Risk Assessment of Aquatic Invasive Species' Introductions via European Inland Waterways

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Introduction

European inland waterways have provided opportunities for the spread of invasive alien aquatic (IAS) species for many centuries. Over the past century, the potential for species to expand their range has been enhanced both as a result of the construction of new canals and due to increased trade. At present, the complex European network of inland waterways is made up of > 28,000 km of navigable rivers and canals, connecting 37 countries in Europe and beyond (Figure **1**). This aquatic network connects the previously isolated catchments of the southern European seas (Caspian, Azov, Black, Mediterranean) and the northern European seas (Baltic, North, Wadden, White), to provide corridors for IAS. In Europe, there are thirty main canals with >100 branch canals and > 350 ports (Galil et al. 2007). There are plans to deepen many of these canals to accommodate larger vessels and to prepare for the lower anticipated water levels arising from climate changes. The future developments of the European network of inland waterways will highly facilitate the transfer of IAS across European inland waters and coastal ecosystems. Appropriate risk assessment-based management options are required to address risks posed by human-mediated introductions of these species (Panov et al. 2007).

Considering the current gap in addressing invasive alien species in European river basin management, our goal was to develop relevant risk assessment protocols and water quality indicators on IAS for possible consideration in the Common Implementation Strategy of the EC Water Framework Directive and as part of a holistic (cumulative) risk-based management of European river basins. The European Environmental Agency (EEA) 'Typology of indicators' and the Driving forces–Pressures–State–Impact–Response (DPSIR) framework was used to structure developed environmental indicators in the socio-economic context (Figure **2**).

