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Assessing the Risks of Aquatic Species Invasions via European Inland Waterways: From Concepts to Environmental Indicators

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EDITOR'S NOTE:

This is 1 of 12 papers prepared by participants attending the workshop "Risk Assessment in European River Basins—State of the Art and Future Challenges" held in Liepzig, Germany on 12–14 November 2007. The meeting was organized within the framework of the European Commission's Coordination Action RISKBASE program. The objective of RISKBASE is to review and synthesize the outcome of European Commission FP4–FP6 projects, and other major initiatives, related to integrated risk assessment–based management of the water/sediment/soil environment at the river basin scale.

ABSTRACT

Over the past century, the potential for aquatic species to expand their ranges in Europe has been enhanced both as a result of the construction of new canals and because of increased international trade. A complex network of inland waterways now connects some previously isolated catchments in southern (Caspian, Azov, Black, Mediterranean seas) and northern (Baltic, North, Wadden, White seas) Europe, and these waterways act as corridors for nonnative species invasions. We have developed a conceptual risk assessment model for invasive alien species introductions via European inland waterways, with specific protocols that focus on the development of environmental indicators within the socioeconomic context of the driving forces–pressures–state–impact–response framework. The risk assessment protocols and water quality indicators on alien species were tested for selected ecosystems within 3 main European invasion corridors, and these can be recommended for application as part of the Common Implementation Strategy of the European Commission Water Framework Directive, which aims to provide a holistic risk-based management of European river basins. The conceptual structure of the online Risk Assessment Toolkit for aquatic invasive alien species is provided and includes 3 main interlinked components: online risk assessment protocols, an early warning system, and an information transmitter for risk communication to end users.

Keywords: Alien species   Risk analysis   Ecological status   River basin management   Water Framework Directive

INTRODUCTION

European inland waterways have provided opportunities for the spread of nonnative aquatic species (see Table 1 for glossary of terms and abbreviations) for many centuries (Copp et al. 2005a). Canals can provide conduits for species to spread between previously separate biogeographic regions by either active movement, drift, and/or as a result of ship transport (Bij de Vaate et al. 2002; Galil et al. 2007). Over the past century, the potential for species to expand their range has been enhanced as a result of both the construction of new canals and increased trade. At present, the complex European network of inland waterways is made up of >28000 km of navigable rivers and canals, connecting 37 countries in Europe and beyond. This aquatic network now connects the previously isolated catchments of the southern European seas (Caspian, Azov, Black, Mediterranean) and the northern European seas (Baltic, North, Wadden, White), providing invasion corridors for alien species. In Europe, there are 30 main canals with >100 branch canals and >350 ports (Bij de Vaate et al. 2002; Ketelaars 2004; 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 change.

The current invasion corridors and the projected future developments of the European network of inland waterways may highly facilitate the transfer of alien species across European inland waters and coastal ecosystems. Appropriate risk assessment–based management options are required to

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address risks posed by human-mediated introductions of these species (Gollasch and Leppäkoski 2007; Panov et al. 2007).

During the development of methods to assess the risks of alien species introductions via European inland waterways, we considered the relevant provisions of international legal instruments on invasive alien species, specifically the Convention on Biological Diversity (CBD) guiding principles for the prevention, introduction, and mitigation of impacts of alien species that threaten ecosystems, habitats, or species (CBD COP6 Decision VI/23 2002), which includes 3 main guiding principles (1–3) and associated principles (13–15): 1) precautionary approach—"The precautionary approach should also be applied when considering eradication, containment and control measures in relation to alien species that have become established. Lack of scientific certainty about the various implications of an invasion should not be used as a reason for postponing or failing to take appropriate eradication, containment and control measures"; 2) 3-stage hierarchical approach—"Priority should be given to preventing the introduction of invasive alien species, between and within States. If an invasive alien species has been introduced, then early detection and rapid action are crucial to prevent its establishment. The preferred response is often to eradicate the organisms as soon as possible (Principle 13 [e.g., Britton and Brazier 2006; Copp et al. 2007b; Britton et al. 2008]). In the event that eradication is not feasible, or resources are not available for its eradication, then containment (Principle 14) and long-term control measures (Principle 15) should be implemented"; and 3) ecosystem approach—"Measures to deal with invasive alien species should, as appropriate, be based on the ecosystem approach."

Also, we considered relevant recommendations of the European Strategy on Invasive Alien Species (Genovesi and Shine 2004), specifically those on the listing system for alien species. The European Environmental Agency's "Typology of Indicators" and the driving forces–pressures–state–impact–response (DPSIR) framework were used to structure developed environmental indicators in the socioeconomic context (Smeets and Weterings 1999; Gabrielsen and Bosch 2003; Maxim et al. 2007) (Figure 1). In addition, considering the current gap in addressing invasive alien species in European river basin management, our goals were also to develop relevant risk assessment protocols and water quality indicators for alien species to gain possible consideration in the Common Implementation Strategy of the European Commission Water Framework Directive (European Commission 2000; Cardoso and Free 2008) and as part of a holistic (cumulative) risk-based management of European river basins (Brack et al. 2009).

CONCEPTUAL MODEL OF RISK ANALYSIS OF ALIEN SPECIES INTRODUCTIONS VIA EUROPEAN INLAND WATERWAYS

Modern risk analysis takes its root from radiology and the development of the nuclear power industry. These protocols were subsequently adapted to assess a range of hazards, most recently alien species. Many risk analysis schemes exist; however, all of them normally consist of 4 main components: 1) risk identification, 2) risk assessment (of the likelihood of introduction, establishment, dispersal, and impact), 3) risk management, and 4) risk communication (Van Leeuwen and Vermeire 2007). Various parts of the risk analysis process may be employed as required in different decision-making contexts, ranging from specific case studies to strategic regulation and policymaking. In terms of risk identification and assessment, there are 2 main types of approach: qualitative and quantitative. Quantitative risk assessment normally requires much numerical data, which may not always be available. It may therefore be better to examine issues and convey conclusions (and the associated uncertainties) in qualitative terms. Because of the high degree of scientific uncertainty when dealing with such a global and complex ecological issue as large-scale intercontinental and intracontinental introductions of nonnative species, the qualitative model was selected for risk analysis of alien species introductions via European inland waterways. Initially, the developed conceptual model included 2 main specific methodologies—an environmental matching risk assessment and a species-specific risk assessment—and this model was tested for selected ecosystems (risk areas or assessment units) of one of the largest European navigable waterways, linking the Black and Caspian seas with the Baltic and White seas via the Volga River (Panov et al. 2007). The present variant of this qualitative model of risk analysis of alien species introductions via navigable waterways includes 7 main components:

1. Identification of main invasion gateways, routes, and corridors in Europe
2. Selection of ecosystems as assessment and management units (assessment units) within invasions corridors/invasion network
3. Identification and analysis of pathways of alien species introductions within the ecosystem—"driving forces" according to the DPSIR framework
4. Assessment of inoculation rates (propagule pressure) within the ecosystem—DPSIR "pressures"
5. Assessment of biological contamination of the ecosystem—DPSIR "state"
6. Assessment of invasiveness of alien species, established in the ecosystem (biological pollution risk)—DPSIR "impacts"
7. Development of an online Risk Assessment Toolkit 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-y 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 levels of the ecosystem. The observation period since 1900 corresponds to the European Environmental Agency SEBI 2010 indicator "'Invasive Alien Species in Europe," element "Cumulative Number of Alien Species in Europe since 1900" (European Environment Agency 2007). For developing indicators for DPSIR "Impacts," we considered generally the grey, white, and black listing system used in the European strategy on invasive alien species (Genovesi and Shine 2004; Nehring and Klingenstein 2008).

