

Risk Assessment

A pathways risk assessment of aquatic non-indigenous macroinvertebrates passing to, and through, the Central European invasion corridor

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Abstract

A pathways risk assessment is a part of an integrated assessment for the horizon scanning of non-indigenous species introductions. We examined past pathways, and their vectors, of aquatic NIS already present in Belarus in order to predict those species likely to spread to Belarus and arrive to Western Europe along the Central European invasion corridor. Twenty-four aquatic non-indigenous macroinvertebrates are known within Belarusian rivers, lakes and reservoirs, six of these have already spread westwards through Belarus. The modes of spread for these NIS were vessel transport, navigation corridors, and natural spread following an initial introduction.

Key words: alien species, benthos, vectors, waterbodies, Belarus

Introduction

It would be valuable from an ecosystem management perspective, to assess the potential of non-indigenous (NIS) spread by different pathways and their vectors to specific regions and to include their likely economic impacts and effects upon native ecosystems (Andersen et al. 2004; Marbuah et al. 2014). In the Aichi Target 9 it is pointed out that “...by 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment...” (CBD 2014a).

Identifying how NIS spread forms part of an overall risk assessment to, within and beyond a region (Ricciardi and Rasmussen 1998; Hulme et al. 2008; Matthews et al. 2017a, b). The term “pathway” according to the CBD refers to any direct or indirect human activity, which enables the entry or spread of NIS (CBD 2014b). However, a single pathway may not be responsible for an introduction, as a relay of different pathways and their vectors, could be involved (Minchin 2007; NOBANIS 2015). These may include the spread overland between waterbodies by small craft (Martens



Figure 1. Central invasion corridor (from Bij de Vaate et al. 2002 with modification). Red dashed lines: 1 – Dnieper-Bug Canal, 2 – Augustow Canal, 3 – Vistula-Oder Canal (Bydgoszcz Canal), 4 – Havel-Oder – Mittelland – Dortmund-Ems – Rhine-Herne Canals

and Grabow 2008), recreational activities (Anderson et al. 2015), or with ornamentals distributed through garden centers or release from aquaria (Nunes et al. 2015; AquaNIS 2015). For some NIS there may be a means of reducing the risk of such spread. For example, by considering the biological traits (Bij de Vaate et al. 2002) and physiology of such NIS, that are involved in trade, can be useful characteristics to consider.

The majority of NIS are unintentionally introduced and often associated with deliberate human activities over which there may be little control. NIS may also be distributed purposefully. This has often been to improve fisheries, for aquaculture or introduced as ornamentals. An example of a deliberate introduction involved the restocking of lakes and reservoirs of crustaceans in a mid-twentieth century acclimatization program (Arbačiauskas 2002). It is for this reason it is necessary to distinguish between intentional and unintentional introductions (Hulme et al. 2008) as unintended introductions are more difficult to manage and some of these may even be unmanageable.

In Europe many species have been limited to separate river catchments until, at such time, these will have become linked with canal connections. While canals facilitated commerce, involving more than 350 ports (Panov et al. 2007), these enable an inland waterway navigation network from eastern to western Europe. This network provided conduits for the spread of aquatic organisms. There are three main inland waterway routes in Europe (Bij de Vaate et al. 2002) from which there are further, more localized, opportunities for dispersal by means of subsidiary connections.

Prior to 1992 the central corridor was the main westward route that passed through Belarus by means of the Dnieper, Bug to the Vistula rivers, then ultimately to the Oder, Elbe rivers and the Rhine by means of the lowland northern European waterway (Bij de Vaate et al. 2002) (Figure 1).



Figure 2. Map of the waterbodies of Belarus.