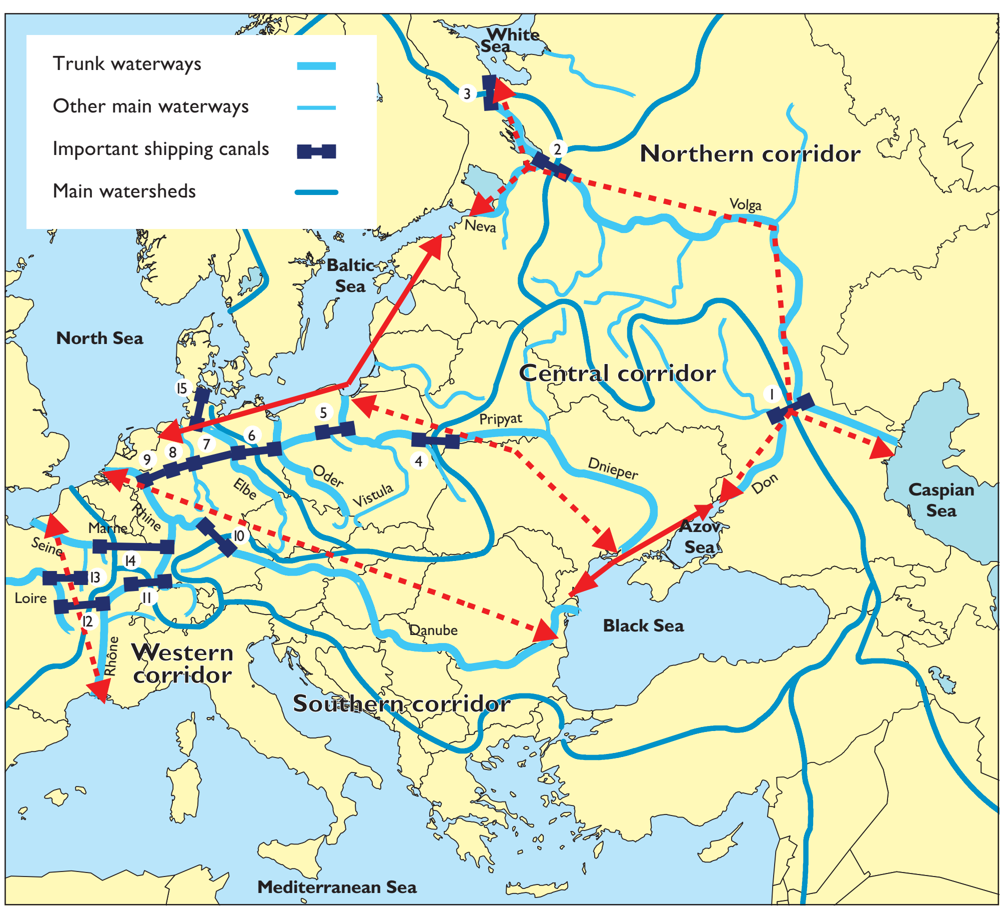

Figure 1. Important European waterways and invasion corridors for the spread of aquatic species (after Galil et al. 2007, modified). Main canal number: *1* – Volga-Don Canal, *2* – Volga-Baltic Canal, *3* – White Sea – Baltic Sea Canal, *4* – Bug-Pripyat Canal, *5* – Vistula-Oder Canal, *6* – Havel-Oder Canal, *7* – Mittelland Canal, *8* – Dortmund-Ems Canal, *9* – Rhine-Herne Canal, *10* – Ludwig Canal and Main-Danube Canal, *11* – Rhine-Rhône Canal, *12* – Canal du Centre, *13* – Canal de Briar, *14* – Rhine-Marne Canal, *15* – Kiel Canal. Solid red arrows indicate the Southern meridian invasion corridor and the Northern meridian invasion corridor.

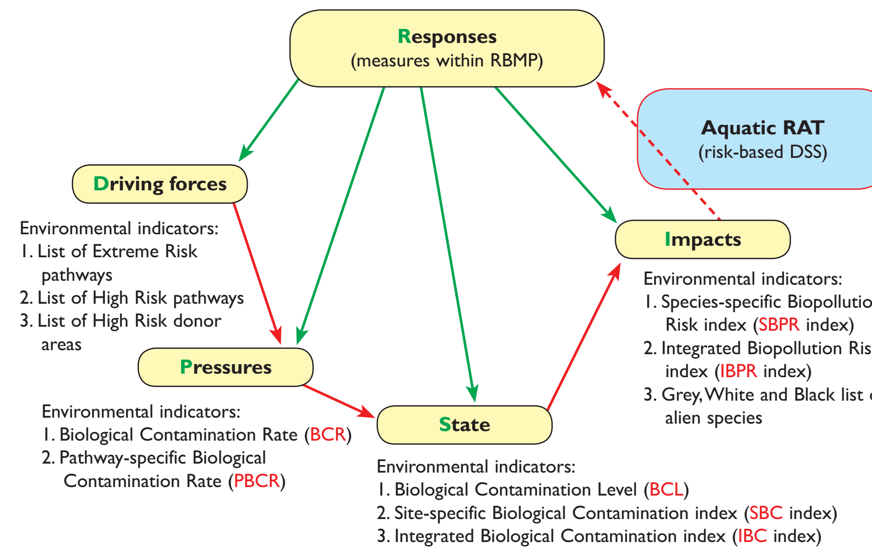

Figure 2. Environmental indicators and Risk Assessment Toolkit (RAT) for introductions of aquatic invasive species in the DPSIR framework (after Panov et al. 2009, modified). RBMP – River Basin Management Plans, DSS – Decision Support System on aquatic invasive species (for description of specific environmental indicators see text).

Conceptual model of risk assessment of IAS introductions via European inland waterways

Owing to the high degree of scientific uncertainty when dealing with such a global and complex ecological issue as large-scale intercontinental and intra-continental introductions of IAS, the qualitative model of risk assessment was selected for risk assessment of IAS introductions via European inland waterways (Panov et al. 2007, 2009). The present variant of this qualitative model of risk assessment of IAS introductions via navigable waterways includes six main components:

- Identification of main invasion gateways, routes and corridors in Europe, and selection of ecosystems as assessment and management units (AUs) within invasions corridors/invasion network.
- Identification and analysis of pathways of IAS introductions within the ecosystem – "**Driving forces**" according to the DPSIR framework.
- Assessment of inoculation rates (propagule pressure) within the ecosystem– DPSIR "**Pressures**";
- Assessment of biological contamination level of the ecosystem – DPSIR "**State**".
- Assessment of invasiveness of alien species, established in the ecosystem (potential biopollution risk) – DPSIR "**Impacts**".
- Development of an online Risk Assessment Toolkit (RAT) with early warning service for reporting of environmental indicators and recommendations for risk management to stakeholders – DPSIR "**Responses**".

For the purpose of testing this model, we selected a 10-year observation period (1997-2007) for analysis of pathways and assessment of propagule pressure within the selected ecosystems (Assessment Unit), and an observation period of time since 1900 for the assessment of biological contamination level of the ecosystem.

Identification of main invasion gateways, routes and corridors in Europe

There are four principal invasion corridors in Europe (Figure **1**):

- **The Northern corridor:** linking the Black and Azov seas with the Caspian Sea via the Azov – Caspian waterway including the Volga-Don Canal, and with the Baltic and White seas *via* the Volga-Baltic waterway including the Volga-Baltic Canal, and the White Sea – Baltic Sea waterway, including the White Sea – Baltic Sea Canal.
- **The Central corridor:** connecting the Black Sea with the Baltic Sea region *via* Dnieper and Bug-Pripyat Canal, with Nemunas River branch connected to Pripyat and Bug by Oginsky and Augustov canals, correspondingly.

