

**Research article****Non-native fishes of Belarus: diversity, distribution, and risk classification using the Fish Invasiveness Screening Kit (FISK)**Sergey E. Mastitsky<sup>1,2\*</sup>, Alexander Y. Karatayev<sup>2</sup>, Lyubov E. Burlakova<sup>2</sup> and Boris V. Adamovich<sup>3</sup><sup>1</sup>General Ecology Department, Biology Faculty, Belarusian State University, 4 Nezalezhnasti Avenue, Minsk, 220030 Belarus<sup>2</sup>Great Lakes Center of the Research Foundation of SUNY, 261 Science Building, Buffalo State College, 1300 Elmwood Avenue, Buffalo, NY 14222, USA<sup>3</sup>Republican Unitary Enterprise 'Institute of Fish Industry', 22 Stebeneva Street, Minsk, 220024 BelarusE-mail: [aliensinbelarus@gmail.com](mailto:aliensinbelarus@gmail.com) (SEM), [karataay@buffalostate.edu](mailto:karataay@buffalostate.edu) (AYK), [burlakle@buffalostate.edu](mailto:burlakle@buffalostate.edu) (LEB), [borya\\_mail@mail.ru](mailto:borya_mail@mail.ru) (BVA)

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**Abstract**

As of the end of 2008, 25 species of non-native fishes have been documented in the Republic of Belarus. Of these, 17 (68%) species were deliberately introduced for aquaculture, six (24%) species invaded from the adjacent territories by natural dispersal, and two (8%) species were likely introduced accidentally. During the 20th century, the number of non-native fishes in Belarus increased exponentially, resulting in significant shifts in taxonomic composition of the country's ichthyofauna. For the first time, we assessed the invasive potential of the introduced fishes by applying a uniform protocol, the Fish Invasiveness Screening Kit (FISK). Based on the total FISK scores, all the non-native fishes in Belarus were classified into two groups: high and medium risk of becoming invasive. In terms of the economic sectors at risk ('aquacultural/fisheries', 'environmental', and 'nuisance'), all species were classified into three distinct groups. The highest risk to all of these sectors was posed by the brown bullhead *Ameiurus nebulosus* Le Sueur, 1819, gibel carp *Carassius gibelio* (Bloch, 1782), round goby *Neogobius melanostomus* (Pallas, 1814), Amur sleeper *Perccottus glenii* Dybowski, 1877, and topmouth gudgeon *Pseudorasbora parva* (Temminck & Schlegel, 1846). The two risk categories identified in the present study can be used in prioritizing the resources for the management of non-native fish species of Belarus and in countries with similar environmental conditions.

**Key words:** invasiveness potential, risk analysis, vector of introduction**Introduction**

The Republic of Belarus is currently subject to introductions of many non-native species (Semenchenko and Pugachevskiy 2006; Karatayev et al. 2008), including fishes (Rizevsky and Ermolaeva 2002; Rizevsky 2004; Semenchenko and Pugachevskiy 2006; Rizevsky et al. 2007; Mastitsky and Veres 2008). The geographic position of Belarus on the continental divide between the Black Sea and Baltic Sea basins as well as the country's ongoing development of a market economy are expected to promote new invasions (Semenchenko and Pugachevskiy 2006; Karatayev et al. 2008). In addition, the translocations of non-native fishes that have already been introduced in Belarus are on the official agenda of the government, which aims at increasing the volume of fish production (The Republican Programme 2006). Despite the growing diversity and distribution of non-native

fishes in Belarus, relevant studies documenting and quantifying their negative impacts on the environment and economy are scarce. At the same time, the identification of potentially harmful non-native fishes is a critical step in prioritizing the increasingly limited managerial resources. The main aim of the present study was to identify which of the existing non-native fishes of Belarus are potentially invasive. This is intended to assist environmental managers in deciding which of the existing non-native species would be suitable for use in aquaculture without posing a substantial risk to the environment. To achieve this aim, we first reviewed current knowledge on the diversity and distribution of non-native fishes of Belarus, and then classified the list of existing non-native species according to their invasiveness potential as defined using scores produced by FISK, the Fish Invasiveness Screening Kit (Copp et al. 2005b, 2009). Species that are found to pose particularly high risks to

Belarus should be subjected to subsequent full risk assessment (Copp et al. 2005b).

## Material and methods

### Study area

Belarus has a territory of approximately 200 000 km<sup>2</sup>, which is characterised by a moderate continental climate. The highest mean monthly air temperatures and precipitation are typically observed from June to September, varying among different regions from 15–16°C and 280–310 mm, respectively (State Water Cadastre 2004). Inland standing waters are normally frozen from the late November or early December until March or early April (State Water Cadastre 2002). Based on the number of days with daily air temperature >15°C and the absence of Zone I, the territory of Belarus can be divided into two major fish-farming zones (Konchits et al. 2005): Zone II comprises ≈75% of the territory (76–90 days) and the rest falls under Zone III (91–105 days), and Zone IV, the latter represented by one large-scale warm-water fishery ‘Selets’ (Figure 1).

The territory of Belarus includes the continental divide between the Black Sea and Baltic Sea basins. About 57% of the territory drains into the Black Sea through the rivers Dnieper and Pripyat, whereas the remaining 43% drains into the Baltic Sea through the rivers Neman, Zapadnaya Dvina, Narev, Zapadniy Bug, and Lovat (Blue treasure of Belarus 2007). In the late 1700s and early 1800s, three canals were constructed in Belarus to connect the River Dnieper (Black Sea basin) with the rivers of the Baltic Sea. These shipping corridors also facilitated the exchange of aquatic species between the Ponto-Caspian and Baltic biogeographical regions (Karatayev et al. 2008). Only the Dnieper-Bug Canal (part of the ‘central European invasion corridor’; Bij de Vaate et al. 2002) is still in operation, whereas the other two canals were abandoned in the first half of the 20th century (Karatayev et al. 2008).

