Black Sea - Baltic Sea invasion corridors

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INTRODUCTION

The Black and Baltic seas are geologically-young, brackish seas, that have undergone drastic changes since the end of the Ice Age in size and shape, hydrological and hydrochemical regimes, and connections with neighbouring seas. Their ecosystems are still undergoing changes, due to maturation processes. Consequently, most animal and plant species living in the Baltic and Black seas are postglacial immigrants, many of them living close to their salinity tolerance limits (Leppäkoski and Olenin, 2001; Gomoiu *et al.*, 2002). The process of natural enrichment of their biota with invading species (spontaneously or by means of passive dispersal) from the adjacent, more saline seas still continues.

From a biogeographical point of view, both basins represent isolated “ecological islands”, separated from other brackish water bodies by physical and ecological barriers, such as land masses and fully marine waters (Leppäkoski and Olenin, 2000a). These barriers has been breached two hundred years ago, with the construction of the first invasion corridor.

An invasion corridor is defined here as a regular human-mediated connection between isolated biogeographical regions, that cuts through natural environmental barriers and enables transfer of alien species. An invasion corridor may be established in different ways e.g., as high volume overseas shipping, transporting species in ballast tanks or on ship hulls; frequent air or surface transportation of species for stocking, seeds, or as an inland waterway.

This paper is a brief overview of the history and functioning of the inland aquatic invasion corridors between the Baltic and the Black seas, and including the Caspian and the White seas as parts of the Eastern European system of invasion corridors.

The Eastern European system of invasion corridors

Though archeological finds substantiate extensive trade and travel between the Baltic and Black Seas through Eastern Europe since early times, no organisms have been transported as far as we know. Aquatic invasion corridors have been established since the end of the 18th century, when the construction of the waterway system connecting the Baltic Sea and the Ponto-Caspian region (including the Black, Azov and Caspian seas) began (Table 1, Fig. 1). At present, Europe is covered by the ramified net of the waterways linking its western, central and eastern parts and coastal seas into an intercontinental aquatic transportation system. This aquatic web provides the invasion corridors for hundreds of alien species, spreading from previously isolated biogeographical regions either by natural means or assisted by ship traffic or by other human mediated vectors (Jazdzewski and Konopacka, 2002; Minchin and Gollasch, 2002a; Slynko *et al.*, 2002).

Table 1. The elements of the Baltic Sea-Ponto-Caspian invasion corridor system.

Year of opening	Canal (Remote connection)	References
1768	Oginskij Canal: Nemunas - Pripet (Baltic Sea - Black Sea)	Kolupaila, 1953
1775	Bug - Pripet (Baltic Sea - Black Sea)	Jazdzewski and Konopacka, 2002
1810	Mariinskij Waterway: Sheksna - Lake Beloye - Kovzha - Vytegra - Lake Onega - Svir - Lake Ladoga –- Neva (Caspian Sea - Volga - Baltic Sea)	Multimedia Encyclopaedia of Cyril and Mefodij, 2000
1829	Severo-Dvinskiy Waterway: Sheksna - Lake Kubenskoje - Sukhona, Northern Dvina (Caspian Sea - Volga - White Sea)	Multimedia Encyclopaedia of Cyril and Mefodij, 2000
1952	Volga - Don Canal (Caspian Sea – Black Sea)	Multimedia Encyclopaedia of Cyril and Mefodij, 2000

CONNECTION OF THE SOUTH-EASTERN BALTIC COASTAL LAGOONS TO THE RIVER DNIEPR WATERSHED

The first canal linking rivers of the Baltic Sea and Black Sea watersheds, was the Oginskij Canal, named after the Voivode of Vilnius, who built the canal in 1765-1768. The canal is 54 km long, connecting the lake Vygonovskoje with Jaselda, a tributary of the river Pripet, itself a major tributary of the river Dnieper. The Shchara river, originating in lake Vygonovskoje, flows into the river Nemunas (Neman). The canal was built for the rafting of timber from the Belarusian Polesjye to the Baltic Sea ports, Klaipeda (formerly Memel) through the Curonian Lagoon, and Gdansk (Danzig) through East Prussian rivers (Deima, Pregel), small canals and the Vistula lagoon. The Oginskij canal was destroyed during the two World Wars (in 1916 and 1944), then reconstructed (Kolupaila, 1953).

The next invasion corridor appeared within less than one decade with the construction of the canal between the Pripet and the Bug, a tributary of the Vistula (Wisla), connecting the port of Gdansk with the Belarusian Polesjye (Jazdzewski and Konopacka, 2002). Finally, the Vistula and the Nemunas were connected via small tributaries and lakes by the August waterway in 1830 (Kolupaila, 1953).

The introduction of the zebra mussel, *Dreissena polymorpha*, into the Vistula and Curonian coastal lagoons in early 1800s was most likely due to transportation of molluscs attached to the lumber rafts. The zebra mussel was next recorded in London (1824) and Amsterdam (1826), at that time the recipient ports for the Baltic timber trade (Olenin *et al.*, 1999). Only later did the species spread in the inland waters of western and central Europe.