This route became possible with the construction of the canal between the Pripyat and the Bug rivers to provide a corridor that passes through Belarus. The connection to the Bug River then to the Vistula River ferried species to the Vistula Lagoon in the Polish southern Baltic Sea. In addition, species that will have used the southern route by means of the Danube (Bij de Vaate et al. 2002) may also result in NIS arriving in the Baltic Sea. Species once established in the Baltic Sea these may then gain access to Belarus, by means of a roundabout route, from the north *via* the Neman River. Species may also flow from the Vistula River *via* its recently restored Augustow Canal to the Neman River (Figures 1, 2) (Romanova et al. 2018). Whereas the Dnieper–Zapadnaya Dvina Canal to Latvia has not been restored and was in use by shipping till 1917 with the notable spread of the zebra mussel *Dreissena polymorpha* (Pallas, 1771) with exports of timber floated downriver in the nineteenth century (Karatayev et al. 2008). The central corridor has been important for the spread of several Ponto-Caspian species (Semenchenko et al. 2011) including crustaceans (Jażdżewski and Konopacka 2000).

The routes NIS gained access to Belarus involved shipping and fisheries (Karatayev et al. 2008) as well as by natural dispersal incrementally spreading along the waterway perhaps aided by human activities. There is however, some controversy as to whether such spread along corridors can be considered to be a natural spread. This is because Gilroy et al. (2016) considered that those species, that moved by their own means within

canals, should not be considered NIS. However, without the linkage of man-made cuts these species wouldn't have had the opportunity to extend their range and so should be considered as NIS (Hulme et al. 2017) and is consistent with our views.

Records as to how species spread previously provides useful knowledge for future management and as such patterns may be repeated, as NIS continue to extend their ranges about Belarus. This is because inland navigations provide opportunities for the spread of species in either direction and not just from the Ponto-Caspian region or the Baltic Sea. Some species are spreading from the west, for example the North American *Gammarus tigrinus* Sexton, 1939, now established in the southern and eastern Baltic Sea (Kotta et al. 2013) and may be expected to arrive from Poland or Lithuania at some future time. Determining those species that may arrive in the future provides for a set of target species that can be searched for, using the most appropriate sampling methods. However, many NIS are benign and do not appear to have any serious impacts to society or the environment, but a smaller number do. It is the selection of those species that may arrive and deserve special attention that require management where this is possible. Here we review the past modes of arrival for selected invertebrates and the means by which they may have arrived.

Materials and methods

The checklist of aquatic macroinvertebrate NIS of oligochaetes, polychaetes, molluscs and crustaceans (mysids, amphipods and decapods) already present in Belarus were used for the pathways risk assessment. Such NIS (Karatayev et al. 2008; Semenchenko et al. 2009, 2016; Lipinskaya et al. 2018) and their distribution (Semenchenko et al. 2013; Lipinskaya et al. 2017) (Supplementary material Table S1) were examined for the modes of their spread from the three transboundary river basins (Dnieper, Pripyat and Neman rivers) and other water bodies (the Mukhavets River, Dnieper-Bug canal, Lake Drysviaty and Vileyka reservoir).

Categorization of pathways

Categorization of pathways and vectors proposed by the 18th Subsidiary Body on Scientific, Technical and Technological Advice to the Convention on Biological Diversity was used for this study as it provides a comprehensive classification that can integrate data across all taxonomic groups and habitats without distinction and provides a standard terminology that may be broadly applicable at a global scale (CBD 2014b). According to this classification, there are six principle pathways:

- 1) *Release in nature* refers to the *intentional introduction* of live alien organisms for the purpose of human use in the natural environment;

Table 1. Results of scoring of the pathways of NIS introduction in aquatic ecosystems of Belarus by UK non-indigenous organism risk assessment scheme.