- **The Southern corridor:** linking the Black Sea basin with the North Sea basin *via* the Danube-Main-Rhine waterway including the Main-Danube Canal.
- **The Western corridor:** linking the Mediterranean with the North Sea *via* the River Rhône and the Rhine-Rhône Canal.

These principal corridors are interlinked via two additional invasion corridors: **the Southern meridian corridor** linking the Northern, Central and Southern corridors on the south, and **the Northern meridian corridor**, linking the Northern, Central, Southern and Western on the north (Figure **1**). This complex system of navigable waterways and invasion corridors can be considered as an **European inland water invasion network** (Figure **1**), with estuaries of large European rivers (Don, Danube, Dnieper, Neva, Odra, Rhine) and lagoons (Curonian, Vistula) serving as entries to the main invasion corridors and considered as "invasion gateways" (Panov et al. 2009). In our study, we selected assessment units within three main invasion corridors (Northern, Central and Southern) in order to consider an ecosystem approach to the management of IAS using river basins as the main management units (Figure **3**).

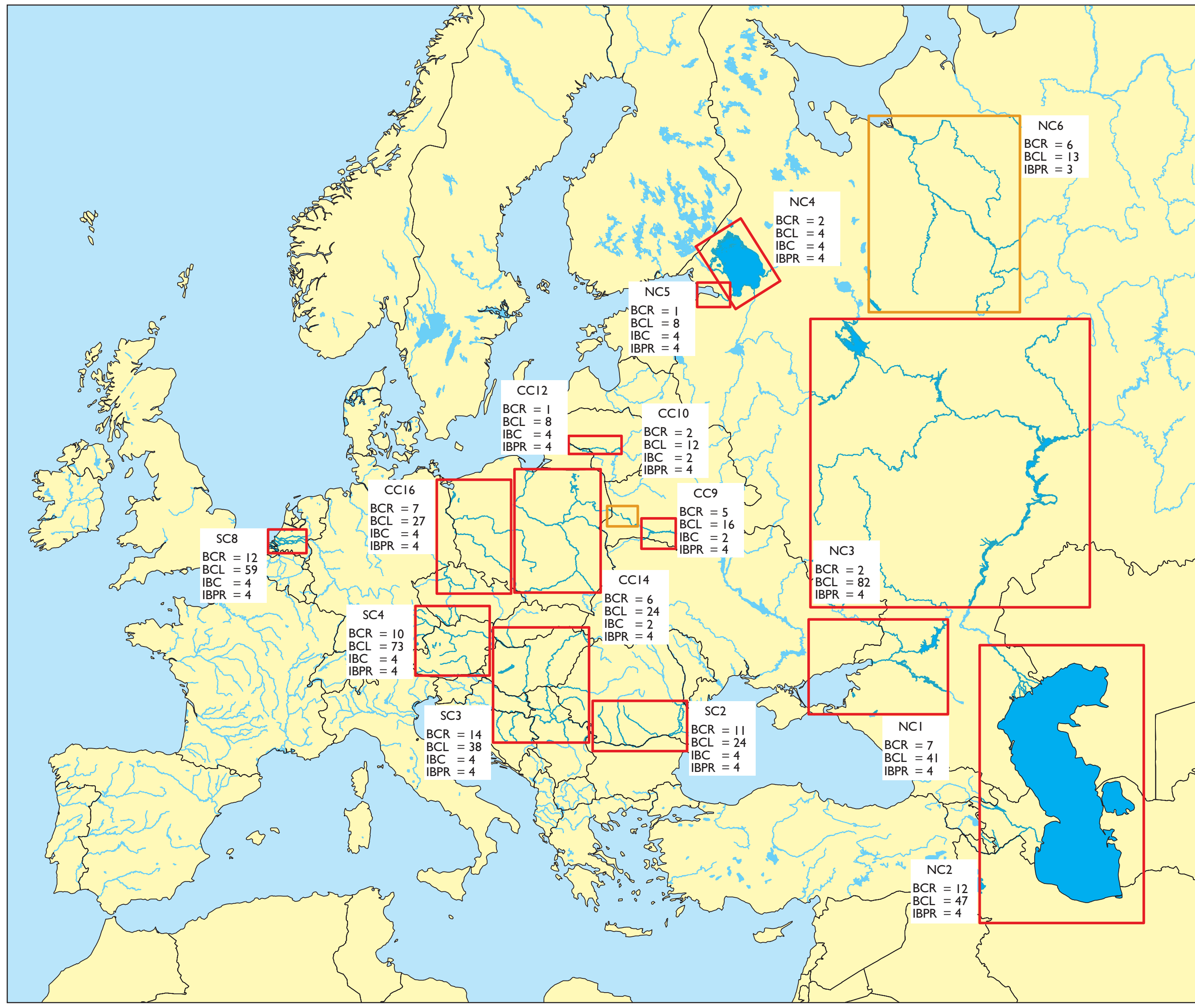

Figure 3. Assessment units selected within the Northern, Central and Southern inland water invasion corridors (NC, CC and SC, respectively): NC1 – River Don and Azov Sea, NC2 – lower part of River Volga and Caspian Sea, NC3 – upper and middle parts of River Volga, NC4 – Lake Ladoga, NC5 – River Neva estuary, NC6 – River Severnaya Dvina, CC9 – middle part of River Pripyat, CC10 – Dnieper-Bug canal, CC 12 – lower part of River Nemunas, CC14 – River Vistula, CC16 – River Oder, SC2 – lower part of River Danube, SC3 – middle part of River Danube, SC4 – upper part of River Danube, SC8 – lower part of River Rhine. The Integrated biological pollution risk (IBPR) is indicated both by numbers and colours of area boundaries (High biopollution risk and Very high biopollution risk are in orange and red, respectively).

Identification and analysis of pathways of IAS introductions within the ecosystem

Pathways involved in the introductions of IAS can be considered as "Driving forces" according DPSIR framework (Figure **2**). Principal pathways of aquatic IAS spread in Europe and qualitative descriptors of principal human activities involved in the spread of IAS have been identified (see in Panov et al. 2009). For the purpose of the present qualitative risk assessment of IAS introductions via inland waterways, these principal human activities were considered as potential pathways for any selected ecosystem (assessment unit – AU). Pathways are defined according to three classifications:

