodarum*, *M. arenaria*, and *A. tonsa*) are examples of ballast water-borne species [6, 26]. However, only the latest newcomer, *A. tonsa* is thought to be brought to Europe in...
ballast water; M. arenaria may have been introduced as food or bait, while P. antipodarum could have been transported in barrels with drinking water [6]. Recent invasions of bivalves to the Black Sea (M. arenaria) [4] and to the Great Lakes in North America (D. polymorpha) [3, 6] clearly show that such species belong at present to the "ballast water group", as both of them have planktonic larvae.

Some authors stress the role of inland canals and shipping in introductions and/or the range extension of freshwater species and those tolerating low salinity brackish water (e.g.: D. polymorpha, C. curvispinum, P. antipodarum, and C. caspia) [6, 11]. Another amphipod species *Corophium multisetosum* Stock, 1952 reported by Jazdzewski [23] from the Polish Baltic estuarine waters since the 1960s, is very common in the river Swina [33]. The species is regarded by Leppakoski [26] as having been possibly introduced, the manner of its dispersal being, however, unknown.

Less abundant (or less common) alien species reported from the estuary include:

*Branchiura sowerbyi* Beddard, 1892, a thermophilous oligochaete (of Asian origin) reported from the Lagoon since 1976 [24];

*Eriocheir sinensis* Milne-Edwards, 1854, the Chinese mit ten crab, found at first in the Szczecin Lagoon in 1928 [20] and later in many places in the estuary [27];

*Rhithropanopeus harrisi* (Gould, 1841), the American dwarf or mud crab, rarely encountered in the Szczecin Lagoon where it was found for the first time in 1950s [27];
*Orconectes limosus* (Rafinesque, 1817), the American pygmy crayfish, introduced into the river Odra drainage basin in the end of the 19th century, reported from the estuary since at least 1930s [27]; *Lepomis gibbosus* (Linnaeus, 1758), the common (or pumpkinseed) sunfish, brought to Europe from North America, reported from the Lower Odra since 1983 [25].

The species listed above could have been brought into the estuary in a variety of ways. There exist examples of ballast species unintentionally introduced to one of European estuaries which subsequently spread to other rivers and their estuaries (e.g. *E. sinensis* and *R. harrisii*) [20, 21,27]. Some species can be imported along with ornamental aquatic plants (*B. sowerbyi*) [37]. Still other species were intentionally brought to aquaria and ponds in Europe and either escaped (*L. gibbosus*) [25] or were deliberately released for stocking purposes (*O. limosus*) [27].

### 3.2 Recent Newcomers

Introductions of alien species are still going on and a global increase in the amount of successful colonisation events is being observed. Within 1988-1991 three new benthic species: the spionid polychaete *Marenzelleria viridis* (Verrill, 1873), the gammarid crustacean *Gammarus tigrinus* Sexton, 1939, and another gammarid, *Pontogammarus robustoides* G. 0. Sars, 1894 were found in samples collected in the inshore Pomeranian Bay, from the river Swina, and from the littoral in the eastern part of

![Map of the Odra drainage basin](image.png)
the Szczecin Lagoon, respectively. In addition, early larval stages of M. viridis were found in plankton samples collected from the northern part of the Lagoon in November 1988.

In the 1990s, all the three new species: M. viridis (Fig. 2), G. tigrinus (Fig. 3), and P. robustoides (Fig. 4) turned out to be common in the estuary; in some places, they proved very abundant components of the biota. Each of them, however, has a different distribution pattern, depending on environmental requirements as to the salinity and substrate type.

Marenzelleria viridis is a North American species recorded from the Baltic Sea since 1985 [38]. A juvenile spionid polychaete found by Maslowski [34, 39] in the northern part of the Szczecin Lagoon in June 1986 turned out to be M. viridis. As no M. viridis was found in the Świna mouth area in September 1984, in contrast to the polychaete's wide distribution in 1988 [39], it is then inferred that the species was probably discharged to the Odra estuary with ballast water from a ship entering one of the harbours there (Swinoujście or Stralsund) in 1984 or 1985. By the early 1990s M. viridis managed to colonise almost the whole Baltic Sea. In the river Odra estuary, it inhabits more saline areas, its density reaching about 3 000 ind./m² [17, 40].