Pathway (vector)	Score*	Taxon (number of species)
RELEASE IN NATURE (intentional introduction: biological control; fishery in the wild (including game fishing); fauna “improvement” in the wild; release in nature for use; other intentional release)	6	Mysida (1), Decapoda (2)
ESCAPE FROM CONFINEMENT (unintentional introduction: aquaculture; aquarium/terrarium species (including live food for such species); live food and live bait; aquaria (excluding domestic aquaria); pet/aquarium/terrarium species (including live food for such species); ornamental purpose; research and <i>ex-situ</i> breeding (in facilities); other escape from confinement)	13	Gastropoda (1)
TRANSPORT – CONTAMINANT (contaminated bait; contaminant on animals (except parasites, species transported by host/vector); parasites on animals (including species transported by host and vector); contaminant on plants (except parasites, species transported by host/vector); transportation of habitat material (soil, vegetation))	16	Oligochaeta (4), Polychaeta (1), Hirudinea (1), Gastropoda (2), Bivalvia (1)
TRANSPORT – STOWAWAY (angling/fishing equipment; hitchhikers on ship/boat (excluding ballast water and hull fouling); people and their luggage/equipment (in particular tourism); ship/boat hull fouling; vessels; other means of transport)	26	Gastropoda (3), Bivalvia (1), Amphipoda (7)
CORRIDOR (interconnected waterways/basins/seas)	23	Oligochaeta (4), Polychaeta (1), Amphipoda (4), Gastropoda (1), Bivalvia (1), Decapoda (1)
UNAIDED (natural spread across borders of invasive alien species)	22	Amphipoda (8), Mysida (2), Decapoda (1)

* The calculation of the score for each pathway consists of sixteen questions and a level of confidence in an excel file (Pathway Risk Assessment Module 2005).

- 2) *Escape* refers to the movement of (potentially) invasive alien species from confinement (e.g., zoos; aquaria; botanic gardens; agriculture; horticulture; aquaculture and mariculture facilities; scientific research or breeding programmes; or from keeping as pets) into the natural environment;
- 3) *Transport–Contaminant* refers to the unintentional movement of live organisms as contaminants of a commodity that is intentionally transferred through international trade, development assistance, or emergency relief;
- 4) *Transport–Stowaway* refers to the moving of live organisms attached to transporting vessels and associated equipment and media;
- 5) *Corridor* refers to movement of alien organisms into a new region following the construction of transport infrastructures in whose absence spread would not have been possible;
- 6) *Unaided* refers to the *secondary natural dispersal* of invasive alien species that have been introduced by means of any of the foregoing pathways.

The pathways have different subcategories that we named as vectors and used only applicable vectors to freshwater ecosystems (Table 1).

Selection of pathways risk assessment method

To identify the most common pathway that have been used by the twenty-four NIS in Belarus (Table S1) and the frequency of past invasion events (Figure 3).