Several other invertebrate species invaded the Baltic Sea coastal regions during the 19th century and early 1900s most likely through the above invasion corridors (Table 2). The hydrozoan *Cordylophora caspia* dwelling on hard substrates; the corophiid amphipod *Chelicorophium (Corophium) curvispinum* attaching its tubes to hard surfaces, including mussel shells; the snail *Litoglyphus naticoides* commonly inhabiting zebra mussel aggregates in the Curonian lagoon, might have used rafts and boats for their travel along canals and rivers (Olenin and Leppäkoski, 1999; Jazdzewski and Konopacka, 2002). In the mid 1990s, two Ponto-Caspian gobiid fishes, *Neogobius gymnotrachelus* and *N. fluviatilis* were found in the Vistula and some of its tributaries, near the Bug-Pripet canal, demonstrating active invasion through that corridor. A cogener, the round goby *Neogobius melanostomus*, was found in the Gulf of Gdansk in the Baltic Sea in 1990. It might have arrived via the Bug-Pripet canal, but also been transported in ballast waters either directly from the Black Sea (ship voyage around Europe) or through the Volga-Baltic Waterway (Jazdzewski and Konopacka, 2002, and references therein). This last is supported by findings of *N. melanostomus* in 1980s-1990s far beyond its historical range in the Caspian and Black seas, in the upper Volga and the Moskva River, a secondary tributary of the upper Volga (Slynko *et al.*, 2002, and references therein).

Fig. 1. Map showing the elements of the Baltic Sea-Ponto-Caspian invasion corridor system.
1 - Oginskij Canal
2 - Bug - Pripet canal
3 - Volga - Baltic Waterway (primarily - Mariinskij Waterway)
4 - Severo-Dvinskiy Waterway
5 - Volga - Don Canal.

Invasions through those corridors are unidirectional: no species from the Baltic Sea is known to have used those canals to enter the Black Sea. Also, neither the Oginskij, nor the Bug-Pripet canals were used for the direct Baltic Sea-Black Sea ship traffic. In these terms they could not be compared with the inner European Russian waterways.

THE CASPIAN SEA-VOLGA-BALTIC INVASION CORRIDOR

The construction of waterways that ultimately would connect the Volga River and the Baltic, White, Caspian, Azov and Black seas began in the time of Peter the Great. Between 1703 and 1718 connections were established between tributaries of the Volga River and rivers falling into Ilmen and Ladoga Lakes and further to the Baltic Sea. However, a navigable link between the Volga River and Baltic and White seas was constructed only at the beginning of the 19th century. This waterway was expanded and improved in 1930-1940s, and was reconstructed and reopened as the Volga-Baltic Waterway (about 1,100 km in length) in 1964. Presently, the cargo turnover through the Caspian-Volga-Baltic route is more than 300 million tons per year (Slynko *et al.*, 2002). This route became also the major invasion corridor along Europe's largest longitudinal river, the Volga River. Unlike the two previous invasion corridors, it is bi-directional, facilitating invasions in both "North-South" and "South-North" directions, and is far more important in species exchange.

Table 2. Ponto-Caspian species which most probably penetrated to the Baltic Sea coastal lagoons and their watershed through the Oginskij and Bug-Pripet canals*1

Species	Time of introduction	
	Curonian Lagoon	Vistula Lagoon
Zebra mussel *Dreissena polymorpha*	1803	Early 1800s
Athecate hydrozoan *Cordylophora caspia*	Early 1800s	Early 1800s
Snail *Litoglyphus naticoides*	Early 1900s	1870s in Poland
Amphipod *Chelicorophium curvispinum*	1921, in the River Nemunas	Before 1920s in the Vistula River and the Lagoon
Amphipod *Chaetogammarus ischnus*	1960, in the lower Nemunas	1928 in middle and lower Vistula
Round goby *Neogobius melanostomus*	2002*2	1990*3 in the Gulf of Gdansk, since late 1990s in the Lagoon
Goad goby *N. gymnotrachelus*	-	1995 in the River Bug
Monkey goby *N. fluviatilis*	-	1997 in the Muchawiec River, affluent of Bug

*1 based on: Leppäkoski and Olenin, 2000b; Arbaciauskas, 2002; Jazdzewski and Konopacka, 2002; and references therein;
*2 apparently due to secondary spread from the Polish waters (Yu. Maksimov and T. Zolubas, pers. comm.);
*3 other vectors/invasive corridors may be involved, see text

Recently, Slynko *et al.* (2002) wrote in their comprehensive review: *"The north-south transfer of species in the Volga River basin is not new, but the scale and nature of invasions changed along the Volga-Baltic corridor following transformation of the Volga River from a riverine environment to one of a series of cascading reservoirs. Southward penetration of northern species was facilitated by the formation of a cold-water hypolimnion in the Volga reservoirs. Following reservoir impoundment, 106 invasive species have been found in the Volga River basin, a process that occurred over two different time periods. The first period of invasions occurred between 1940 and 1970, and involved many northern species (77% of total species) moving downstream by passive dispersal. The second period of invasions is still on going and involves invasions by many Ponto-Caspian species (51% of total species) while new invasions by northern species have decreased substantially (7% of total species). The proportion of exotic species (i.e., invaders originating from basins not adjacent to the Volga basin) increased from 7% during the first period to 41% during the second period. Since the late 1970s, water temperatures in the Volga basin have continued to increase and it is postulated that many invasions during the second period are related to global climatic change"*.