The maximum density of 28 000 ind./m² was revealed in Kleines Haff in 1993 [17]. Successful colonisation of the Szczecin Lagoon by M. viridis in 1990-1992 was probably the effect of a low precipitation and thus a lower water flow in the Odra in late 1980s and beginning of 1990s [41], whereby the Baltic water (containing M. viridis in autumn) entered the Lagoon in amounts larger then usual.
The inflow of Baltic water resulted in increase of the average water salinity (from 1 to 2...3 PSU) [42], which in turn provided more favourable conditions for reproduction and development of M. viridis and for extension of its range in the estuary. Early developmental stages (which are all planktonic from the moment eggs are fertilized until metamorphosis of larvae [43, 44]) were recorded in plankton from September until May. They appeared in mass amounts in autumn (October-November) attaining densities of about 1 Mio ind./m³. According to unpublished data collected by the Polish State Environmental Protection Inspection (PIOŚ) from the middle part of the Szczecin Lagoon, density can be as high as 5 Mio ind./m³. The species was observed over the whole Lagoon and even as far south as the downstream section of the Odra near Police (Fig. 2). After the increase of the water flow in the Odra in 1994, the M. viridis population in the middle part of the estuary declined. The polychaete has never been found in Lake Dabie or in the Odra near or south of Szczecin. In less than 10 years after its introduction, M. viridis managed to dominate the benthos and (seasonally) the plankton in the northern part of the Odra estuary, especially in the inshore highly productive waters (see also [17]). Gammarus tigrinus is another North American species, although it was originally described by Sexton from England where it was first found in 1931 [45]. The species has been successfully conquering European continent since the late 1950s [11] and reached the Baltic Sea area (fjord Schlei) by 1975 [22]. The first specimens found in the Odra estuary were collected by Piesik and Wawrzyniak-Wydrowska from the river Swina in 1991. Rudolph [28] reported that G. tigrinus was present in the Peenestrom and the Achterwasser in 1992. Later in the 1990s,
the species was present almost throughout the estuary (Fig. 3), inhabiting a wide range of habitats: from hard bottom (e.g., concrete constructions) covered with algal vegetation to sandy sediments at even very shallow depths (e.g., on beaches) to muddy sediment covering river beds and the central part of the Szczecin Lagoon both in the German and Polish parts. The salinity tolerance of G. tigrinus should be stressed, as the species can be encountered both in typically fresh, riverine water and in brackish mesohaline water of the inshore part of the Pomeranian Bay. The few samples collected from Lake Dabie and the Odra between Szczecin and Police contained no specimens of G. tigrinus during the discussed period. Further studies on the bottom fauna of the area should show whether this newcomer has been able to colonise that, quite polluted, part of the estuary. In the Szczecin Lagoon, the species has replaced G. pulex that used to be found there until the 1970s [27] and disappearance of which could be related to the Lagoon's salinity increase in the late 1970s and early 1980s [42]. In addition, the distribution of G. tigrinus in Mecklenburg-Vorpommern (in coastal waters and along navigable rivers the Peene and the Elbe, and canals) [31] shows the species' preference for brackish water and/or the role of shipping in its dispersal. As early as in 1992, it was found in the Odra [46] and in the Berlin/Brandenburg waterways connected with the river by the Havel-Odra canal [47].