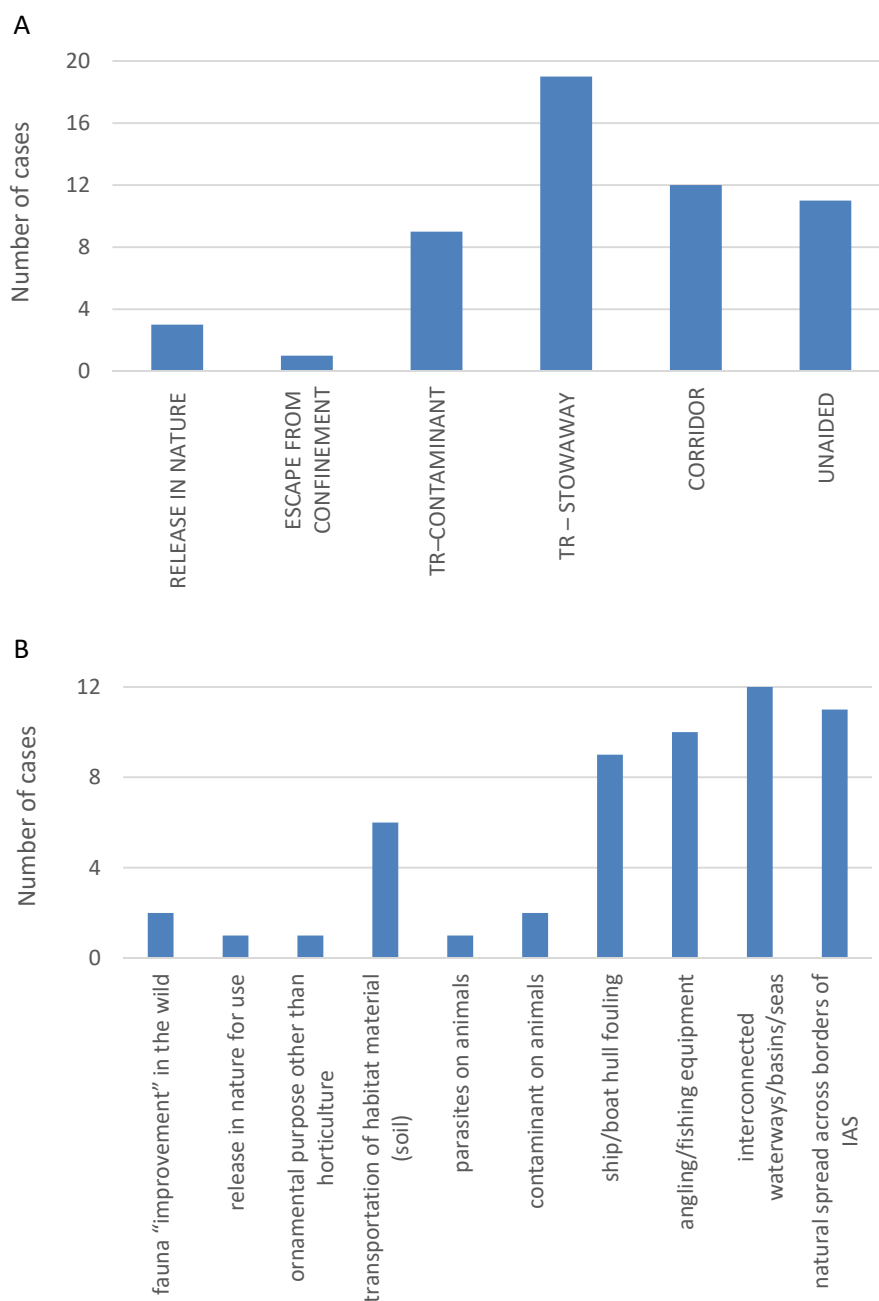


Figure 3. Frequency of introduction pathways (A) and vectors (B) of known cases of introduction of 24 NIS in Belarus

Such spread may occur through combinations of natural dispersal and human-associated activities (Minchin 2007). Pathway risk assessment of NIS can be a qualitative, semi-quantitative or quantitative and depends on the reliability of the available data.

The CBD (CBD 2014b) recommends that an analysis of a pathway of introduction and spread should include a wide range of available data on NIS (WGIAS 2018).

The following approaches for pathway risk assessment were used in this study:

1. Vectors and Pathways for Nonindigenous Aquatic Species in the Great Lakes (Kelly 2007).
2. Assessing the level of certainty of the pathway/vector involved in the initial arrival (AquaNIS 2015).
3. Identifying potentially invasive NIS and their introduction pathways (Matthews et al. 2017b).
4. NOBANIS pathway risk assessment (NOBANIS 2015; Madsen et al. 2014; WGIAS 2018).
5. UK non-indigenous organism risk assessment scheme (Pathway Risk Assessment Module 2005; Baker et al. 2008).

The following criteria used for selection of the most suitable methods:

- assessment should be quantitative;
- assessment should be rapid and taking into account the specific features of each event.

The first two approaches are semi-quantitative and based on the number of NIS spreading by any pathway/vectors. AquaNIS system contains three levels of certainty according to each introduction according to the pathway and the vector involved.

The third method aggregates different data including a black list, climate data in the invaded region, potential ecological impact, and its type. This method is semi-quantitative and aggregated risk score calculation derived from a certain number of risk classifications. This method requires a wide range of data for each NIS. In order to separate “high risk” species from other species (Matthews et al. 2017b).

The NOBANIS risk assessment requires data on number of introduced invasive species by a pathway and the number of introductions *via* this pathway. However, other parameters apart from the pathway analysis and the horizon scanning are essential in making adjustments to the prioritization of pathways (NOBANIS 2015; Madsen et al. 2014).