There are 1072 lakes of >0.1 km<sup>2</sup>, most of these are of glacial origin and situated in northern part of Belarus within the drainage basin of the River Zapadnaya Dvina. The river valleys of Belarus, in particular those of the rivers Dnieper, Pripyat and Sozh (Black Sea drainage), also contain >1000 floodplain lakes, which are typically very small (Kurlovich and Serafimovich 1981).



**Figure 1.** Map of Belarus with the fish-farming zones indicated.

### Screening for potentially invasive fish species

The list of non-native fishes of Belarus examined in this study was compiled from reports published between 1999 and 2008 (Gulyugin and Kunitskiy 1999; Rizevsky and Ermolaeva 2002; Kunitskiy 2001; Zhukov 2002; Konchits et al. 2003a,b; Rizevsky 2004; Dudarenko 2005; Mamedov 2006; Kostousov 2007; Rizevsky et al. 2007). The taxonomy used in the present paper follows that in FishBase (<http://www.fishbase.org>). We used the biogeographical approach in defining a species as non-native (alien, exotic). A species (sub-species, variety or race) is considered non-native if it has not previously occurred in a geo-graphical area because of a certain barrier, e.g. unsuitable climatic or hydrological regime, absence of hydrological links between drainage basins, etc. Overcoming a biogeographical barrier is usually mediated by humans, whether deliberately or unintentionally (Copp et al. 2005a).

Non-native species were considered invasive if they ‘...spread, with or without the aid of humans, in natural or semi-natural habitats, producing a significant change in composition, structure, or ecosystem processes, or cause severe economic losses to human activities’

(Copp et al. 2005a). To assess the invasiveness potential of fishes alien to Belarusian waters, we used the Fish Invasiveness Screening Kit (FISK), a tool adapted for freshwater fishes by Copp et al. (2005b, 2009) from the Weed Risk Assessment scheme (Pheloung et al. 1999). FISK is a semi-quantitative scoring system, based in Excel® with Visual Basic® driven menus, composed of 49 questions on biogeography, invasion history, biology and ecology of a species under evaluation. With each response, the assessor must indicate his/her level of confidence, ranging from 4 (=highly certain) to 1 (=very uncertain). We calculated the mean certainty across all 49 questions to estimate the overall certainty for each of the 25 species tested, and the percentage of questions answered for a given species. The assessments of all species had initially been conducted by one of the authors (SEM) and then were discussed with other authors to come up with joint decisions. Consistent with Copp et al. (2005b), the FISK assessments were undertaken in conjunction with thorough literature and web-based searches, which included: primary papers in scientific journals available through the Web of Science, ScienceDirect, SpringerLink, and JSTOR; books and 'gray' literature; FishBase (<http://www.fishbase.org>); FAO (<http://www.fao.org>); Pesticide Action Network Pesticides Database (<http://www.pesticideinfo.org>), and regional exotic species databases.

The assessments were carried out using the calibrated version of FISK, which is freely available for download (v1.19, <http://www.cefas.co.uk/4200.aspx>). The critical thresholds for categorizing fish species as low, medium or high risk of being invasive have been calibrated by Copp et al. (2009), whereby scores <1 indicate low risk, scores of 1 to 18.9 indicate medium risk, and scores of ≥19 (to a maximum of 54) indicate high risk. These threshold values were used in the present study.

Although the total FISK score *per se* provides important information for developing management strategies for non-native fishes, it does not discriminate among species in relation to their potential effects. However, all the FISK questions are automatically grouped into several categories, including those that reflect the economic sectors that are most likely to be affected, i.e. 'aquacultural/fisheries' (8 questions), 'environmental' (8 questions), 'nuisance' (n = 2), and 'combined' (31 questions), with the scores assigned to the category 'combined'

shared by the categories 'aquacultural/fisheries' and 'environmental' (Copp et al. 2005b). We used the summed scores for the categories 'aquacultural/fisheries', 'environmental' and 'nuisance' to reveal the groups of non-native fishes similar in their potential effects. This classification was facilitated by running the hierarchical cluster analysis based on Euclidian distance as the similarity measure and the group mean as clustering algorithm. Statistical significance of dissimilarity among the found clusters was tested by analysis of similarity (ANOSIM; 1000 permutations) at the significance level of 0.05 (Clarke and Warwick 2001). Both the cluster analysis and ANOSIM were performed with the help of PRIMER 6 software (PRIMER-E Ltd, 2006).

## Results

### *Diversity and reproductive status of non-native fishes*

As of the end of 2008, 25 non-native fishes representing six orders and eight families were reported in Belarus (Table 1). Only three species had been recorded before 1900; however, their number increased exponentially over the 20th century (Table 1; Figure 2). Seventeen alien fish species (68%), mainly originating from Asia or North America, were introduced intentionally for aquaculture, six species (24%) invaded the territory of Belarus from the neighboring countries by natural dispersal, and two species (8%) were likely introduced accidentally (Table 1).