IDENTIFICATION OF MAIN INVASION GATEWAYS, ROUTES, AND CORRIDORS IN EUROPE

Four principal invasion corridors exist in Europe (Figure 2):

1. Northern corridor: Has 6500 km of navigable waterways and 21 inland ports of international importance. The corridor links the Black and Azov seas with the Caspian Sea via the Azov–Caspian waterway, including the

Table 1. Definitions and abbreviations of key terms for risk assessment of aquatic nonnative species

Terms and abbreviations	Definition	Reference
Alien species	Refers to a species, subspecies, or lower taxon, introduced outside its natural past or present distribution; includes any part, gametes, seeds, eggs, or propagules of such species that might survive and subsequently reproduce	CBD COP6 Decision VI/23
Nonnative, nonindigenous species	Synonyms for "alien species"	Present study
Invasive species	Means indigenous or nonindigenous species that spreads, with or without the aid of humans, in natural or seminatural habitats, producing a significant change in composition, structure, or ecosystem processes or causing severe economic losses to human activities	Copp et al. (2005a)
Introduction	Refers to the movement by human agency, indirect or direct, of an alien species outside its natural range (past or present); this movement can be either within a country or between countries or areas beyond national jurisdiction	CBD COP6 Decision VI/23
Establishment	Refers to the process of an alien species in a new habitat successfully producing viable offspring with the likelihood of continued survival	CBD COP6 Decision VI/23
Risk analysis	Refers to 1) the identification of risks and their assessment with regard (in nonnative species terms) to the likelihood and consequences of the introduction, establishment, spread, and impact of an alien species using science-based information (i.e., risk assessment) and 2) the identification of measures that can be implemented to reduce or manage these risks (i.e., risk management), taking into account socioeconomic and cultural considerations	CBD COP6 Decision VI/23
Assessment unit	Part of aquatic ecosystem, serving as assessment and management unit	Present study
Biological contamination (biocontamination)	The introduction of alien species that may or may not result in noticeable or measurable effects	Modified from Elliott (2003)
Biological contamination rate	The number of recorded alien species in the assessment unit per reporting period	Present study
Pathway-specific biological contamination rate	The number of recorded alien species in the assessment unit by specific pathway during reporting period	Present study
Biological contamination level	The number of established alien species in assessment unit since 1900	Present study
Site-specific biological contamination	Index for estimation of biological contamination of the specific location (sampling site) within the assessment unit and ecological status of the specific location within the water body	Present study
Integrated biological contamination	Index for estimation of biological contamination of the assessment unit and ecological status of the water body	Present study
Biological pollution (biopollution)	The introduction of alien species with noticeable effects on individuals, populations and communities of native species and/or resulting in adverse socioeconomic consequences	Modified from Elliott (2003)
Biological pollution level	Index for estimation of actual impacts of alien species in assessment units	Olenin et al. (2007)
Species-specific biological pollution risk	Index for estimation of potential invasiveness of the species	Present study
Integrated biological pollution risk (IBPR)	Index for estimation of potential impacts of alien species in the assessment unit and ecological status of the water body	Present study

Table 1. Continued

Terms and abbreviations	Definition	Reference
Invasibility	The probability of establishment of alien species as a complex function of abiotic and biotic resistance by the ecosystem to introductions under a specific level of propagule pressure	Present study
Invasiveness	The degree to which an organism is able to spread from site of primary introduction, to establish a viable population in the ecosystem, to negatively affect biodiversity on the individual, community, or ecosystem level and cause adverse socioeconomic consequences	Present study
Pathways	Principal human activities involved in the spread of alien species	Minchin et al. (2007)
Low-risk pathway	A pathway with low certainty of the existence of a specific pathway for a specific assessment unit	Present study
High-risk pathway	A pathway with a high level of certainty of its existence in the assessment unit (operating pathway) but with no evidence existing of the introduction of alien species into the assessment unit by this pathway during the observation/reporting period	Present study
Extreme-risk pathway	An operating pathway responsible for an introduction of specific alien species into an assessment unit during an observation/reporting period	Present study
Invasion route	The route between the source region of alien species and its location of introduction	Present study
Invasion gateway	Refers to a transitional type of ecosystem (brackish to fresh water estuary, coastal lagoon, or lake) that, because of its salinity regime and high level of human activity (ship transportation), may serve as an "acclimatization chamber" for potentially euryhaline species, enabling them further to colonize inland waters	Present study
Vector	Specific human transport or natural carrier that transmits alien species to the recipient ecosystem	Present study

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.

2. Central corridor: Connects the Black Sea with the Baltic Sea region via Dnieper and Bug–Pripyat Canal, with the Nemunas River branch connected to Pripyat and Bug by the Oginsky and Augustov canals, respectively.
3. Southern corridor: Links the Black Sea basin with the North Sea basin via the Danube–Main–Rhine waterway, including the Main–Danube Canal. The length of the corridor from the Black Sea (Sulina Arm) up to the North Sea is about 3500 km. More than 125 harbors and 67 locks are situated along the waterway.
4. Western corridor: Links the Mediterranean Sea with the North Sea via the Rhône River and the Rhine–Rhône Canal.

These principal corridors are interlinked via 2 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, and Southern corridors on the north (Figure 2). Also, other corridors exist, such as the Canal du Midi linking the Mediterranean Sea to the Atlantic, and there are also navigable canals in Britain, Finland, and Ireland, representing local national networks of inland waterways that are linked with the main European intracontinental invasion corridors primarily by international shipping. This complex system of navigable waterways and invasion corridors can be considered a European inland water invasion network (Figure 2).

Estuaries of large European rivers (Don, Danube, Dnieper, Neva, Odra, Rhine and lagoons, Curonian, Vistula) serve as entries to the main invasion corridors and can be considered "invasion gateways." Invasion gateways represent a transitional type of ecosystem (brackish-to-freshwater estuary, coastal lagoon, or lake) that, because of its salinity regime and high level of human activity (ship transportation and hydromorphological modification), may serve as an "acclimatization chamber" for potentially euryhaline species, enhancing their ability to colonize inland waters.

SELECTION OF ECOSYSTEMS AS ASSESSMENT AND MANAGEMENT UNITS

In general, the term "assessment and management unit" (assessment unit) could be used to describe each part of an aquatic habitat, the evaluation criterion for the level of biological pollution or contamination (sensu Elliott 2003). The selection method for appropriate assessment units depends mainly on 2 elements: the aim of the assessment and the type of