We used UK non-indigenous organism risk assessment scheme (Pathway Risk Assessment Module 2005) because it is quantitative, user-friendly and takes into account the specific features of each area being assessed. The calculation of the score for each pathway consists of sixteen questions and a level of confidence in an excel file. These questions include information on the diversity of organisms associated with the pathway or vectors, the abundance of organisms in the pathway, volume of movement along the pathway (i.e. shipping activities, fisheries). Verbrugge et al. (2012) mentioned that this risk assessment scheme can be used for all taxonomic groups and considered by González-Moreno et al. (2019) to be one of the best approaches for a risk assessment.

Results

Updated checklist of aquatic macroinvertebrates of Belarus

The current NIS checklist includes twenty-four species with additional information on their distribution across Belarusian water bodies, pathways and vectors responsible according to our level of certainty of their arrival. (Table S1).

The number of NIS recorded in each of the studied river basins varied (Table S1). For example, only six NIS macroinvertebrates, of which four were invasive, were recorded in the Belarusian part of the Neman River basin. Whereas, fourteen and seventeen NIS macroinvertebrates were recorded in the Dnieper and Pripyat River basins respectively. These differences may be explained by the number of introduction events to donor reservoirs and the numbers of NIS that became established there, and the distance to Belarus (Arbačiauskas 2002; Semenchenko et al. 2014).

Categorization of pathways

The twenty-four aquatic NIS, the most of them established, have arrived in Belarus *via* six pathways involving ten separate vectors (Figure 3A, B). Some used multi-pathways (e.g. amphipods and mysids). Our study showed that the highest number of introductions occurred through the “transport-stowaway” pathway (Figure 3A), followed by corridor transmission and natural spread. If the number of introductions are compared according to the vectors involved, we can see that interconnected waterways, natural spread, angling/fishing equipment, and ship/boats hull fouling played important role for spread of NIS passing to, and through Belarus (Figure 3B).

Pathways risk assessment using UK non-indigenous organism risk assessment scheme

A pathways risk assessment can help identify potential NIS entry pathways.

The pathways of past invasions and new records of NIS in the studied river were used for scoring by using the UK scheme (Table 1).

RELEASE IN NATURE

Only three species (*Paramysis lacustris* (Czerniavsky, 1882), *Macrobrachium nipponense* De Haan, 1849, and *Faxonius limosus* (Rafinesque, 1817)) were intentionally released. *Paramysis lacustris* was introduced in the Vileyka Reservoir and spread downstream into the Svisloch River and naturally spread to the Neman River from the Kaunas reservoir (Lithuania) where it was introduced in 1961 (Arbačiauskas 2002). The freshwater shrimp *M. nipponense* was introduced to the warm water discharges of the cooling lakes of Lake Beloe and Lake Lukomlskoe (Khmeleva et al. 1982). The spread of this species is limited to heated water and so remains confined.

Initially, crayfish *F. limosus* spread naturally *via* the Augustow Canal from Poland to the Neman River basin; but was later found in the chalkpits unconnected with rivers following an intentional introduction or inadvertent transmission with fish equipment (Alekhovich *pers. comm.*).

ESCAPE FROM CONFINEMENT

Only one NIS, mollusk *Haitia acuta* (Draparnaud, 1805), was introduced *via* escape from confinement following release from aquaria.

TRANSPORT – CONTAMINANT

The leech *Caspiobdella fadejewi* (Selensky, 1915) has been distributed as an ectoparasite attached to fish. *Haitia acuta* was unintentionally introduced in Lake Beloe together with the Far East shrimp *M. nipponense* and fishes. The oligochaetes and the polychaete *Hypania invalida* Ostroumouff, 1897, and the bivalve *Dreissena polymorpha* (Pallas, 1771) might also have been transferred with the transportation following the dredging (habitat material) within ports and the building of canals.

TRANSPORT – STOWAWAY

The shipping intensity in the Pripyat and Dnieper rivers facilitated NIS spread (Karatayev et al. 2008). Several gammarids and molluscs will have spread along the navigations of Belarus as a result of hull fouling. The molluscs *D. polymorpha* and *Lithoglyphus naticoides* (C. Pfeiffer, 1828) have become widely spread across Belarussian aquatic ecosystems. In most of these cases the spread was due to movements of fishing equipment and boats overland (Karatayev et al. 2008). Some NIS (*Dikerogammarus villosus* (Sowinski, 1894), *Dikerogammarus haemobaphes* (Eichwald, 1841), *Pontogammarus robustoides* (Sars, 1894), *Echinogammarus trichiatus* (Martinov, 1932)) are often associated with macrophytes and could have been spread as contaminants on seine-nets generally used in the fishing industry and moved between separate water bodies.