Twelve species (48%) have established self-sustaining populations, including the brown bullhead *Ameiurus nebulosus* Le Sueur, 1819, gibel carp *Carassius gibelio* (Bloch, 1782), common carp *Cyprinus carpio* (Linnaeus, 1758), Amur sazan *Cyprinus carpio haematopterus* Temminck et Schlegel, 1846, threespine stickleback *Gasterosteus aculeatus* Linnaeus, 1758, monkey goby *Neogobius fluviatilis* (Pallas, 1814), racer goby *Neogobius gymnotrachelus* (Kessler, 1857), round goby *Neogobius melanostomus* (Pallas, 1814), Amur sleeper *Perccottus glenii* Dybowski, 1877, tubenose goby *Proterorhinus marmoratus* (Pallas, 1814), topmouth gudgeon *Pseudorasbora parva* (Temminck & Schlegel, 1846), and ninespine stickleback *Pungitius pungitius* (Linnaeus, 1758). However, the current geographical distribution of these established species is not

**Table 1.** Non-native fishes documented in Belarus by the end of 2008 (except the hybrids and species with uncertain status). Suspected vectors of introduction: AQ – aquaculture, NS – natural spread from the adjacent territories, UN – unintentional, OR – ornamental. Donor area: HA – Holarctic, NA – North America, PC – Ponto-Caspian, AS – South-Eastern Asia.

Species	Donor area	Date of introduction or first record	Vector of introduction	Distribution	Percent of FISK questions answered
<i>Acipenser ruthenus</i>	PC	1948 <sup>19</sup>	AQ, NS	Naturally occurs in the River Dnieper basin, though extremely rarely <sup>11,14</sup> ; introduced into the River Zapadnaya Dvina <sup>14</sup> ; fish farms <sup>14</sup>	91.8
<i>Ameiurus nebulosus</i>	NA	1935 <sup>13</sup>	AQ	Zapadnyi Bug and Pripyat river basins <sup>13,25,11</sup>	91.8
<i>Aristichthys nobilis</i>	AS	1965 <sup>25</sup>	AQ	Fish farms, several natural lakes <sup>25</sup>	89.8
<i>Carassius gibelio</i>	AS	1864 <sup>24</sup>	AQ	Basins of all large rivers <sup>25,1</sup>	91.8
<i>Coregonus lavaretus maraenoides</i>	HA	1926 <sup>7</sup>	AQ	A few natural waterbodies within the Zapadnaya Dvina and Neman river basins <sup>25</sup>	85.7
<i>Coregonus peled</i>	HA	1957 <sup>21</sup>	AQ	Fish farms; natural waterbodies, especially in the northern part of Belarus <sup>21,10,25</sup>	91.8
<i>Ctenopharyngodon idella</i>	AS	1965 <sup>25</sup>	AQ	Fish farms; several natural waterbodies <sup>25</sup>	89.8
<i>Cyprinus carpio</i>	PC	Late 16th century <sup>26</sup>	AQ, NS	Fish farms and natural waterbodies all over the country <sup>26,1</sup>	91.8
<i>Cyprinus carpio haematopterus</i>	AS	1948 <sup>3</sup>	AQ	Fish farms and natural waterbodies all over the country <sup>25</sup>	85.7
<i>Gasterosteus aculeatus</i>	HA	Second half of the 20th century <sup>27</sup>	NS	Naturally occurs in rivers of the Baltic Sea basin; penetrated into the River Dnieper basin <sup>25,11,1</sup>	85.7
<i>Hypophthalmichthys molitrix</i>	AS	1965 <sup>25</sup>	AQ	Fish farms; several natural waterbodies <sup>25</sup>	89.8
<i>Ictalurus punctatus</i>	NA	1979 <sup>22</sup>	AQ	Lake Beloe (cooling reservoir for the Berezovskaya Power Plant); fish farms <sup>22,11</sup>	89.8
<i>Ictiobus bubalus</i>	NA	1976 <sup>8</sup>	AQ	Fish farms <sup>8</sup>	91.8
<i>Ictiobus cyprinellus</i>	NA	1976 <sup>8</sup>	AQ	Fish farms <sup>8</sup>	89.8
<i>Ictiobus niger</i>	NA	1976 <sup>8</sup>	AQ	Fish farms <sup>8</sup>	89.8
<i>Mylopharyngodon piceus</i>	AS	1977 <sup>25</sup>	AQ	Fish farms <sup>25,4</sup>	89.8
<i>Neogobius fluviatilis</i>	PC	1937 <sup>23</sup>	NS	Dnieper and Zapadnyi Bug river basins <sup>23,6,16,1</sup>	87.8
<i>Neogobius gymnotrachelus</i>	PC	1998 <sup>6</sup>	NS	Dnieper and Zapadnyi Bug River basins <sup>6,16</sup>	81.6
<i>Neogobius melanostomus</i>	PC	1998 <sup>6</sup>	NS	Dnieper River basin <sup>6,16</sup>	91.8
<i>Oncorhynchus mykiss</i>	NA	1956 <sup>2</sup>	AQ	Fish farms <sup>2,25</sup> , streams and rivers adjacent to some of the fish farms <sup>15</sup>	89.8
<i>Perccottus glenii</i>	AS	1972 <sup>17</sup>	UN, OR?	Dnieper River and Zapadaya Dvina river basins <sup>17,11,20</sup>	91.8
<i>Polyodon spathula</i>	NA	2001 <sup>9</sup>	AQ	Fish farms <sup>9</sup>	89.8
<i>Proterorhinus marmoratus</i>	PC	2007 <sup>18</sup>	NS	River Pripyat <sup>18</sup>	87.8
<i>Pseudorasbora parva</i>	AS	1996 <sup>12</sup>	UN	River Ptich <sup>12</sup>	91.8
<i>Pungitius pungitius</i>	HA	1906 <sup>5</sup>	NS	Neman and Pripyat river basins <sup>25,11</sup>	85.7