- A pathway with low certainty of the existence of a specific pathway for a specific AU, can be defined as "**Low Risk (LR) pathway**".
- A pathway with a high level of certainty of its existence in the AU, but with no evidence existing of the introduction of alien species in AU by this pathway during the past 10 years, can be defined as "**High Risk (HR) pathway**".
- Where the operating pathway can be defined as responsible for an introduction of specific alien species into a AU during the past 10 years (even if only one record of alien species within this period can be attributed with some level of certainty to the specific pathway), it can be defined as "**Extreme Risk (ER) pathway**".

Assessment of inoculation rates within the ecosystem

In the present study we suggest assessing inoculation rate indirectly via the Biological Contamination Rate (BCR). "**Biological contamination**" of the ecosystem means the introduction of alien species regardless of their abilities to cause negative ecological and/or socio-economic impacts; in a case where impacts of introduced alien species are measurable, the "**biological pollution**" of the ecosystem should be evaluated (see in Panov et al. 2009).

The **Biological Contamination Rate** (**BCR**) of the ecosystem or any assessment unit (AU) can be estimated as the number of recorded alien species in AU per observation/reporting period (e.g., total number of recorded alien species per year or per 10 years). BCR values for selected assessment units for last reporting period (1997-2007 in the present study) are provided in Figure **3**.

The **Pathway-specific Biological Contamination Rate (PBCR)** reflects the inoculation rate in AU by specific pathways and can be estimated by the number of recorded alien species in AU by specific pathway during the reporting period. PBCR can be used as a DPSIR Environmental indicator for "Pressures". Where PBCR = 0, there is no biological contamination by existing pathway, whereas if PBCR > 0, then the Extreme Risk pathway (ER pathway) can be distinguished.

Assessment of biological contamination level of the ecosystem

Biological contamination level (BCL) of the AU (ecosystem) reflects the invasibility of the ecosystem (probability of establishment of alien species as a complex function of abiotic and biotic resistance of the ecosystem to biological invasions under a specific level of propagule pressure). This feature of the ecosystem can be assessed via estimation of the number of established alien species and their relative roles in the structural organization of plant and animal communities. For the purposes of our study, BCL is estimated as the number of established alien species in AU since 1900 (BCL estimates for selected assessment units are provided in Figure **3**). BCL can be used as a DPSIR Environmental indicator of "State".