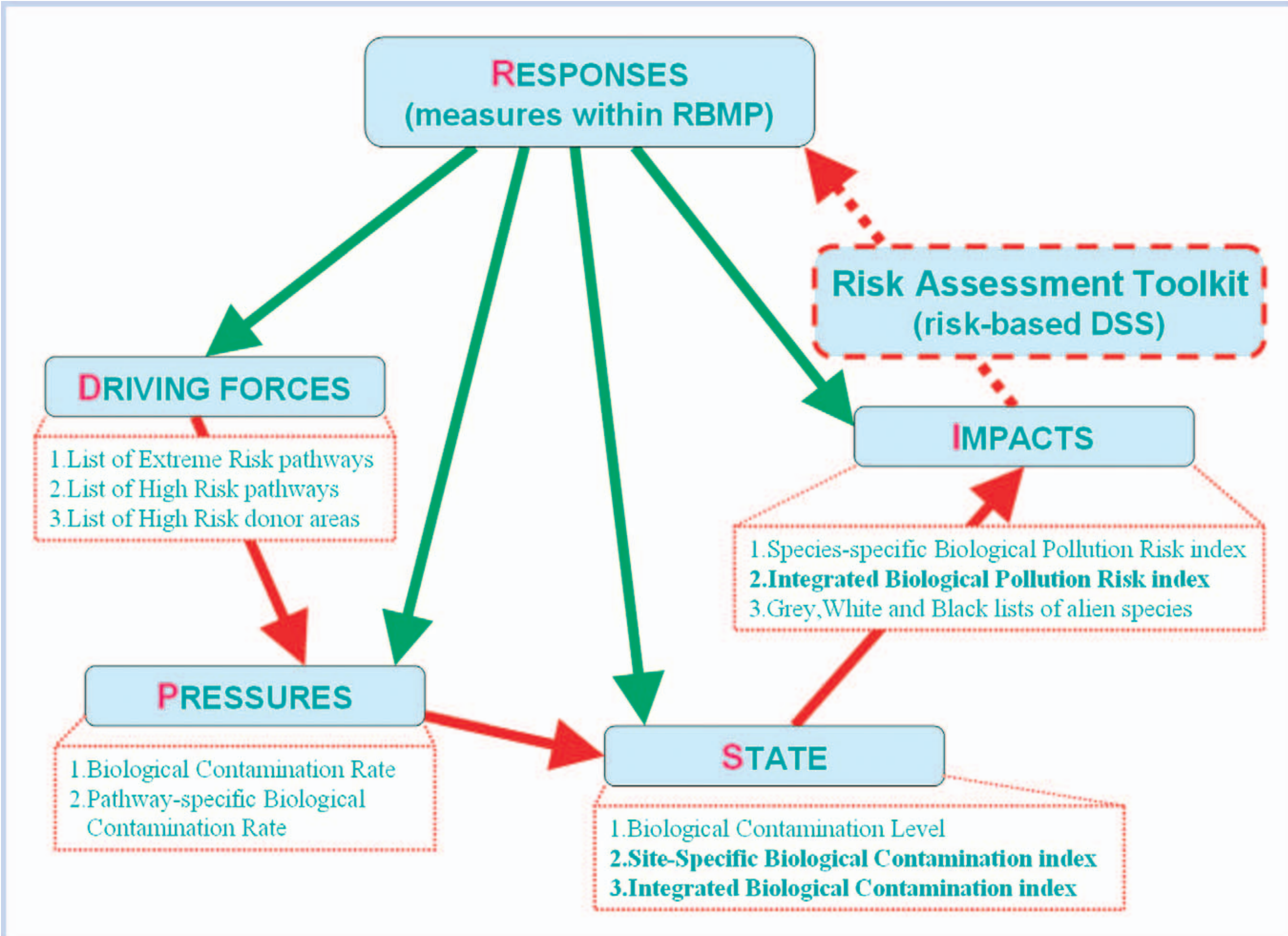

Figure 1. Environmental indicators and Risk Assessment Toolkit (RAT) for introductions of aquatic alien species in the driving forces–pressures–state–impact–response (DPSIR) framework. RBMP = river basin management plans, DSS = decision support system on aquatic alien species (for description of specific environmental indicators, see text). Indicators recommended for assessment of ecological status of aquatic ecosystems are in bold.

water body. With regard to assessment aims, 3 main levels can be identified: management, monitoring, and research.

The management level of assessment, which is the main subject of this conceptual model, requires the overall evaluation of large areas in addition to information of basinwide importance. Accordingly, the assessment units should be defined as larger units of water bodies, and delineation should be based on general criteria, mostly those that are not affected by human influence or that are slightly sensitive to human disturbance. The main criteria for delineation of assessment units for management level assessment are 1) alteration in geology and hydromorphology, 2) altitude change and lake or coastal area depth, and 3) biogeographical criteria. The "ecoregion" approach could be the option, especially taking into consideration the necessity of linking nonnative species risk analysis with management of ecological status of water bodies, as required by the Water Framework Directive (European Commission 2000).

For monitoring programs, assessment units should in general be smaller than those used for management-level assessments, and additional selection criteria should be used: the influence of point and nonpoint sources of pollution, the impact of major hydraulic structures, the influence of tributaries, and so on. Assessment units involved in research activities are the most flexible category. At this level, assessment units could be of different sizes, ranging from a sampling site, a part of the water body, or an entire drainage basin. A sampling site is defined in various ways for different ecological groups of aquatic organisms as well as for different types of aquatic habitats.

The monitoring and research levels of assessment should provide the necessary data for evaluating the management-level evaluations of nonnative species and for testing, applying, and further development of the risk assessment model. For the monitoring of alien species, assessment units are equal to a water body or group of water bodies that are the object of routine biological monitoring. The data generated for invasive species, primarily from surveillance monitoring sites, and extrapolated to relevant water bodies could be an important input for management-level assessments of alien species.

In our study, we selected 33 assessment units within 3 main invasion corridors (Northern, Central, and Southern) in order to consider an ecosystem approach to the management of invasive species using river basins as the main management units (Figure 2).

IDENTIFICATION AND ANALYSIS OF PATHWAYS OF ALIEN SPECIES INTRODUCTIONS WITHIN THE ECOSYSTEM

Pathways involved in the introductions of alien species can be considered "driving forces" according the DPSIR framework (Figure 1). Driving forces are changes in the social,

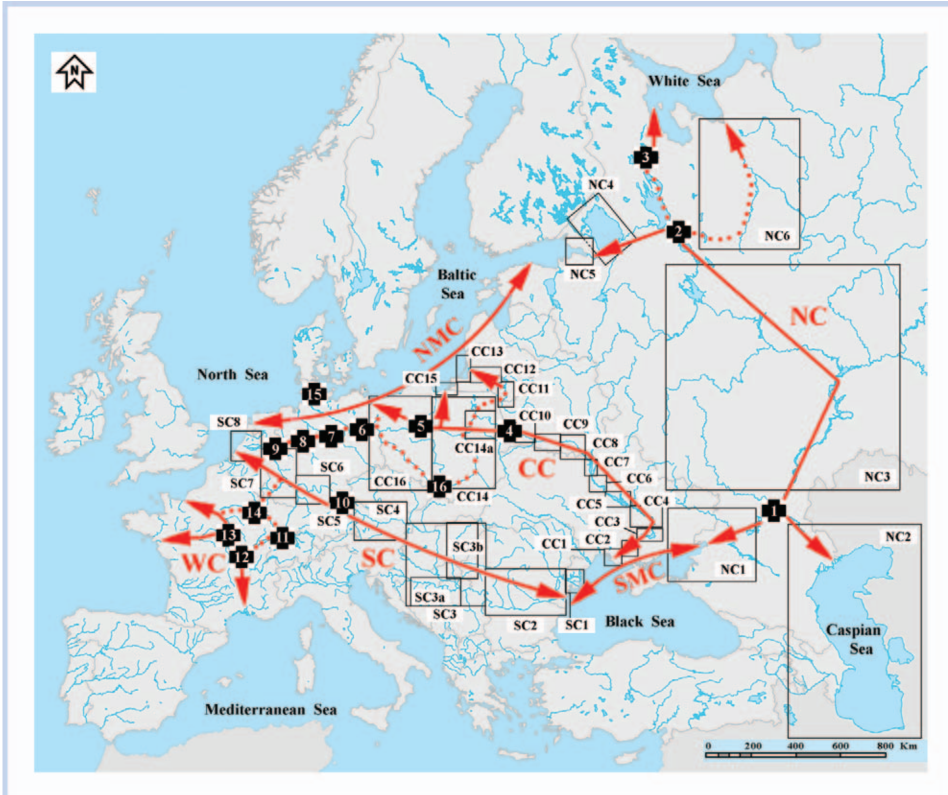

Figure 2. The European inland water invasion network. Main European invasion corridors for the spread of aquatic species are indicated by solid lines: The Northern corridor (NC), the Central corridor (CC), the Southern corridor (SC), the Western corridor (WC), the Southern Meridian corridor (SMC), and the Northern Meridian corridor (NMC). Black crosses indicate main canals: *1* Volga–Don Canal, *2* Volga–Baltic Canal, *3* White Sea–Baltic Sea Canal, *4* Bug–Pripyat Canal, *5* Vistula–Oder Canal (Bydgoski 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, and *16* Gliwice Canal (after Galil et al. 2007, modified). Boxes indicate assessment units along main invasion corridors: NC1 = Don River and Azov Sea, NC2 = lower part of Volga River and Caspian Sea, NC3 = upper and middle parts of Volga River, NC4 = Lake Ladoga, NC5 = Neva River Estuary, NC6 = Severnaya Dvina River, CC1 = Dnieper–Bug Liman, CC2 = Dnieper River delta, CC3 = Kahovka Reservoir, CC4 = Zaporozhje and Dneprodzerzhinsk reservoirs, CC5 = Kremenchug reservoirs, CC6 = Kiev Reservoir, CC7 = Kanev Reservoir, CC8 = lower part of Pripyat River, CC9 = middle part of Pripyat River, CC10 = Bug–Pripyat Canal, CC11 = middle part of Nemunas River, CC12 = lower part of Nemunas River, CC13 = Curonian Lagoon, CC14 = middle and lower parts of Vistula River, CC14a = Bug River, CC15 = Vistula Lagoon, CC16 = Oder River with Bydgoski Canal and Szczecin Lagoon, SC1 = Danube River delta, SC2 = lower part of Danube River, SC3 = middle part of Danube River, SC3a = Sava River, SC3b = Tisa River, SC4 = upper part of Danube River, SC5 = Main–Danube Canal, SC6 = Main River, SC7 = Rhine River, SC8 = Rhine River delta.

economic, and institutional systems that directly or indirectly trigger the creation of invasion corridors resulting in the introduction of alien species (Maxim et al. 2007). Principal pathways and the dispersal vectors of invading aquatic species in Europe have been identified (Minchin et al. 2007), as have qualitative descriptors of principal human activities involved in nonnative species dispersal (Table 2). For the purpose of the present qualitative risk assessment of alien species introductions via inland waterways, all these principal human activities were considered potential pathways for any selected ecosystem (as an assessment unit). Pathways are defined according to 3 classifications (Table 3):

1. A pathway with low certainty of the existence of a specific pathway for a specific assessment unit can be defined as a "low-risk pathway."
2. A pathway with a high level of certainty of its existence in the assessment unit (as defined by the descriptors for the operating pathway in Table 2) but with no evidence existing of the introduction of alien species into the assessment unit by this pathway during the observation period (for the past 10 y in the present study), can be defined as a "high-risk pathway."
3. Where the operating pathway can be defined as responsible for an introduction of specific alien species into an assessment unit during the past 10 y (even if only 1 record of alien species within this period can be accounted for with some level of certainty to the specific pathway), it can be defined as an "extreme-risk pathway."