CORRIDOR

Aquatic NIS regularly pass through the inland waterways of Europe (Nunes et al. 2015), in particular crustaceans (Bij de Vaate et al. 2002). Since the linking of the Dnieper-Bug Canal there has been an expansion of Ponto-Caspian amphipods from the Pripyat River to Poland (Bij de Vaate et al. 2002; Jazdzewski et al. 2002; Grabowski et al. 2007). Whereas, *F. limosus* spread *via* the Augustow Canal from Poland to the Neman River basin.

UNAIDED (NATURAL SPREAD)

This pathway may account for most of the NIS spread to, and through, Belarus. Many crustaceans that include amphipods and mysids *P. lacustris*

and *Limnomysis benedeni* Czerniavsky, 1882 are very likely to have migrated along the Dnieper and Pripyat rivers from the Kiev Reservoir (Ukraine), where they were intentionally introduced in the 1970s. The decapods *F. limosus* naturally spread from Poland to the Neman River basin (Alekhnovich et al. 1999) extending their range into Belarus.

Discussion

The identification and prioritization of pathways play a key role in the minimization and prevention of establishment and spread of NIS through the complex of pathways (Orr and Fisher 1996; Panov et al. 2009) and is a basis for horizon scanning for further introductions of NIS (Roy et al. 2014).

Our result showed the most frequent pathways for established NIS of macroinvertebrate in Belarus in order of importance are the “transport-stowaway” pathway, corridors, and natural spread. Of the inter-basin canals built in Belarus only two now operate through which future arrivals may be expected. In addition, the nearby locations of reservoirs to rivers aid the spread of NIS which may involve inadvertent overland movements by fishermen.

The main pathways of introduced NIS (invertebrates and fish) in Europe are from escapes from aquaculture and releases from aquaria and stocking of fisheries (Nunes et al. 2015). Whereas the results of EASIN datasets show, that stowaways and spread through canals are the main pathways for aquatic alien species in Europe (Katsanevakis et al. 2015).

More than ten years have passed after the first review of the aquatic species invasions in Belarus (Karatayev et al. 2008). The Ponto-Caspian oligochaetes *Potamothrix bedoti* (Piguet, 1913), *Potamothrix bavaricus* (Oschmann, 1913), *Potamothrix moldaviensis* (Vejdovský & Mrázek, 1903), and *Tubifex newaensis* (Michaelsen, 1903) were not recorded during the last decade, probably because of identification of this taxonomic group in the recent studies have been only to a higher systematic level (subclass, family). The snail *Potamopyrgus antipodarum* (Gray, 1843) has only been recorded by Polischuk et al. (1976). However, it is possible that it might have been misidentified, being morphologically similar to the native *Marstoniopsis scholtzi* (A. Schmidt, 1856). *Potamopyrgus antipodarum* is widespread in Poland (Lewin and Smolinski 2006), and Lithuania (Rakauskas et al. 2018) and is known to occur in the Ukraine (Son 2008). Thus, we cannot eliminate the record by Polischuk et al. (1976). It is possible that this snail may be transported in the gut of fish as well as carried within the digestive tract of birds, or otherwise attached to their legs or feathers (Vinson and Baker 2008).