The **Site-specific Biological Contamination** (**SBC)** index has been elaborated to assess biological contamination of the specific sampling site within AU with respect to "taxonomic" and "abundance" contamination (Arbačiauskas et al. 2008). For ranking of SBC index see Table **1**; an example of assessment of SBC indices for macrozoobenthic communities and the corresponding ecological quality for 13 locations in three assessment units of River Pripyat are provided in Figure **5**.

The **Integrated Biological Contamination (IBC)** index for the

Table 1. Scoring of Site-specific and Integrated Biological Contamination indices (SBC and IBC) with respect to abundance contamination index (ACI) and taxonomic contamination index (TCI). SBC or IBC ranks: 0 (high status, no biological contamination (BC), blue cell), 1 (good status, low BC, green cell), 2 (moderate status, moderate BC, yellow cells), 3 (low status, high BC, orange cells), 4 (bad status, very high BC, red cells) (after Arbačiauskas et al. 2008).

TCI	ACI				
	none	0.01 – 0.10	0.11 – 0.20	0.21 – 0.50	>0.50
none	none				
0.01 – 0.10		1	2	3	4
0.11 – 0.20		2	2	3	4
0.21 – 0.50		3	3	3	4
>0.50		4	4	4	4

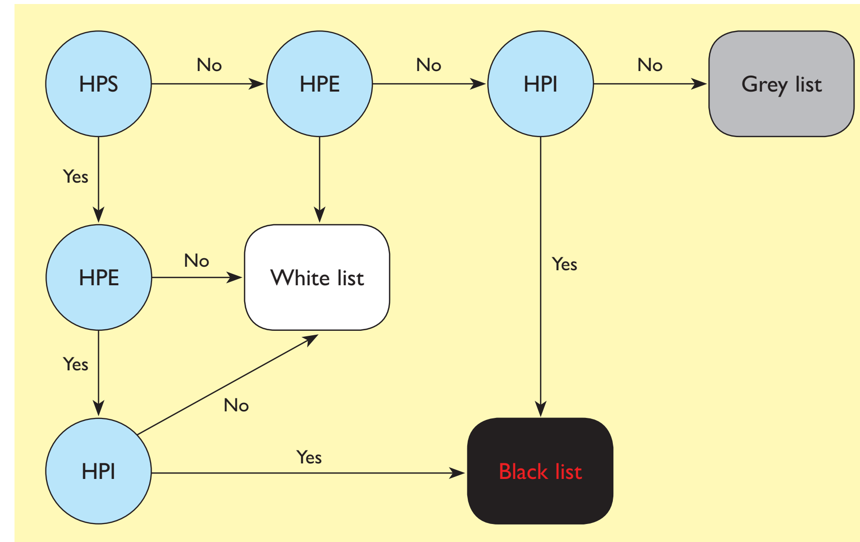

Figure 4. Procedure for listing alien species according their potential invasiveness (after Panov et al. 2009, modified). "Yes" in this scheme means that information on potential invasiveness of the species is available, "No" means "Unknown", or information is not available (HRD – High risk of dispersal, HRE – High risk for establishment in new environment, HRI – High risk to cause ecological and negative socio-economic impacts).

AU can be estimated by averaging "taxonomic" and "abundance" contamination of study sites (within AU), and can be ranked in the same way as SBC index (see Table **1** and example for macrozoobenthos of Pripyet River in Figure **5**). The IBC index can be used both as DPSIR Environmental indicator of "State" (Figure **2**) and for assessment of ecological status of the whole AU (aquatic ecosystem) (Figure **5**). IBC indices for selected assessment units are provided in Figure **3**.

Assessment of invasiveness of alien species (potential biopollution risk)

Estimations of actual impacts of alien species in specific aquatic ecosystems (e.g., AUs) are not always possible and usually require costly long-term research efforts in the specific water body. In this regard, a risk-based assessment of invasiveness of the established alien species can be considered the most cost-effective way for developing practicable indicators for "Impacts" in the DPSIR framework. For this purpose we have developed a **Species-specific Biopollution Risk (SBPR)** index, which is based on the general assessment of the level of invasiveness of the specific alien species according to the estimates of three such descriptors of the species as High risk for dispersal (HRD), High risk for establishment in a new environment (HRE), and High risk to cause ecological and negative socio-economic impacts (HRI). The knowledge on HRD, HRE and HRI of the alien species is generally available from scientific reports and publications associated with a particular species introduction (Panov et al. 2009). This approach to the risk-based assessment of invasiveness of the alien species, established in the aquatic ecosystem (AU), was further used in the formal procedure of listing of alien species into the Grey, White and Black Lists (Figure **4**).