<sup>1</sup>Adamovich et al. (2009); <sup>2</sup>Borovik (1969); <sup>3</sup>Chesalin (1958); <sup>4</sup>Dudarenko et al. (2005); <sup>5</sup>Gratsianov (1907), cited after Semenchenko et al. (2009); <sup>6</sup>Gulyugin and Kunitskiy (1999); <sup>7</sup>Kokhnenko and Borovik (1973); <sup>8</sup>Konchits (2003a); <sup>9</sup>Konchits et al. (2003b); <sup>10</sup>Kostyuchenko (1972); <sup>11</sup>Kunitskiy (2001); <sup>12</sup>Kunitskiy and Plyuta (1999); <sup>13</sup>Makushok (1951); <sup>14</sup>Mamedov (2006); <sup>15</sup>Rizevsky (2004); <sup>16</sup>Rizevsky and Ermolaeva (2002); <sup>17</sup>Rizevsky et al. (1999); <sup>18</sup>Rizevsky et al. (2007); <sup>19</sup>Schetinina (1960); <sup>20</sup>Semenchenko and Pugachevskiy (2006); <sup>21</sup>Shteinfeld (1958); <sup>22</sup>Shumak and Mischenko (1989); <sup>23</sup>Vorontsov (1937); <sup>24</sup>Zelenskiy (1864), cited after Semenchenko et al. (2009); <sup>25</sup>Zhukov (1988); <sup>26</sup>Zhukov (1994); <sup>27</sup>Zhukov et al. (1986)

uniform. For example, gibel carp, common carp, and Amur sazan occur in nearly all major river basins of Belarus, whereas the distribution of Ponto-Caspian gobies is restricted to the Dnieper and Pripyat river basins in the southern part of the country (Table 1).

Five species (20%) cannot reproduce under the climatic and hydrological conditions of Belarus: bighead carp *Aristichthys nobilis* (Richardson, 1845), grass carp *Ctenopharyngo-*

*don idella* (Valenciennes, 1844), silver carp *Hypophthalmichthys molitrix* (Valenciennes, 1844), black carp *Mylopharyngodon piceus* (Richardson, 1846), and rainbow trout *Oncorhynchus mykiss* (Walbaum, 1792). These species occur mainly in the ponds of fish farms and/or in a few stocked natural waterbodies (Table 1). Channel catfish *Ictalurus punctatus* (Rafinesque, 1818) is also unable to reproduce in Belarus under natural conditions; however, this

species has established a self-sustaining population in the warmer conditions of Lake Beloe, which serves as a power plant cooling reservoir.

The other seven species are able to reproduce but currently either do not occur in open waters: the smallmouth buffalo *Ictiobus bubalus* (Rafinesque, 1818), bigmouth buffalo *I. cyprinellus* (Valenciennes, 1844), black buffalo *I. niger* (Rafinesque, 1819), and paddlefish *Polyodon spathula* (Walbaum, 1972) or have reached rather limited distribution and abundance: the sterlet *Acipenser ruthenus* (Linnaeus, 1758), peled *Coregonus peled* (Gmelin, 1789), and peipsi whitefish *Coregonus lavaretus maraenoides* Berg, 1916.

### FISK analyses

Twelve of the 25 examined fish species received FISK scores  $\geq 19$  (scores between 19 and 37), and thus could be classified as species posing high risk of becoming invasive in Belarus (Figure 3). The remaining 13 species were classified as medium risk (scores from 3 to 18). The fraction of questions answered for each of the 25 assessment runs was high and did not vary substantially among species (Table 1). The mean certainty of responses to FISK questions was also high (Figure 4), varying among species from  $3.3 \pm 0.09$  to  $3.7 \pm 0.06$  ( $\pm$  SE). The five questions answered with the lowest certainty were related to dispersal and impacts of the tested species: Q45 – Any life stage likely to survive out of water transport? ( $2.9 \pm 0.07$ ); Q48: Does the species tolerate or benefit from the environmental disturbance? ( $2.9 \pm 0.13$ ); Q39: Are life stages likely to be dispersed as a contaminant of commodities? ( $3.0 \pm 0.08$ ); Q15: Does the species outcompete with native species? ( $3.0 \pm 0.12$ ); Q12: In the species naturalized range, are there impacts to rivers, lakes or amenity values? ( $3.0 \pm 0.15$ ).

Three distinct groups of fish species were revealed by cluster analysis, differing in the level of risk posed to the three sectors examined, i.e. ‘aquacultural/fisheries’, ‘environmental’ and ‘nuisance’ (Figure 5). For all of these categories, the level of risk was found to increase gradually from the group of species A to the group C (Figure 6). The greatest differences among groups were observed for the aquacultural/fisheries and environmental sectors, whereas the risk of becoming nuisance was similarly low in all of the fishes. In contrast to the levels of risk,

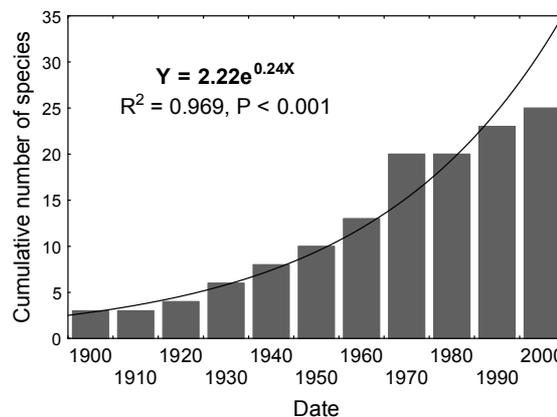


Figure 2. Cumulative curve of the number of non-native fish species in Belarus in the 20th century.

the number of species gradually decreased from 12 in group A (48% of all species examined) to 5 in group C (20%) (Figure 5). The five species found to pose the highest risk were brown bullhead, gibel carp, round goby, Amur sleeper, and topmouth gudgeon.