Analysis of the data presented in the above paper shows two dispersal patterns of alien species along the Ponto-Caspian-Volga-Baltic invasion corridor. The first one ("continuous") suggests gradual semi-natural dispersal of species due to removal of previous physico-chemical barriers and emergence of new suitable habitats, e.g. cold-water hypolimnion or, conversely, areas of thermal pollution from power plants. The second pattern ("discrete") involves ship traffic – ballast water or hulls of "ships of opportunity" – allowing some species to "jump" over the Upper Volga and the Volga-Baltic system of canals and pass directly into the eastern Gulf of Finland, the terminus of this invasion corridor. It is noteworthy that nearly all ship-transported species are of Ponto-Caspian origin. The exception is the Chinese mitten crab, *Eriocheir sinensis*, which was noted during the 1990s in the Volga River delta. In 2001 adult specimens were found for the first time in Cheboksary (Middle Volga) and Rybinsk (Upper Volga) reservoirs, suggesting crab invasions in Volga River reservoirs originating from both southern (River Don and Volga River delta) and northern locations (Gulf of Finland) (Slynko *et al.*, 2002).

The network of Baltic Sea-Black Sea invasion corridors was completed by the Volga-Don Canal, opened in 1952. More than 20 species have been known to pass from the Black Sea into the Caspian Sea, rapidly increasing in abundance and often dominating the coastal plankton and benthos of the Caspian Sea (see Gomoiu *et al.*, 2002 and Aladin *et al.*, 2002 for the most recent reviews). The opposite movement has been disproportionately small: only two Caspian species,

the alga *Ectocarpus caspicus* and crustacean *Shizopera neglecta*, have reached the Black Sea, where they have not flourished (Gomoiu *et al.*, 2002).

Another important intracontinental waterway rapidly becoming a major cross-European "latitudinal" invasion corridor which may facilitate species exchange between the Black Sea and the northwestern Europe, including the Baltic Sea, is the Main-Danube waterway, constructed in 1992 (van der Velde *et al.*, 2002; Nehring, 2002).

ENVIRONMENTAL MATCHING AND CHANGES ALONG THE WATERWAYS RESULT IN FACILITATION OF SPECIES EXCHANGE

The Baltic, Black and Caspian seas provide a broad range of habitats due to various combinations of salinity, temperature, substrate and depth along their environmental gradients (Table 3). These habitat continuums largely coincide, especially in coastal lagoons and river mouths, facilitating the transfer of alien species from one end to another.

Table 3. Physico-geographical characteristics of the Baltic, Black and Caspian seas*[1].

	Baltic Sea	Black Sea*[2]	Caspian Sea
Connection with adjacent seas	**Danish Straits**	**Bosporus Strait**	**Rivers and canals**
Latitude, °N	54 - 66	41 - 46	36 - 47
Major axis length, km	1,300	1,150	1,200
Surface area, 10^3 km^2	412	423	378
Catchment area, 10^3 km^2	1,730	1,860	3,700
Maximum depth, m	459	2,212	1,025
Salinity in central parts (surface), PSU	6-7	17-18	12-13
Temperature in central parts (surface, summer), °C	14-16	22-26	22-28

**[1] modified from Leppäkoski and Olenin 2000b; *[2] excluding the Sea of Azov.*

Another instrumental factor in the spread of the invasive species is the environmental change within the river systems themselves. In the Volga environmental changes include the formation of large lacustrine water bodies along the river channel (water reservoirs) and deceleration of river flow, pronounced thermal stratification of water masses and existence of a cold water hypolimnion, construction of locks and removal of rapids in the Samara Arch, Middle Volga (Slynko *et al.*, 2002).

K. Jadzewski (pers. comm.) suggested that one of the possible reasons behind the recent massive invasion of Ponto-Caspian species in northern, central and western Europe, is the increasing ionic content of large European rivers in recent decades, caused by industrial and agricultural pollution. This rise in the "salinity" of the Dnieper, Vistula, Oder or Danube could reach a "critical point" that permits invasion by oligohaline species (Jazdzewski and Konopacka, 2002). The same factor ("increased mineralisation of water") is mentioned as a possible reason, facilitating the spread of Ponto-Caspian species along the Volga-Baltic invasive corridor (Slynko *et al.*, 2002).

CONCLUDING REMARKS

The role of intracontinental and intercontinental invasion corridors will grow larger in the future, as the inland waterways are increasingly used for international ship traffic. In 2000, a treaty for the construction of the Transport Corridor "North-South" between India, Iran and Russia was undersigned. This corridor is intended to follow the line: European Union - St. Petersburg - Astrakhan - Caspian Sea - Iran - Persian Gulf - India (Tkachenko and Brodin, 2002). Implementation of this project will increase the intensity of shipping and cargo turnover by an order of magnitude. Consequently, the risk of new species introductions will increase if no appropriate measures are taken.