This ranking of alien species according their invasiveness along with information on relative abundance of invasive alien species in specific locations of the AU can be further used for estimation of the **Integrated Biopollution Risk (IBPR)** index. Where no alien species are present in the AU, IBPR = 0 (No biopollution risk: reference conditions, or "High" ecological status *sensu* the Common Implementation Strategy of the EC Water Framework Directive). If alien species from "Grey" or "White" lists are present in relatively low abundances (less than 20 % of total abundance of alien and native species in the community), then IBPR = 1 (Low biopollution risk: this may correspond to "Good" ecological status of a water body). Relatively high abundance of alien species (exceeding 20 %) from "Grey" or "White" lists corresponds to IBPR = 2 (Moderate biopollution risk: "Moderate" ecological status). Where alien species from the "Black list" are present in the community, the IBPR can be estimated as 3 in a situation with relatively low abundance of these species (High biopollution risk: "Poor" ecological status), or 4 in a situation with relatively high abundance of "Black list" species (Very high biopollution risk: "Bad" ecological status) with the same 20 % threshold for "low" and "high" relative abundances (see Figures **3** and **5** for examples).

Grey, White and Black Lists of IAS, SBPR and IBPR indices can be used as DPSIR Environmental indicators of "Impacts" (Figure **2**). Also, the Black List can be used as the EEA SEBI 2010 indicator "Invasive alien species in Europe", element 'Worst invasive alien species threatening biodiversity in Europe" (European Environment Agency 2007). In addition, the IBPR index can be recommended for the risk-based estimation of ecological status of water bodies considering alien species introductions as a specific pressure (Panov et al. 2009).

Development of an online risk assessment toolkit with an early warning service for reporting of environmental indicators and recommendations for risk management to stakeholders

The aquatic component of the online Risk Assessment Toolkit (RAT) includes risk assessment protocols for IAS introductions via European inland waterways, supporting database and electronic journal "Aquatic Invasions" (Figure **6**). The latter serves as an instrument to protect authors' rights on IAS information stored in the database and as an early warning tool (Panov et al. 2008, see also Figures **6** and **7**). The aquatic part of RAT will also serve as the decision-support sys-