Since the account by Karatayev et al. (2007) seven additional NIS have been recorded in Belarus (Semenchenko et al. 2007, 2009; Semenchenko and Vezhnovetz 2008; Semenchenko and Laenko 2008; Lipinskaya and Makarenko 2015; Lipinskaya et al. 2018) and three (*L. benedeni*, *O. crassus*,

P. lacustris) were predicted to arrive by them. They also predicted that the number of pathways and their vectors would increase with the growth in recreational activities and the ornamental trade. Indeed, several warm water fishes have been found in inland waters having escaped or released from aquaria which include the spotted gar (*Lepisosteus oculatus* Winchell, 1864), red piranha (*Pygocentrus nattereri* Kner, 1858), pirapitinga (*Piaractus brachypomus* (Cuvier, 1818) and armored catfish (*Pterygoplichthys gibbiceps* (Kner, 1854). These did not become established on account of low winter temperatures (V.K. Rizevski *pers. comm.*). However, *M. nipponense* survived winter temperatures on account of being confined to thermal discharges (Alekhnovich and Kulesh 2001; Kulesh et al. 2015).

According to Protasov and Silaeva (2010), Son et al. (2013), and Semenchenko et al. (2016) there are forty-nine NIS macroinvertebrates in the Ukrainian part of the Central European invasion corridor, thirty-seven of these are of Ponto-Caspian origin. It should be noted that fifteen Ponto-Caspian species were introduced to Belarus from the Kiev Reservoir and six of these passed through Belarus to Poland *via* the Dnieper-Bug Canal (Grabowski et al. 2007). Only the North American spiny-cheek crayfish, *F. limosus* is known to have spread from Poland to Belarus *via* the Augustow Canal and it has more recently been found in the Mukhavets River (Alekhnovich and Molotkov 2016) and in the Dnieper-Bug Canal during 2017 (Moroz and Lipinskaya 2020). It is expected to spread to the Pripyat River. We expect that due to the recent increase in mineralization in the Pripyat River, arising from discharges of industrial water and decreasing of water level in the summer period (Van der Velde et al. 2000; Jażdżewski et al. 2002; Morozova 2011; Semenchenko and Rizevski 2017), will lead to suitable conditions for the spread of further invertebrate NIS.

It is expected there will be further NIS arriving to Belarus from the Baltic Sea by means of the Vistula River (*G. tigrinus*), the Neman River (*Hemimysis anomala* G.O. Sars, 1907; *Chaetogammarus warpachowskyi* Sars, 1897) and the Daugava River and from other waterbodies in Latvia (*G. tigrinus*, *Eriocheir sinensis* H. Milne Edwards, 1853).

The pathways and their vectors of introduction are complex (CBD 2014b). In some cases, it is hard to separate the natural spread of NIS following an initial introduction and the role played by further spread from human activities. Both the physical and chemical changes of environments in river ports and within canals can lead to a decrease in abundance and even a disappearance of some native species and thereby facilitate establishment of NIS arising from competition and available ecological niches.

The introduction of aquatic NIS is a dynamic process that requires constant monitoring and requires taxonomic expertise (Jabłońska-Barna and Koszałka 2019). Pathways and vectors change over time according to their intensity and alterations of human activity, and according to physiological opportunities (Ricciardi and Rasmussen 1998) and those

provided following extreme weather events under global climate change (Walther et al. 2009; Semenchenko et al. 2018). In the future, the spread *via* the European navigation network will lead to further NIS arriving from different directions. Some of these will have consequences for economies and the environment requiring regular monitoring.

Following the completion of the Dnieper-Bug Canal there has been a spread to, and through, Belarus of NIS, especially of Ponto-Caspian species. Further such spread from the Ponto-Caspian region may be expected as well as species arriving from western Europe. The pathways involved in the spread of NIS are seldom well understood. There are few species where the associated pathways can be ascribed with full certainty. Most deductions of an arrival are based on a rationale as to how a species may be spread based on local information as being very likely. The arrival of species is unsure; yet possible modes as to how the species will have arrived can form some basis for practical management. The spread of invasive alien species has consequences for the Belarus economy and for its environment. This will require further monitoring of aquatic waterbodies targeting particular species in a horizon exercise since the principal routes and modes of spread from past arrivals are known.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Updated checklist of non-indigenous aquatic macroinvertebrates in Belarus.

This material is available as part of online article from:

http://www.reabic.net/journals/mbi/2020/Supplements/MBI_2020_Lipinskaya_et_al_SupplementaryMaterials.xlsx