The 2nd stage of pathways analysis includes the estimation of potential species-specific pathways for alien aquatic species introduced into European inland, transitional, and coastal waters via inland waterways that can be further used for estimation of species invasiveness (see the following discussion).

The following DPSIR environmental indicators can be used for the assessment of "driving forces" with regard to alien species:

1. List of extreme-risk pathways for the assessment unit
2. List of high-risk pathways for the assessment unit
3. List of high-risk donor areas for the assessment unit

The high-risk donor areas for the assessment unit can be defined in the process of the predictive environmental match risk assessment coupled with an analysis of invasion routes associated with shipping, canals, leisure activities, and some other pathways, which is a matter for further studies and is not considered in this paper.

Table 2. List of pathways of invasive alien species introductions in Europe with descriptors for assessment of pathways, currently operating in the assessment unit (AU) (modified from Minchin et al. 2007)

Nr	Pathway	Descriptors of operating pathway in AU
1	Shipping	Regular passage of ships or port within the AU
2	Canals	Presence of the canal within assessment unit or within river basin
3	Wild fisheries	Commercial fishery exists in the area (stock movements, population reestablishment, releases of organisms intended as living fish food supplements, movement of fishing equipment)
4	Culture activities	Aquaculture is practiced within the catchment area, or aquaculture industry is present (including live bait trade)
5	Ornamental and live food trade	Ornamental industry (including garden centers, ornamental ponds, public aquaria) or live food trade exists in the area
6	Leisure activities	Marina or marinas within AU or leisure craft visit AU or high human activity with festivals and sporting events (including angling) with provided access via public parks; SCUBA diving
7	Alteration to natural water flow	Changes of habitats during hydrotechnical activities (creation of reservoirs, dams, dredging activities)
8	Thermal pollution	Regular discharges of heated waters (power plants, untreated wastewater discharges)
9	Research and education	Experimental research activities with alien organisms are taking place, or demonstration cultures of alien organisms exist
10	Biological control	Biological control activities are known
11	Other	Organic and chemical pollution, other habitat modification, discharged live packing material used for nonliving products

ASSESSMENT OF INOCULATION RATES (PROPAGULE PRESSURE) WITHIN THE ECOSYSTEM—DPSIR "PRESSURES"

At the present, it is mainly indirect estimations of inoculation rates (propagule pressure) that are possible via proxies in relation to the quantitative estimations of specific pathway strength. For instance, this approach can be applied to shipping as a case study (cargo turnover for relative estimations of inoculation via ballast water, ships hulls, and so on). An alternative means of measuring propagule pressure is via fish imports, which for England has been demonstrated to provide a statistically significant means of estimating the number of nonnative species (regulated species and ornamental varieties) in the wild from imports both at the regional level and at the finer scale of 100 km^2 (Copp et al. 2007a).

Direct estimations of the "absolute" inoculation rate are possible in specific cases for intentional introductions if the exact number of introduced species is known. In this study we suggest assessing inoculation rate indirectly via the biological contamination rate ("biological contamination" of the ecosystem means the introduction of alien species regardless of their abilities to cause negative ecological and/or socioeconomic impacts; in a case where impacts of introduced alien species are measurable, the "biological pollution" of the ecosystem should be evaluated—see the following sections and definitions in Table 1).

The biological contamination rate (BCR) of the ecosystem or any assessment unit can be estimated as a number of recorded alien species in the assessment unit per reporting period (e.g., total number of recorded alien species per year or per 10 y). BCR values for the last reporting period (1997–2007 in this study) were lowest for selected assessment units within the Central invasion corridor, ranging from 0 to 7 alien species per 10 y, and highest for water bodies of the Northern and Southern invasion corridors, ranging from 2 to 12 and from 3 to 14 alien species per 10 y, respectively (Table 4). The BCR can be used as a DPSIR environmental indicator for "pressures."

The pathway-specific biological contamination rate (PBCR) reflects the inoculation rate in the assessment unit by specific pathways and can be estimated by the number of recorded alien species in the assessment unit by a specific pathway during the reporting period. The PBCRs for selected assessment units for the last reporting period are provided in Table 4. The PBCR can be used as a DPSIR environmental indicator for "pressures." Where this rate $= 0$, there is no biological contamination by the existing pathway (high-risk pathway), whereas if PBCR > 0, then the extreme-risk pathway can be classified.

ASSESSMENT OF BIOLOGICAL CONTAMINATION OF THE ECOSYSTEM—DPSIR "STATE"

The biological contamination level (BCL) of the assessment unit (ecosystem) reflects the invisibility 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, the BCL is estimated as a number of established alien species in the

Table 3. Identification of potential (0, low risk) and operational (1, high risk; 2, extreme risk) pathways in assessment units (AUs). NC = Northern corridor, CC = Central corridor, SC = Southern corridor (for descriptors of pathways, see Table 2). Numbers in parentheses indicate pathway-specific biological contamination rates (species per the period 1997–2007) for the extreme-risk pathways

Code of AU	Pathway							
	1	2	3	4	5	6	7	8–11
	Shipping	Canals	Wild fisheries	Culture activities	Ornamental and live food trade	Leisure activities	Alteration to natural water flow	Other pathways
NC1	2 (2)	2 (5)	1	1	1	1	1	1
NC2	2 (12)	2 (1)	1	1	1	1	1	1
NC3	1	2 (2)	1	1	1	1	1	1
NC4	2 (1)	2 (1)	1	1	1	1	1	1
NC5	2 (4)	2 (1)	1	2 (1)	2 (1)	1	1	2 (1)
NC6	2 (1)	2 (4)	2 (1)	1	1	1	1	1
CC1[a]	1	1	1	1	0	1	0	1
CC2[a]	1	1	1	1	2 (5)	1	1	1
CC3	1	1	1	1	1	1	1	1
CC4[a]	1	1	1	1	1	1	1	1
CC5	1	1	2 (1)	1	1	1	1	1
CC6[a]	1	1	1	1	2 (3)	1	1	1
CC7[a]	1	1	1	1	1	1	1	1
CC8	2 (2)	1	1	2 (1)	1	1	1	1
CC9	2 (4)	1	1	2 (1)	1	1	1	0
CC10	2 (2)	1	1	1	1	1	1	0
CC11	1	2 (1)	1	1	1	1	1	0
CC12	1	2 (1)	1	1	1	1	1	0
CC13	2 (1)	2 (1)	1	1	1	1	1	0
CC14	0	2 (5)	2 (2)	2 (2)	1	1	2 (5)	1
CC14a	0	2	2	2	0	0	0	1
CC15	2 (3)	2 (4)	1	1	1	1	1	1
CC16	2 (5)	2 (4)	2	1	1	1	2 (5)	2 (3)
SC1[a]	1	1	1	1	2 (3)	1	1	1
SC2	2	1	1	2	1	1	2	1
SC3	2	2	1	2	1	1	2	1
SC3a	2	1	1	1	1	1	2	1
SC3b	2	2	1	1	1	1	2	1
SC4	2	2	1	1	1	1	2	1
SC5	2	1	1	1	1	1	2	1
SC6	2	2	1	1	1	1	2	1
SC7	2	2	1	1	1	1	2	1
SC8	2 (2)	2 (11)	1	1	1	1	2	1

[a] Assessment units with natural dispersal as dominating vector of alien species introductions.