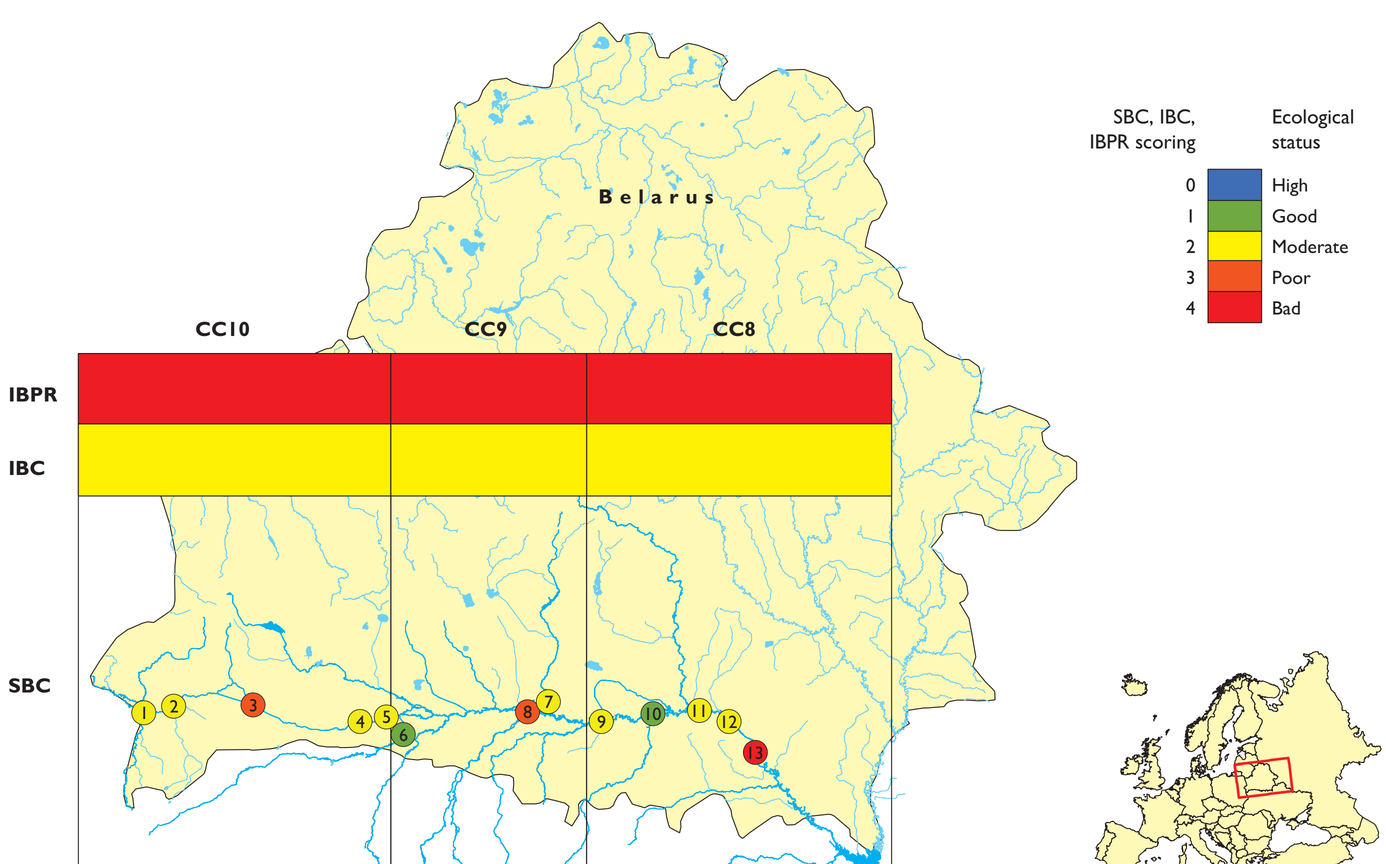

Figure 5. Assessment of ecological status of three assessments units and specific locations in the River Pripyat basin based on estimations of Site-specific biological contamination (SBC), Integrated biological contamination (IBC) and Integrated biological pollution risk (IBPR) indices (after Panov et al. 2009, modified).

tem (DSS), the online transmitter of essential information needed for decision-making (Figure **2**, Panov et al. 2008), and will provide links to other IAS risk assessment protocols (http://www.reabic.net and http://www.cefas.co.uk/4200.aspx).

Conclusions

The developed DPSIR environmental indicators for alien species ("Drivers" – List of Extreme Risk pathways for AUs, List of High Risk pathways for AUs, List of High Risk Donor Areas for AUs; "**Pressures**" **–** Biological Contamination Rate (BCR), Pathway-specific Biological Contamination Rate (PBCR); "**State**" **–** Biological Contamination Level (BCL), Site-specific Biological Contamination (SBC) index, Integrated Biological Contamination (IBC) index; "**Impacts**" **–** Species-specific Biopollution Risk (SBPR) index, Grey, White and Black lists of alien species and Integrated Biopollution Risk (IBPR) index, Figure **2**) can be useful for risk management at the local, river basin, national and regional levels.

Management measures for the DPSIR "Driving forces" and "Pressures" may include preventive actions toward management of Extreme Risk and High Risk pathways. Biological Contamination Rate (BCR) and Pathway-specific Biological Contamination Rate (PBCR) can be used as indicators of the effectiveness of preventive management. In contrast, the management actions for "State" and "Impacts" may involve the control and eradication of established species from Black List (according to CBD provisions), and Site-specific and Integrated Biological Contamination indices. Along with the Integrated Biopollution Risk index, these can be used as comparatively simple indicators of the effectiveness of these measures.

Three environmental indicators from this list can be recommended as cost-effective "Quality Elements" (QEs) according to the Common Implementation Strategy of the Water Framework Directive for assessment of ecological status of aquatic ecosystems: Site-specific Biological Contamination (SBC) index, Integrated Biological Contamination (IBC) index and, specifically, based on precautionary approach, the Integrated Biopollution Risk (IBPR) index.