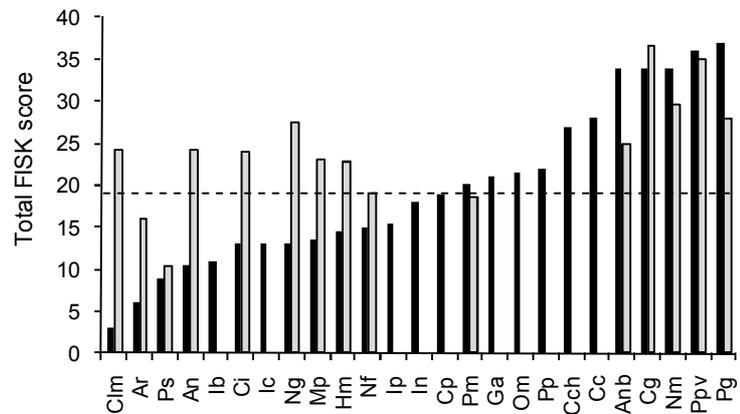
### Discussion

#### Introduction histories and diversity of non-native fishes

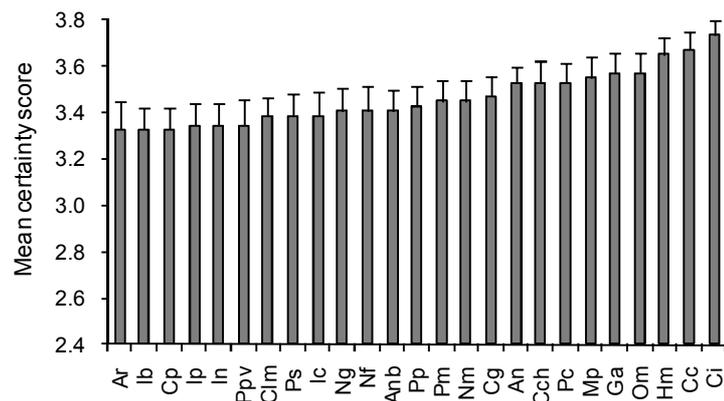
Of the 65 fish taxa recorded in Belarus by the end of 2008, 25 species (38%) are non-native. Twelve of these 25 species (48%) established self-sustaining populations in open waters (Table 1). Non-native species introductions have thus increased considerably the diversity of fishes in Belarus, with four of the eight introduced fish families (Catastomidae, Gobiidae, Ictaluridae, and Polyodontidae) being not previously recorded in the country. Similarly, Karatayev et al. (2008) found a very high proportion of non-native species in selected taxonomic groups of aquatic benthic invertebrates of Belarus, indicating that invaders can strongly shift the taxonomic structure of native benthic communities. Exponential growth of the number of non-native fishes revealed in our study (Figure 2) suggests that the rate of taxonomic shifts in native fish fauna of Belarus may increase accordingly.

The true number of non-native fish species currently present in the country is probably higher than reported here. For example, there have been oral reports in the mass media that

**Figure 3.** Non-native fishes of Belarus ranked by their total FISK scores obtained in this study (dark bars). The dashed horizontal line corresponds to the threshold score of 19 (see Copp et al. 2009). Grey bars represent the total FISK scores from the UK study (Copp et al. 2009). The abbreviations of species names are as follows: Clm – *C. l. maraenoides*; Ar – *A. ruthenus*; Ps – *P. spathula*; An – *A. nobilis*; Ib – *I. bubalus*; Ci – *C. idella*; Ic – *I. cyprinellus*; Ng – *N. gymnotrachelus*; Mp – *M. piceus*; Hm – *H. molitrix*; Nf – *N. fluviatilis*; Ip – *I. punctatus*; In – *I. niger*; Cp – *C. peled*; Pm – *P. marmoratus*; Ga – *G. aculeatus*; Om – *O. mykiss*; Pp – *P. pungitius*; Cch – *C. c. haematopterus*; Cc – *C. carpio*; Anb – *A. nebulosus*; Cg – *C. gibelio*; Nm – *N. melanostomus*; Ppv – *P. parva*; Pg – *P. glenii*.