Table 4. Selected environmental indicators on alien species for selected assessment units (AUs). BCR = biological contamination rate, records of alien species per 10 y (1997–2007); BCL = biological contamination level, number of established alien species since 1900; IBC = integrated biological contamination index (estimated for macrozoobenthos, after Arbačiauskas et al. 2008), BPL = biopollution level index (see Olenin et al. 2007), IBPR = integrated biopollution risk index (estimated for macrozoobenthos) (see also Table 1 for definitions). N/A = not assessed. Colors of cells for IBC and IBPR indices correspond to ecological status estimates (see classes in Table 5)

Code of AU	BCR	BCL	IBC	BPL	IBPR
NC1	7	41	N/A	N/A	4
NC2	12	47	N/A	N/A	4
NC3	2	82	N/A	N/A	4
NC4	2	4	4	3	4
NC5	8	27	2	4	4
NC6	6	13	N/A	N/A	3
CC1	1	15	N/A	N/A	3
CC2	2	5	N/A	N/A	3
CC3	0	4	N/A	N/A	4
CC4	5	30	N/A	N/A	4
CC5	1	36	N/A	N/A	4
CC6	3	35	N/A	N/A	4
CC7	2	27	N/A	N/A	4
CC8	3	14	2	N/A	4
CC9	5	16	2	N/A	4
CC10	2	12	2	N/A	4
CC11	1	6	3	N/A	3
CC12	1	8	4	N/A	4
CC13	2	14	N/A	3	4
CC14	6	24	3	N/A	4
CC14a	6	10	2	N/A	4
CC15	6	20	N/A	N/A	4
CC16	7	27	4	N/A	4
SC1	3	15	N/A	N/A	4
SC2	11	24	4	2	4
SC3	14	38	4	3	4
SC3a	9	17	4	2	4
SC3b	3	15	4	3	4
SC4	10	73	4	3	4
SC5	5	20	3	N/A	4
SC6	11	37	4	N/A	4
SC7	13	51	4	N/A	4
SC8	12	59	4	N/A	4

assessment unit since 1900 (see Table 4). The 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 the assessment unit with respect to "richness" and "abundance" contamination (see also Arbačiauskas et al. 2008). In accordance to proportion of alien taxonomic orders in the community (ordinal richness contamination) and the relative abundance of alien individuals in the community (abundance contamination), the ecological status of specific location in the assessment unit may decline from "high status" (SBC index = 0, alien species absent) to "bad status" (SBC index = 4, ordinal richness contamination and/or abundance contamination are higher than 50%) (see Table 5 for biological contamination classes). An example of assessment of SBC index for macrozoobenthic communities and the corresponding ecological quality for 13 locations in 3 assessment units of River Pripyat are provided (Figure 4). The SBC index can be used as a DPSIR environmental indicator of "state" and for assessment of ecological status of the specific location in a water body (assessment unit) (Tables 4 and 5 and Figure 4).

The SBC index can be used to compare the biological contamination of different locations within the assessment unit (e.g., at or between specific sites, in different parts of an invasion corridor) as well as for estimation of the integrated biological contamination (IBC) index for the assessment unit by averaging "richness" and "abundance" contamination of study sites (within the assessment unit). The IBC index can be ranked in the same way as the SBC index (Table 5; see also example for macrozoobenthos of River Pripyet in Figure 4). If the IBC indices for different communities of the assessment unit (i.e., benthos, fish, macrophytes, and so on) are available, an integrated estimation of biological contamination of the whole ecosystem of the assessment unit may be obtained as a median of the IBC indices of studied communities. The IBC index can be used both as the DPSIR environmental indicator (Figure 1) and for the assessment of ecological status of the entire assessment unit (aquatic ecosystem) (Figure 4). The IBC index estimates for selected assessment units indicate high and severe biocontamination (low or bad ecological status, respectively) of most studied ecosystems within the European inland waterways (Table 4).

ASSESSMENT OF INVASIVENESS OF ALIEN SPECIES, ESTABLISHED IN THE ECOSYSTEM (BIOLOGICAL POLLUTION RISK)—DPSIR "IMPACTS"

Actual impacts of established invasive alien species on native species, communities, habitats, and ecosystem functioning can be assessed using a biological pollution level (BPL) index—an index developed to classify impacts of alien species to 5 different levels (for detailed protocols, see Olenin et al. 2007). However, estimations of actual impacts of alien species in specific aquatic ecosystems (e.g., assessment units) 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 biological pollution 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 3 such descriptors of the species as potential to spread, potential for establishment in a new environment, and potential to cause ecological and negative socioeconomic impacts.

The species potential to spread is defined by many species traits that can be species and life stage specific. Because of the high level of complexity of these traits and uncertainty in their relative ranking, the risk of rapid species dispersal can be estimated qualitatively via such integrated descriptors as the known diversity of species-specific pathways of introduction. This knowledge is generally available from publications on invasion histories of introduced aquatic species. Records of alien species in more than 1 assessment unit can also be used

Table 5. Assessment of site-specific biological contamination (SBC) index in relation to ratio of alien species in the taxonomic composition of the specific aquatic plant or animal community (richness contamination) and/or in total abundance of aquatic organisms (abundance contamination). SBC index classes: 0, no biological contamination, blue cell; 1, low biological contamination, green cell; 2, moderate biological contamination, yellow cells; 3, high biological contamination, orange cells; 4, severe biological contamination, red cells, corresponding to high, good, moderate, poor, and bad ecological status, respectively (modified from Arbačiauskas et al. 2008)

Richness contamination (%)	Abundance contamination (%)				
	0	1–10	11–20	21–50	>50
0	0				
1–10		1	2	3	4
11–20		2	2	3	4
21–50		3	3	3	4
>50		4	4	4	4

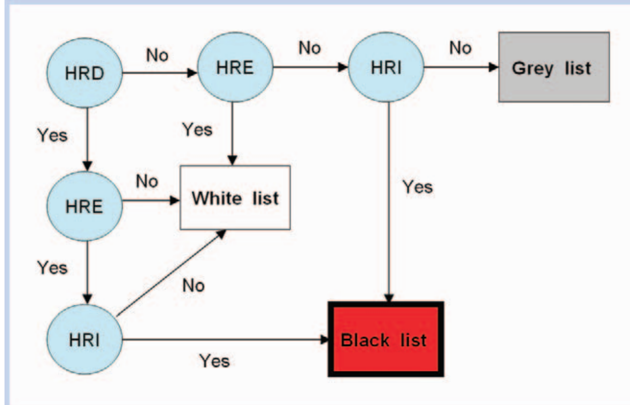

Figure 3. Procedure for listing alien species according their potential invasiveness. "Yes" in this scheme means that information on potential invasiveness of the species is available, and "no" means "unknown," or information is not available (HRD = high risk of dispersal, HRE = high risk of establishment in new environment, HRI = high risk of adverse ecological and/or socioeconomic impacts). See results of application of this procedure for benthic macroinvertebrate species in Table 6.

as a qualitative indicator of high dispersal risk (see examples in Table 6).

The potential for establishment in a new environment is defined by biological traits of the species, such as their euryhalinity, temperature tolerance, habitat generalism and some other traits. Generally, the risk of rapid establishment in a new environment can be attributed to a species if found at high abundances in 2 or more invaded areas (assessment units).

The ecological impact of an invasive alien species can be defined as the quantifiable negative effect on the recipient environment, which can be measured using the existence of scientific reports and publications (peer reviewed or not) associated with a particular species introduction (Gozlan 2008). For example, if an aquatic alien species, following its introduction into any particular country (within any water body or the assessment unit), has been reported to cause habitat degradation, to compete with native species for spawning habitat, to hybridize with native species threatening species integrity, and/or to prey on native species population resulting in their decline or a depletion of native food resources, such alien species can be considered as possessing a high risk of causing ecological and socioeconomic impacts.

The risks of these adverse impacts can be also estimated using the "ecosystem service approach for socioeconomic impacts." The following classification of impacts is adapted from the ecosystem services approach described in the Millennium Ecosystem Assessment (2003) (see also Binimelis et al. 2007). By affecting the ecological processes, biological invasions modify the provision of ecosystem services. Ecosystem services are defined as "the conditions and the processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life" (Daily 1997), encompass both ecological and socioeconomic aspects, illustrating human dependence on ecosystem functioning.