Pontogammarus robustoides is a Ponto-Caspian species [48-50] brought to the Baltic Sea area (some reservoirs and lakes in Lithuania, the Curonian Lagoon, and the river Daugava in Latvia) along with several other amphipods and some mysids as a result of acclimatisation attempts in the former Soviet Union in the 1950s and 1960s [4, 5, 11, 26]. In the Odra estuary, the earliest samples with specimens of P. robustoides were taken by Wawrzyniak-Wydrowska in 1988 from coastal reeds in the south-eastern part of the Szczecin Lagoon. In 1993 and later on, the species turned out to be abundant on very shallow sandy bottoms in a vast part of the estuary where freshwater or oligohaline conditions prevailed (Fig. 4); it frequently co-occurred with G. tigrinus. In two instances, few specimens of G. zaddachi, a species native to the Baltic, were additionally found along with the two new gammarids in the northern part of the Lagoon and in the Swina, the areas often affected by Baltic waters inflows. In 1994, P. robustoides was found in the Peene opening to the Szczecin Lagoon [30]. However, the species apparently avoids river outlets to the Pomeranian Bay and the inshore Bay waters due to higher salinity. This suggests its further dispersal away from the Bay along inland shipping routes, including the Odra; in 1996 and 1997, P. robustoides was found in a few localities along waterways in Mecklenburg-Vorpommern and Brandenburg [31].

Most probably, when and how the three most recent newcomers reached the Odra estuary will never be known. While the time of introduction is of lesser importance at the moment (and is roughly indicated by the years when they were recorded for the first time in area), identification of the ways these species could have been introduced can help to minimise the risk of future introductions of alien species to the estuary and their further dispersal in the river Odra system and/or the Baltic Sea area.

A sudden appearance and a very rapid spread of M. viridis to various and remote places around almost the whole Baltic by the end of 1980s [5,40, 51], far away from the species' area of origin (estuaries of the Atlantic coast of North America), renders transport of this infaunal and meroplanktonic species in ships' ballast tanks most probable. In the sea harbours situated in more saline parts of estuaries, ships can be ballasted with water which may contain larval M. viridis. It makes the species especially invasive at the time of a year when mass reproduction takes place. That is the period of autumn storms, which is of fundamental significance for the species' natural dispersal in estuaries and along the coasts (following the net current) [51, 52].

Similarly, G. tigrinus was probably brought to Europe from America in ballast water, but its further expansion in Europe points to the significance of waterways, especially canals joining different river systems, and inland shipping. The species' presence in the coastal Lake Bukowo in the central part of the Polish coast [53], however, shows that this gammarid can migrate along the Baltic coast.

The new localities of P. robustoides in the Baltic region mentioned above, suggest inland way of dispersal, although, as there are no other new records of the species in the western and southern European inland waterways system, transfer in ballast water should not be ruled out. According to Jazdzewski (pers. comm.), P. robustoides was also found in the river Vistula estuary.

There is still another newcomer in the Odra estuary, namely the European physa (a freshwater pulmonate gastropode), Physella acuta (Draparnaud, 1805), native to the Mediterranean region. Since 1993, the species (brought to Central Europe by aquarists) has been found in the downstream section of
the river Ryck flowing to Greifswalder Bodden, and now it is also present in the river Uecker near its discharge to the Szczecin Lagoon [29].

According to Carlton [54], all sites that receive new invasions thus become new potential donor regions. In the light of the findings discussed above, the river Odra estuary appears to be an important stepping stone in the alien species spread in the Baltic Sea area. It is very probable that due to the large harbours the estuary was the area in which *M. viridis* invasion to the Baltic was initiated. Thus more and more records of both *Gammarus tigrinus* and *Pontogammarus robustoides* should be expected all over the Baltic Sea area and, as both species are able to survive in fresh waters, especially in the river Odra system (at least in its navigable sections) in the near future.

Having in mind that introduced species can cause changes in the structure of communities, it should also be remembered that no introduced marine organism, once established, has ever been successfully removed or contained, or its spread successfully arrested [3]. Development of ballast water discharge controls in both maritime and inland shipping that will limit further accidental alterations of the aquatic biota is severely needed, not only in the river Odra system, but in the whole Baltic Sea Region.

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**References**