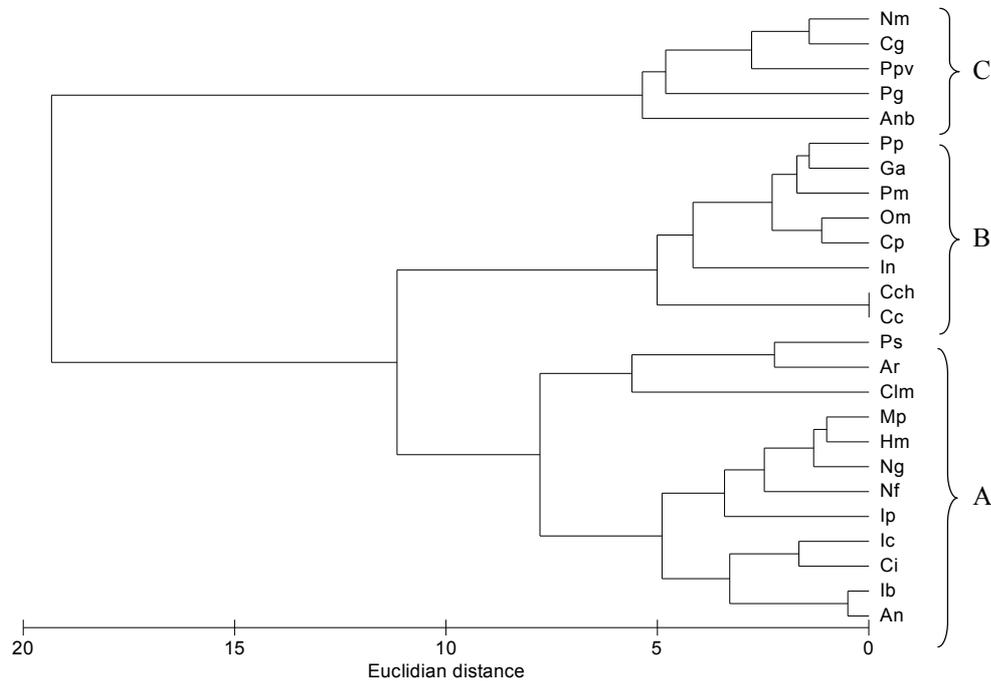
**Figure 4.** Non-native fishes of Belarus ranked by the mean ( $\pm$ SE) certainty of responses to the FISK questions. Maximum possible score of certainty is 4 (see Copp et al. 2005b). The abbreviations of species names correspond to those in Figure 3.



suggest the presence of the black-striped pipefish *Syngnathus abaster* Risso, 1827, southern nine-spined stickleback *Pungitius platygaster* (Kessler, 1859) (Belyavskaya 2008), spotted gar *Lepisosteus oculatus* Winchell, 1864 (ONT TV-channel 2007), the North African catfish *Clarias gariepinus* (Burchell, 1822), and several other species. Field surveys are needed to confirm the records of these species and to reveal the extent of their distribution, their abundance, and whether they can reproduce under natural conditions of Belarus. Another category of species with uncertain status includes those reared at private fish farms in closed recirculating water facilities, e.g., Russian sturgeon

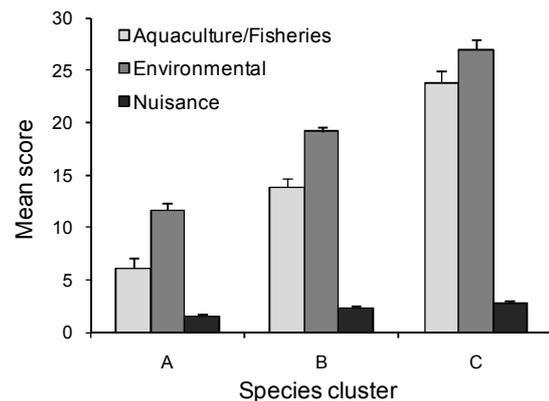
*Acipenser gueldenstaedtii* Brandt & Ratzeburg, 1833 and Siberian sturgeon *Acipenser baerii baerii* Brandt, 1869 (Mamedov 2006). Although the escape of such species into the wild is unlikely and has not been reported thus far, this possibility does exist and should be taken into account in future risk assessments.

Although the first intentional introductions of non-native fishes to Belarus took place at the end of 16th century (Zhukov 1994), an increased rate of introductions did not occur until after World War II (Kostyuchenko 1970; Kokhnenko and Borovik 1973; Figure 2), a pattern in line with that observed in most European countries (Casal 2006; Gozlan 2008; Turchini and De Silva



**Figure 5.** Clusterization of the non-native fish species of Belarus based on the risks they pose to the three economic sectors ('aquacultural/fisheries', 'environmental', and 'nuisance'). Three statistically distinct risk groups (denoted 'A' to 'C') were revealed at the Euclidian distance of 11.2 (ANOSIM,  $P < 0.001$ ). The abbreviations of species names correspond to those in Figure 3.

2008). Non-native fish introductions to Belarus have also followed the global trend, with the majority of species (17 species, or 68%) introduced deliberately for aquaculture, and most species originating from Asia or North America (Table 1). Aquaculture is the leading introduction vector for non-native fishes worldwide (Casal 2006; Gozlan 2008; Turchini and De Silva 2008), being linked to global population growth and the inability of capture-based fisheries to respond to the demand for fish proteins (Casal 2006). Thus, deliberate introductions and translocations may remain as the main vectors of spread of non-native fishes in Belarus. For example, the Belarus Republican Programme for Development of the Fish Industry (2006) implies a number of measures to increase the production of fish in the country, including a wider utilization of Asian phytophagous carps, common carp, gibel carp, and rainbow trout. The implementation of this programme can, therefore, result in multiple translocations of non-native fishes that are already present in the country.



**Figure 6.** The mean sector-related FISK scores in the three risk groups of fishes revealed by the cluster analysis (see Figure 5).