A species can be considered as likely to cause adverse impacts if the answer to any of 8 following questions is "yes":

1. Does it cause loss of native biodiversity at species/population, community, or ecosystem level?
2. Does it cause significant changes in ecosystem functions?
3. Does it cause loss in trophic production (e.g., food, energy supply)?
4. Does it have an impact in terms of human access to natural resources (e.g., biodiversity, wild fish, water supply)?
5. Does it impact on human or domestic (cultured) animal and plant health?
6. Does it cause impacts to recreational and aesthetic activities?
7. Does it cause damage to infrastructure (including shore erosion)?
8. Does it cause economic control costs?

This approach to the risk-based assessment of invasiveness of the alien species, established in the aquatic ecosystem (assessment unit), was further used in the formal procedure of listing of alien species into the grey, white, and black lists (Figure 3). According this procedure, if information on the potential risks of rapid species dispersal, establishment, and adverse impacts is not available, alien species should be attributed to the grey list of species with "unknown risk" (unknown level of invasiveness, and the SBPR index remains unidentified—"N/A"). In the cases where information is available only on the risks of rapid species dispersal or establishment, alien species can be specified as white-list species with low biopollution risk (SBPR index = 1, low level of invasiveness). If information is available on both the risks of rapid dispersal and establishment, then alien species can be specified as white-list species with moderate biopollution risk (SBPR index = 2, moderate level of invasiveness). If information is available on the risks of adverse impacts, regardless of the existence of information on dispersal and establishment risks, then the nonnative species can be specified as a black-list species with high risk (SBPR index = 3, high level of invasiveness).

The black list of alien species for the assessment unit should include all invasive species (i.e., all alien species that have high potential to cause ecological impacts and/or high potential to cause negative socioeconomic impacts).

Grey, white, and black lists can be specific to an assessment unit: water body, river basin, country or region (sea basin) specific, or pan-European. A preliminary list of alien benthic macroinvertebrates for European inland waterways consists of

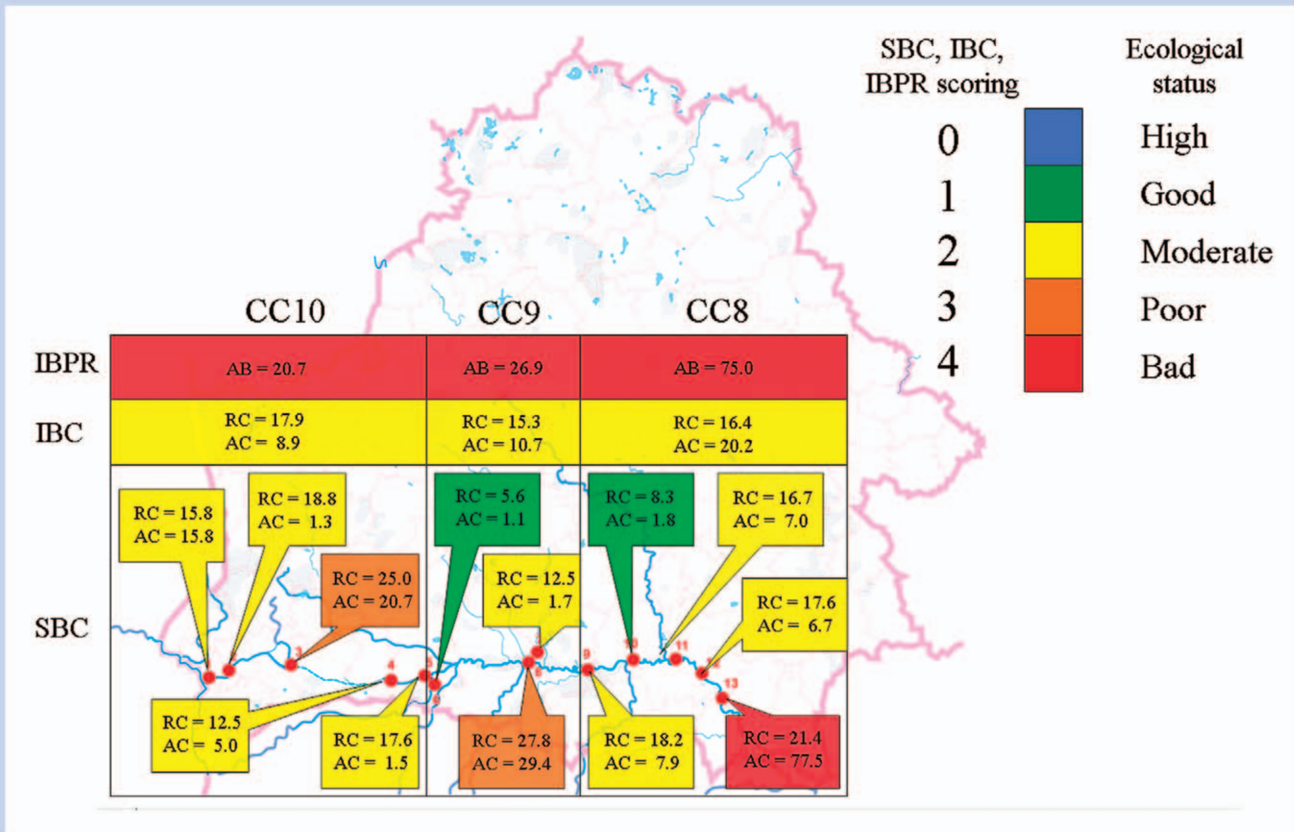

Figure 4. Assessment of site-specific biological contamination (SBC), integrated biological contamination (IBC), and integrated biological pollution risk (IBPR) indices in 3 assessment units: Lower Pripyat River (CC8), middle Pripyat River (CC9) and Pripyat–Bug Canal (CC10), Belarus (rationale for ranking of SBC, IBC, and IBPR indices for assessment of ecological status of specific locations and assessment units is provided in the text). Numbers in boxes, in %, indicate ordinal richness contamination (RC), abundance contamination (AC), and maximal relative abundance of black-list species (AB) as estimate of the IBPR index.

48 species with 9, 15, and 24 organisms belonging to the grey, white, and black lists, respectively (Table 6).

This ranking of alien species, according to their invasiveness along with information on the relative abundance of invasive alien species in specific locations of the assessment unit, can be further used for estimation of the integrated biological pollution risk (IBPR) index. Where no alien species are present in the assessment unit, the IBPR index = 0 (reference conditions, or "high" ecological status sensu the Common Implementation Strategy of the European Commission Water Framework Directive). If alien species from the grey or white list are present in relatively low abundances (less than 20% of total abundance of alien and native species in the community), then the IBPR index = 1 (this may correspond to "good" ecological status of a water body). Relatively high abundance of alien species (exceeding 20%) from the grey or white list corresponds to an IBPR index of 2 ("moderate" ecological status). Where alien species from the black list are present in the community, the IBPR index can be estimated as 3 in a situation with relatively low abundance of these species ("poor" ecological status) or 4 in a situation with relatively high abundance of black-list species ("bad" ecological status) with the same 20% threshold for "low" and "high" relative abundances. Compared with the SBC and IBC indices, the ecological status estimates based on the IBPR indices generally are lower, as black-list species are found at all studied locations in selected assessment units, and the presence (even within 1 location of an assessment unit) of a "high" relative abundance of these species will attribute the highest value of IBPR index to this assessment unit (Figure 4 and Table 4).

Grey, white, and black lists of invasive species, species-specific, and IBPR indices can be used as DPSIR Environmental indicators of "impacts" (Figure 1). Also, the black list can be used as the European Environmental Agency SEBI 2010 indicator "invasive alien species in Europe," element "worst invasive alien species threatening biodiversity in Europe" (European Environment Agency 2007). In addition, the IBP index can be recommended for the risk-based estimation of ecological status of water bodies considering alien species introductions as a specific pressure. The IBPR-based estimates of ecological status of assessment units within European inland waterways are generally lower than the estimates based on the IBC indices, and the ecological status of most of these ecosystems with regard to biopollution can be estimated as "bad" (Figure 4 and Table 4).