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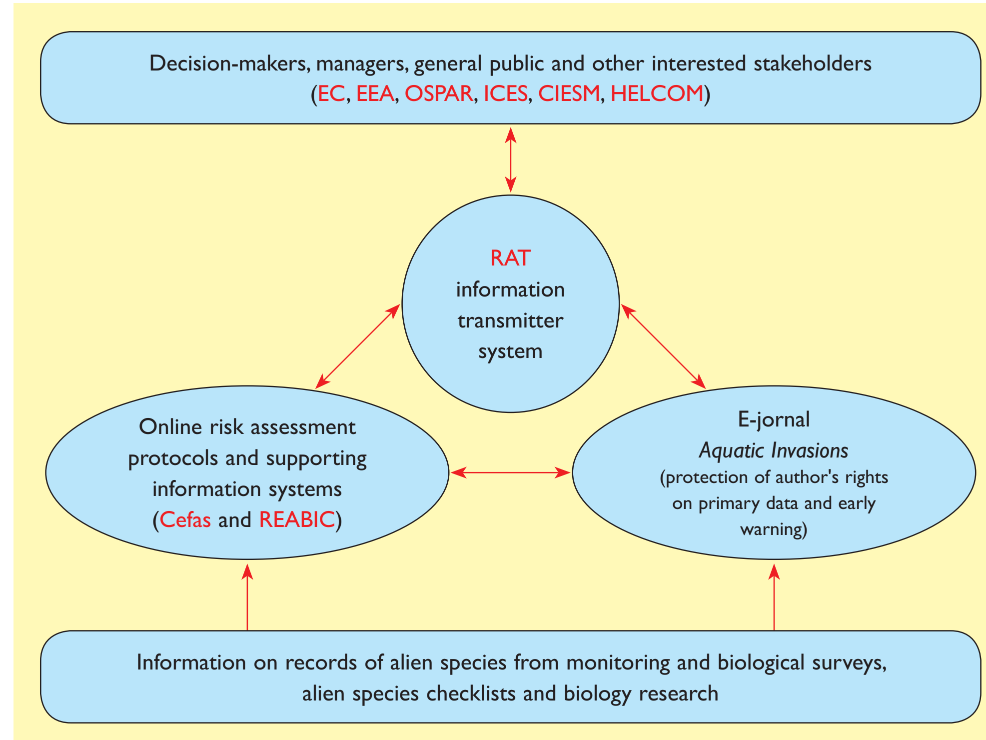

Figure 6. Conceptual structure of the online Risk Assessment Toolkit (RAT) for aquatic alien species with early warning functions (after Panov et al. 2009, modified). EC – European Commission (http://ec.europa.eu/), EEA – European Environment Agency (http://www.eea.europa.eu/), CIESM – International Commission for the Scientific Exploration of the Mediterranean Sea (http://www.ciesm.org), OSPAR – OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic (http://www.ospar.org), HELCOM – Baltic Marine Environment Protection Commission (http://www.helcom.fi), Cefas – Cefas Risks and impacts of non-native species Decision support tools (http://www.cefas.co.uk/4200.aspx), REABIC – Regional Euro-Asian Biological Invasions Centre information system (http://www.reabic.net).

Figure 7. Selected new geo-referenced records of invasive alien species in European coastal and inland waters in 2007, published in the second volume of *Aquatic Invasions* (2007): 1 – the tubenose goby *Proterorhinus marmoratus* from the River Neva estuary, Russia (Antsulevich 2007), 2 – the tubenose goby *Proterorhinus marmoratus* from the Pripyat River, Belarus (Rizevsky et al. 2007), 3 – the Chinese mitten crab, *Eriocheir sinensis* from the River Volga, Russia (Shakirova et al. 2007), 4 – the Ponto-Caspian mysid *Limnomysis benedeni* from the River Pripyat, Belarus (Semenchenko et al. 2007), 5 – the Indo-Pacific humpnose big-eye bream, *Monotaxis grandoculis* in the Mediterranean Sea (Bilecenoglu 2007), 6 – the Red Sea mussel *Brachidontes pharaonis* from the Turkish coasts (Doğan et al. 2007), 7 – the Asian clam *Sinanodonta woodiana* from Eastern Romania (Popa et al. 2007), 8 – the Ponto-Caspian amphipod *Dikerogammarus villosus* ("killer shrimp") in Lac du Bourget, France (Grabowski et al. 2007), 9 – the Quagga mussels *Dreissena bugensis* in Ukraine (Son 2007), 10 – the Quagga mussels *Dreissena bugensis* in the River Main, Germany (van der Velde and Platvoet 2007), 11-12 – the Asian amphipod *Caprella mutica* in coastal waters of UK and Norway (Cook et al. 2007), 13 – the American oyster drill, *Urosalpinx cinerea* in The Netherlands (Faasse and Ligthart 2007), 14 – the Asian tunicate *Styela clava* from the central German Bight (Krone et al. 2007), 15-21 – the North-American ctenophore *Mnemiopsis leidyi* in the Oslofjorden, Norway (Oliveira 2007), in Danish waters (Tendal et al. 2007), in south-western Baltic Sea (Kube et al. 2007), in the Gulf of Gdańsk, southern Baltic Sea (Janas & Zgrundo 2007), in the central Baltic, Gulf of Bothnia and Gulf of Finland, respectively (Lehtiniemi et al. 2007).