The second-most important pathway for non-native fish introductions to Belarus was by natural dispersal from adjacent countries (6 of 25 species), though this type of dispersal has largely been the indirect consequence of human activities. For example, the upstream ‘stepping stone’ (Havel et al. 2005) invasions of Belarusian river basins by four Ponto-Caspian gobies (Table 1) has been facilitated by the creation of river impoundments and canal construction; this now characterizes the man-made hydrologic connection between the rivers Dnieper (Black Sea basin) and Zapadniy Bug (Baltic Sea basin), which was used by these Ponto-Caspian gobies to expand westward through Belarus into Poland (Grabowska et al. 2008). The Ukraine has been and will likely remain the main donor to Belarus of non-native aquatic species that arrive by natural dispersal or unintentional introduction (Gulyugin and Kunitskiy 1999; Rizevsky 2004; Semenchenko and Pugachevskiy 2006; Rizevsky et al. 2007; Karatayev et al. 2008). Several years ago, Rizevsky and Ermolaeva (2002) predicted the arrival of three gobiid species from the Ukrainian territory: the bighead goby *Neogobius kessleri* (Günther, 1861), tubenose goby *Proterorhinus marmoratus*, and stellate tadpole-goby *Benthophilus stellatus* (Sauvage, 1874). The recent record of *P. marmoratus* in the Belarusian section of the River Pripyat (Rizevsky et al. 2007) proves their forecast correct and suggests that the other two gobiids may also be revealed in the near future.

Natural dispersal has also been used by threespine and ninespine sticklebacks, which are native to Belarusian rivers that drain into the Baltic Sea, to invade rivers of the Black Sea via a network of ameliorative canals (Zhukov et al. 1986; Zhukov 1988; Kunitskiy 2001; Adamovich et al. 2009). However, a morphological study of threespine stickleback (Kunitskiy 2001) has hypothesized an alternative pathway through the Belarusian section of the River Dnieper via upstream migration from the Ukraine, where this species widely occurs in the northern Black Sea region.

Two species introduced accidentally to Belarus (Table 1) are topmouth gudgeon and Amur sleeper. Topmouth gudgeon was first recorded in 1996 from the upper River Ptich (a tributary of the River Pripyat) and is thought to have escaped from a nearby fish-farm, where it was delivered with contaminated consignments of Asian carp (Kunitskiy and Plyuta 1999).

A similar means of introduction is hypothesized for Amur sleeper, though Amur sleeper is a popular ornamental species and may have also been deliberately released into the wild by aquarium keepers (Rizevsky et al. 1999; Kunitskiy 2001). Intentional release or escape of the species kept by aquarium keepers is an important pathway of alien fish introductions (e.g., Copp et al. 2005c; Rixon et al. 2005). The pet fish trade is popular in Belarus, with over 50 non-native fish species available in pet shops of the country (Lebedev 2004). This is likely to increase the risk of pet fish introductions; however, this pathway has not been assessed for Belarus and therefore requires investigation.

#### *Risk classifications*

Similar to Copp et al. (2009), who found 51% (34 species) and 48% (32 species) of 67 non-native fishes assessed for the United Kingdom to pose high risk and medium risk, respectively, we classified 48% and 52% of fishes as posing high and medium risks, respectively, of becoming invasive in Belarus (Figure 2). Also, many of the species assessed by Copp et al. (2009) received total FISK scores similar to those in the present study (Figure 3). Nevertheless, some of the fishes ranked as medium risk in our study were classified as high risk by Copp et al. (2009), who conducted dual independent assessments for each of the species. The most drastic differences between the studies were found for the peipsi whitefish, racer goby, bighead carp, grass carp, Chinese black carp, and silver carp (Figure 3). Between-assessor differences in risk category classification are not uncommon in FISK exercises (18% of all species examined by Copp et al. 2009), emphasizing the importance of repeated independent assessments for a species. Such assessments would greatly improve our classification, especially for the aforementioned six species.

The lowest certainty in our assessments was assigned to the five questions related to dispersal and impacts of the examined species. Not surprisingly, similar types of questions were answered with the lowest certainty by Copp et al. (2009). Major obstacles in prediction of non-native species impacts are the limited knowledge of biological traits and a scarcity or complete lack of information on the species’ quantitative effects. However, the high percentage of questions answered (Table 1) and the high overall certainty of responses (Figure 4) suggest

**Table 2.** Selected negative impacts of the 5 non-native fishes identified in this study as having the highest risk of becoming invasive.

Species	Impact category			
	Competition	Predation on native biota	Hosting of pathogenic diseases	Water quality reduction
<i>Ameiurus nebulosus</i>	Strongly competes for food with native fishes <sup>6</sup>	Adults almost exclusively predate on young individuals of native fishes <sup>12,6</sup> . Individuals smaller than 140 cm consume large amounts of chironomid larvae <sup>6</sup>	–	Increases turbidity <sup>17</sup>
<i>Carassius gibelio</i>	Strongly competes for food and space with native fishes, resulting in significantly declined abundances of the latter <sup>18,7</sup>	Consumes large amounts of native benthos and zooplankton <sup>1</sup>	Hosts several recognized parasites, including the ciliates <i>Ichthyophthirius multifiliis</i> and <i>Chilodonella cyprini</i> <sup>15</sup> , and the myxosporean <i>Hoferellus carassii</i> <sup>13</sup>	Increases turbidity due to the (i) sucking up sediments when feeding on benthos, and (ii) predation upon zooplankton, resulting in reduced grazing on phytoplankton <sup>5</sup>
<i>Neogobius melanostomus</i>	Severely affects the recruitment of native fishes through competition for food and aggressive displacement from spawning sites <sup>2,4</sup>	Voracious predation on native benthos, fish eggs, and fish larvae <sup>2,4</sup>	Hosts a diverse range of parasites, including such pathogenic organisms as the nematode <i>Raphidascaris acus</i> and acanthocephalan <i>Pomphorhynchus laevis</i> <sup>14</sup> . Supposedly, promotes the outbreaks of <i>Clostridium botulinum</i> in the Great Lakes <sup>4</sup>	–
<i>Percottus glenii</i>	Strongly competes for food with native fishes <sup>2</sup>	Voracious predation on native benthos and fish, which in combination with strong competition for food often results in local extirpations of native fishes and other aquatic species <sup>2,16</sup>	In its native range, has been reported as host of the oriental liver fluke <i>Clonorchis sinensis</i> , a pathogenic parasite of humans <sup>11</sup> . At least one exotic parasite has been introduced along with <i>P. glenii</i> to Europe, i.e. the tapeworm <i>Nippotaenia mogurndae</i> <sup>9</sup>	–
<i>Pseudorasbora parva</i>	Strongly competes for food with native fishes <sup>10,6</sup>	Consumes large amounts of native planktonic crustaceans and juveniles of valuable fish species <sup>19</sup> , and is known to be a facultative parasite <sup>20,21</sup>	Hosts a rosette-like intracellular eukaryotic parasite, which is a non-specific highly virulent parasite of native European fishes <sup>8</sup>	Feeds on larger species of zooplankton, resulting in an increase of the phytoplankton abundance, and further in facilitation of eutrophication <sup>19</sup>