DEVELOPMENT OF AN ONLINE RISK ASSESSMENT TOOLKIT WITH AN EARLY WARNING SERVICE FOR REPORTING OF ENVIRONMENTAL INDICATORS AND RECOMMENDATIONS FOR RISK MANAGEMENT TO STAKEHOLDERS—DPSIR "RESPONSES"

Development of an online Risk Assessment Toolkit (Figure 1) for user-friendly risk assessment and risk communication purposes is a part of the EC FP6 Integrated Project *ALARM* Description of Work (WP 5.2). The component of the Risk Assessment Toolkit relevant to nonnative species introductions via European inland waterways will include risk assess-

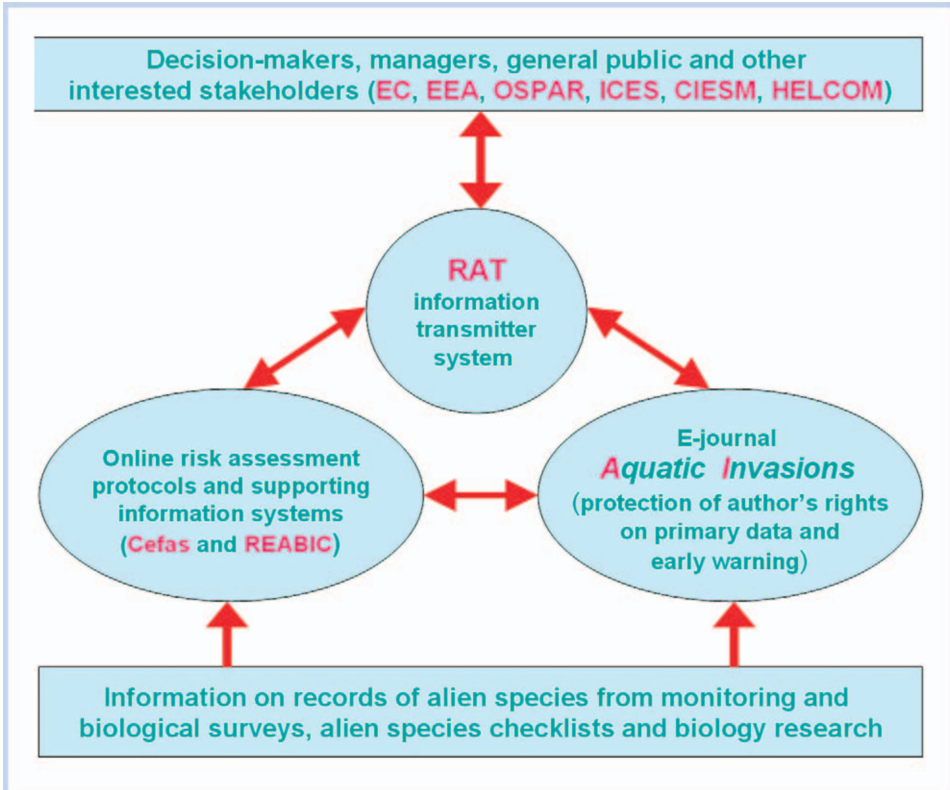

Figure 5. Conceptual structure of the online Risk Assessment Toolkit (RAT) for aquatic alien species. EC = European Commission (http://ec.europa.eu), EEA = European Environment Agency (www.eea.europa.eu), CIESM = International Commission for the Scientific Exploration of the Mediterranean Sea (www.ciesm.org), OSPAR = OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic (www.ospar.org), HELCOM = Baltic Marine Environment Protection Commission (www.helcom.fi), Cefas = Cefas Risks and impacts of nonnative species decision support tools (www.cefas.co.uk/4200.aspx), REABIC = Regional Euro-Asian Biological Invasions Centre information system (www.reabic.net).

ment protocols, supporting information systems, the electronic journal *Aquatic Invasions* (www.aquaticinvasions.ru), and transmitting information to the level of end users (Figure 5). *Aquatic Invasions* is serving as an instrument for protecting authors' rights on alien species information stored in the database and as an early warning tool (Panov and Gollasch 2006). Also, the aquatic part of the Risk Assessment Toolkit will be serving as the decision-support system, the online transmitter of essential information needed for decision making (Figure 1), and will provide links to nonnative species risk assessment protocols and databases developed in frameworks of other projects via the Regional Euro-Asian Biological Invasions Centre Web portal (www.reabic.net). For instance, the risk assessment protocols for aquaculture are currently under development in the Sixth European Framework Programme (FP6) IMPASSE project (www.hull.ac.uk/hifi/IMPASSE).

In addition, the Risk Assessment Toolkit will provide links to the developing "predictive" risk assessment tools aimed at identifying potential invaders such as those developed for freshwater fish, freshwater invertebrates, marine fish, marine invertebrates, and amphibia (Copp et al. 2005b; www.cefas.co.uk/4200.aspx). Although these tool kits are stand-alone packages, they are intended to be used within risk analysis frameworks. For example, FISK and its related tool kits for aquatic species have an integral (hazard identification) role in the GB nonnative species risk assessment framework (www.defra.gov.uk/wildlife-countryside/resprog/findings/non-native-risks/index.htm). FISK has been calibrated and is currently being tested in Belgium (Vandenbergh 2007), and these hazard identification tools will be an integral part of the risk analysis framework being developed by the FP6 IMPASSE project (www.hull.ac.uk/hifi/IMPASSE) for the EU regulation on the use of alien species in aquaculture. The various adaptations of the risk assessment tool kits for aquatic organisms are FISK—Freshwater Fish Invasiveness Scoring Kit, MFISK—Marine Fish Invasiveness Scoring Kit, MI-ISK—Marine Invertebrate Invasiveness Scoring Kit, FISK—Freshwater Invertebrate Invasiveness Scoring Kit, and AmphISK—Amphibian Invasiveness Scoring Kit (www.cefas.co.uk/4200.aspx).

CONCLUSIONS

The developed DPSIR environmental indicators for alien species ("drivers"—list of extreme-risk pathways for assessment units, list of high-risk pathways for assessment units, and list of high-risk donor areas for assessment units; "pressures"—biological contamination rate (BCR) and pathway-specific biological contamination rate (PBCR); "state"—biological contamination level (BCL) and the site-specific biological contamination index (SBC) and integrated biological contamination index (IBC); and "impacts"—species-specific biological pollution risk index (SBPR) and integrated biological pollution risk index (IBPR) and grey, white, and black lists of alien species; Figure 1) 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. The BCR and PBCR can be used as indicators of the effectiveness of this preventive management. In contrast, the management actions

Table 6. Listing of alien species for selected assessment units within European inland waterways (only benthic macroinvertebrates included). Numbers in cells for grey, white, and black lists indicate the species-specific biological pollution risk index (N/A = nonassessed). HRD = high risk for dispersal of the species, HRE = high risk for establishment, HRI = high risk of causing ecological and/or socioeconomic impacts

Higher taxon and species name	Assessment units	Grey list	White list	Black list	References
Hydrozoa					
Cordylophora caspia (Pallas, 1771)	NC5, CC7			3 (HRD, HRE, HRI)	Paavola et al. 2005
Entoprocta					
Urnatella gracilis (Leidy, 1851)	CC1, SC1			3 (HRD, HRE, HRI)	Paavola et al. 2005
Turbellaria					
Dugesia tigrina Girard	SC8	N/A			Present study
Oligochaeta					
Branchyura sowerbyi (Beddard,1892)	SC2, SC3, SC3a, SC3b		2 (HRD, HRE)		Paunović et al. 2005
Polychaeta					
Ficopomatus enigmaticus (Fauvel, 1923)	NC1, NC2		2 (HRD, HRE)		Panov et al. 2007
Hypania invalida (Grube, 1860)	CC4, CC5, CC6, CC7, SC3, SC3a, SC3b, SC4, SC8		2 (HRD, HRE)		Bij de Vaate et al. 2002; Karatayev et al. 2008
Hypaniola kowalewskii (Grimm, 1877)	CC4, CC5, CC7		2 (HRD, HRE)		Alexandrov et al. 2007
Hirudinea					
Cystobranchus fasciatus (Kollar, 1842)	CC5		2 (HRD, HRE)		Alexandrov et al. 2007
Archaeobdella esmonti (Grimm, 1876)	NC3, CC5, CC7		2 (HRD, HRE)		Alexandrov et al. 2007
Gastropoda					
Lithoglyphus naticoides (C. Pfeiffer, 1828)	NC2, NC3, CC8, CC9, CC10, CC11, CC12, CC15, CC16, SC2, SC3, SC3a, SC3b, SC4, SC8			3 (HRD, HRE, HRI)	Bij de Vaate et al. 2002; Karatayev et al. 2008
Potamopyrgus antipodarum (J.E. Gray, 1853)	NC1, CC1, CC14, CC14a, CC15, CC16, SC1, SC3, SC8			3 (HRD, HRE, HRI)	Present study
Theodoxus danubialis (C. Pfeiffer, 1828)	SC3, SC3a			3 (HRD, HRE, HRI)	Present study
Physella acuta (Draparnaud 1805)	SC1, SC8		2 (HRD, HRE)		Son 2007
Physella integra (Haldeman, 1841)	SC1		2 (HRD, HRE)		Son 2007
Ferrissia fragilis (Tryon, 1863)= *Ferrissia wautieri* (Mirolli, 1960)	CC2, CC9, CC10, SC1, SC8		2 (HRD, HRE)		Son 2007