<sup>1</sup>Balik et al. (2003); <sup>2</sup>Bogutskaya and Naseka (2002); <sup>3</sup>Bogutskaya et al. (2004); <sup>4</sup>Corkum et al. (2004); <sup>5</sup>Crivelli (1995); <sup>6</sup>Declerck et al. (2002); <sup>7</sup>Gaygusuz et al. (2007); <sup>8</sup>Gozlan et al. (2005); <sup>9</sup>Košuthová et al. (2004); <sup>10</sup>Kozlov (1974); <sup>11</sup>Lun et al. (2005); <sup>12</sup>Makushok (1951); <sup>13</sup>Molnár et al. (1989); <sup>14</sup>Ondračková et al. (2006); <sup>15</sup>Petrusheskiy and Bauer (1953); <sup>16</sup>Reshetnikov (2003); <sup>17</sup>Rowe (2007); <sup>18</sup>Şaşı and Balik (2003); <sup>19</sup>Witkowski (2006); <sup>20</sup>Trombitskiy and Kakhovskiy (1987); <sup>21</sup>Libosvářský et al. (1990)

that our current risk classification of the non-native fishes of Belarus is reliable and can be used for prioritizing the management resources.

In terms of the economic sectors under threat ('aquacultural/fisheries', 'environmental', and 'nuisance'), the non-native fishes of group C (brown bullhead, gibel carp, round goby, Amur sleeper, and topmouth gudgeon) represent 20% of all the fishes assessed (Figure 5). This agrees roughly with the 'tens rule' (Williamson and Fitter 1996), which predicts that 5% to 20% (on average 10%) of established non-native species become pests in the introduced areas. These five species have previously been documented to impose a wide range of negative impacts on invaded waters, including competition with

native fishes for food and spawning substrates, predation on native biota, the introduction and transmission of infectious agents, and reductions in water quality (Table 2). Although poorly documented to date, similar impacts have been postulated in Belarus. For example, Zhukov (1988) hypothesized that introduced gibel carp will displace its native congener, crucian carp *C. carassius*, such as reported for the lower Danube in Romania (Navodaru et al. 2002). Indeed, results from an extensive fish community survey conducted in the Belarusian section of the River Dnieper during 2002–2003 (Adamovich et al. 2009) failed to find crucian carp, which was previously common, and gibel carp had become one of the dominant species. Similarly, brown

bullhead has become a dominant species in industrial catchments from several lakes in the southern part of Belarus (Makushok 1951), though the kind and extent of the impacts on native species remain poorly understood. Given the variety of potential adverse impacts associated with species from group C (Table 2), especially on the aquacultural/fisheries and environmental sectors, a precautionary approach would be appropriate, with control measures recommended to prevent any further dispersal of these species in Belarus.

The FISK scores associated with members of other two clusters (A and B; Figure 5) were lower (Figure 6); however, the release of these species should be subject to regulation and appropriate risk assessment so that managerial decisions are informed and balanced. Otherwise, any economic profits for aquaculture or other commercial purposes could be outweighed by the subsequent costs to eradicate the species or to mitigate their negative impacts (Turchini and De Silva 2008).

One of the recent examples of ill-conceived aquaculture projects implemented in Belarus is the introduction of grass carp into Lake Bolshie Shvakshty, which is located in Narochanskiy National Park. Despite the inability of this phytophagous fish to reproduce naturally in Belarus (Zhukov 1988), the high stocking rates employed have resulted in a catastrophic decline in the lake's water quality and thus its value as a recreational amenity (Ostapenya and Zhukova 2009). We hope that the risk categorization of non-native fishes in the present study will help environmental managers of Belarus to plan sustainable and ecologically sound aquaculture projects that will not repeat the story of Lake Bolshie Shvakshty. The outcome of the present study can also be used in neighboring countries with similar environmental conditions.

New species of non-native freshwater fish continue to arrive in Belarus, and since completion of this study, five new species have been reported in scientific literature: the Black Sea sprat *Clupeonella cultriventris*, southern ninespine stickleback *Pungitius platygaster*, *Syngnathus abaster* (syn. *nigrolineatus*) Eichwald, 1831 (Semenchenko et al. 2009), white-finned gudgeon *Romanogobio albipinnatus* (Lukasch, 1933), and golden spined loach *Sabanejewia aurata* (De Filippi, 1863) (Rizevsky et al. 2009). These new species will be assessed with FISK in the near future.

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