Table 6. Continued

Higher taxon and species name	Assessment units	Grey list	White list	Black list	References
Bivalvia					
Dreissena polymorpha (Pallas, 1771)	CC9, CC10, CC12, CC14, CC14a, CC15, CC16, SC2, SC3, SC3a, SC8			3 (HRD, HRE, HRI)	Bij de Vaate et al. 2002; Karatayev et al. 2008
Dreissena rostriformis bugensis (Andrusov, 1897)	SC1, SC2, CC3, CC4, CC5, CC6, CC7			3 (HRD, HRE, HRI)	Son 2007
Hypanis colorata (Eichwald, 1829)	CC4, CC5		2 (HRD, HRE)		Son 2007
Corbicula fluminalis (O.F. Müller, 1774)	CC16, SC1, SC3, SC3a, SC3b, SC8			3 (HRD, HRE, HRI)	Haas et al. 2002
Corbicula fluminea (O.F. Müller, 1774)	CC16, SC1, SC2, SC3, SC3a, SC3b, SC8			3 (HRD, HRE, HRI)	McMahon 2000; Paunović et al. 2007
Sinanodonta woodiana (Lea, 1834)	SC3, SC3a, SC3b			3 (HRD, HRE, HRI)	Paunović et al. 2006
Mya arenaria (Linnaeus, 1758)	SC1, CC1, CC15			3 (HRD, HRE, HRI)	Present study
Sessilia					
Balanus improvisus (Darwin, 1854)	NC2, CC15, CC16			3 (HRD, HRE, HRI)	Alexandrov et al. 2007; Present study
Isopoda					
Proasellus meridianus (Racovitza, 1919A)	SC8	N/A			Present study
Proasellus coxalis (Dollfus, 1892)	SC8	N/A			Present study
Jaera istri (Veuille, 1979)	SC3, SC3b, SC4, SC8		1–2 (HRD, HRE)		Bij de Vaate et al. 2002
Jaera sarsi (Valkanov, 1936)	CC4, CC5, CC7	N/A			Alexandrov et al. 2007
Amphipoda					
Chelicorophium curvispinum (Sars, 1895)	CC8, CC9, CC10, CC11, CC12, CC14, CC14a, CC15, CC16, SC2, SC3, SC3a, SC3b, SC8			3 (HRD, HRE, HRI)	Van Den Brink et al. 1993; Bij de Vaate et al. 2002
Corophium robustum (Sars, 1895)	SC3, SC3a, SC8	N/A			Present study
Chaetogammarus warpachowskyi (Sars, 1894)	CC4, CC6, CC7, CC11, CC12		2 (HRD, HRE)		Present study
Chaetogammarus ischnus (Stebbing, 1899)	CC8, CC9, CC14, CC14a, CC15, CC16, SC2, SC3, SC4, SC8			3 (HRD, HRE, HRI)	Bij de Vaate et al. 2002

Table 6. Continued

Higher taxon and species name	Assessment units	Grey list	White list	Black list	References
Gammarus roeselii (Gervais, 1835)	CC14, CC16	N/A			Present study
Gammarus tigrinus (Sexton, 1939)	CC14, CC15, CC16, SC8			3 (HRD, HRE, HRI)	Jazdzewski et al. 2004
Gmelinoides fasciatus (Stebbing, 1899)	NC4, NC5			3 (HRD, HRE, HRI)	Panov and Berezina 2002
Pontogammarus robustoides (G.O. Sars, 1894)	NC5, CC11, CC12, CC14, CC14a, CC15, CC16			3 (HRD, HRE, HRI)	Arbačiauskas and Gumuliauskaitė 2007
Pontogammarus maeoticus (Sowinsky,1894)	CC4, CC5, CC7			3 (HRD, HRE, HRI)	Alexandrov et al. 2007; Present study
Dikerogammarus haemobaphes (Eichwald,1841)	CC5, CC6, CC7, CC8, CC9, CC10, CC14, CC14a, CC15, CC16, SC2, SC3, SC4, SC8, SC3b		2 (HRD, HRE)		Bij de Vaate et al. 2002; Present study
Dikerogammarus villosus (Sowinsky, 1894)	CC5, CC6, CC7, CC8, CC9, CC14, CC14a, CC16, SC3, SC3a, SC3b, SC4, SC8			3 (HRD, HRE, HRI)	Bij de Vaate et al. 2002
Obesogammarus obesus (Sars, 1894)	CC5, CC6, CC7, SC4	N/A			Present study
Obesogammarus crassus (Sars, 1894)	CC5, CC6, CC7, CC8, CC12, CC15, CC16		2 (HRD, HRE)		Konopacka 2003
Mysida					
Paramysis lacustris (Czerniavsky, 1882)	NC1, CC12	N/A			Present study
Limnomysis benedeni (Czerniavsky, 1882)	NC1, CC8, CC9, CC12, SC2, SC3, SC3b, SC8		2 (HRD, HRE)		Bij de Vaate et al. 2002; Present study
Hemimysis anomala (G.O. Sars, 1907)	SC2, SC3, SC8			3 (HRD, HRE, HRI)	Bij de Vaate et al. 2002; Ketelaars et al. 1999
Katamysis warpachowskyi (G.O. Sars, 1893)	CC4			3 (HRD, HRE, HRI)	Wittmann 2005
Decapoda					
Orconectes limosus (Rafinesque, 1817)	CC11, CC12, CC14, CC14a, CC15, CC16, SC3, SC3b, SC8			3 (HRD, HRE, HRI)	Westman 2002
Athyaephyra desmarestii (Millet, 1831)	CC16, SC8	N/A			Present study

Table 6. Continued

Higher taxon and species name	Assessment units	Grey list	White list	Black list	References
Rhithropanopeus harrisii (Gould, 1841)	NC1, NC2, CC1, CC15, SC1, SC8			3 (HRD, HRE, HRI)	Makarov 2004
Eriocheir sinensis (H. Milne-Edwards, 1853)	NC1, NC2, NC3, NC5, NC6, CC1, CC4, CC14, CC15, CC16, NC4, SC1, SC3, SC8			3 (HRD, HRE, HRI)	Ojaveer et al. 2007

for "state" and "impacts" may involve the control and eradication of established species from the black list (according to provisions of the Convention on Biological Diversity). The site-specific and IBC indices along with the IBPR index 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" according to the Common Implementation Strategy of the Water Framework Directive for assessment of ecological status of aquatic ecosystems: the SBC index, the IBC index, and, specifically, based on precautionary approach, the IBPR index.

Protocols for identification of future invaders and assessments of their risks (Copp et al. 2005b; Panov et al. 2007; Baker et al. 2008; Gozlan 2008) as well as for listing high-risk donor areas for the assessment unit (resulting from the coupling of predictive environmental match risk assessment with analysis of invasion routes associated with shipping, canals, leisure activities, hydromorphological alterations of water bodies, and some other pathways of nonnative species introductions) all require further study and can be developed subsequent to the completion of work on the fully operational risk assessment tool kits.

The developing online Risk Assessment Toolkit for aquatic invasive alien species will include 3 main interlinked components: The online risk assessment protocols, the early warning system based on the *Aquatic Invasions* e-journal, and the invasive alien species information transmitter for risk communication to end users.

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