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CHECKLIST OF NON-INDIGENOUS FISH SPECIES OF THE RIVER DANUBE

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Abstract - Twenty non-indigenous fish species were recorded in the Danube River. The manner of their introduction, vectors, pathways, as well as invasive status are discussed. The major modes of introduction and translocation were found to be aquaculture and fish stocking. The main environmental consequences of the spread of alien fish are related to changes in the structure and functioning of the fish community and to the introduction of non-indigenous parasites.

Key words: Non-indigenous fish species, Danube, Southern Invasion Corridor, vectors, pathways, impacts

INTRODUCTION

Humans have assumed the roles of both accidental and deliberate dispersal agents of biota (Balon, 1995), and the last century in particular has witnessed an increasing role of humans in the spread of species beyond their natural range. The consequences of biotic invasions are diverse and interconnected, as invaders can alter fundamental ecological properties, such as the dominant species in a community, productivity and nutrient cycling. Thereby they alter the structure and function of the recipient ecosystem (Mack et al., 2000). Anthropogenic redistribution of plants and animals is considered a major threat to biodiversity (Grigorovich et al., 2003), and aquatic ecosystems are no exception. Ballast water of ships, as well as both deliberate and accidental introduction in fish stocks and aquaculture, have been identified as agents of dispersal of non-indigenous fish species (Gherardi et al., 2009).

In Europe, one of the four principal corridors of invasion is the "Southern Invasion Corridor" (SIC) linking the Black Sea basin with the North Sea basin via the Danube-Main-Rhine waterway that also includes the Main-Danube Canal (Panov et al., 2009). The River Danube and its tributaries are the main recipient areas for invasive fish species, as well as one of the most convenient routes for their dispersal. The Danube can be divided into three sections: the upper Danube section, extending from its source in Germany, to the mouth of the Morava River (upstream of Bratislava); the middle Danube section, stretching from the mouth of the Morava River to the "Iron Gate" dam in Serbia and Romania, and the lower Danube section that lies from the Iron Gate to the beginning of the Danube Delta, downstream from the confluence of the Prut River. The Danube Delta is a separate ecosystem, and is shared by Romania and Ukraine.

Reports of non-native species occurrence in the Danube are only partially complete. In light of the growing concern for biological invasions in Europe, the aim of the present work is to provide information on the recent status of non-indigenous fish species that were recorded in the Danube, and to discuss the agents of introduction and factors that influence the successful dispersal and naturalization of fish species.

MATERIALS AND METHODS

This survey of allochthonous fish species is the result of long-term investigations and literature data on the distribution of non-native fish species in the river Danube in Serbia (Cakić, 1983; Cakić and Hristić, 1987; Cakić et al., 2000; Hegediš et al., 1991; Hristić and Bunjevac, 1991; Janković 1998; Lenhardt et al., 2006, 2011; Maletin and Budakov, 1982; Maletin et al. 1997; Ristić, 1940; Sekulić et al., 1999; Simonović 2001; Simonović and Nikolić 1996; Simonović et al., 1998, 2001, 2006a, b, 2010a, b; Smederevac et al., 2001; Šipoš et al., 2004; Taler, 1954) and other Danubian countries (Anhelt et al., 2001; Balon, 1962; Bănărescu, 1964; Bănărescu and Nalbant, 1965; Berinkey, 1960; Biró, 1972; Ciolac, 2004; Csakany, 1958; Ćaleta et al., 2010; Freyhof, 2003; Harka, 1993; Holcík et al., 1981, Hoščo et al., 2003; Kirka, 1995; Kováč and Siryová, 2005; Lusk et al., 2010; Pintér, 1989; Piria et al., 2011; Pojoga, 1977; Stráňai, 1997; Wiesner, 2005; Wiesner et al., 2000; Žitnan, 1965).

The records of non-native fish species were organized in two databases. The database of Allochthonous Invasive Species of the SIC (AISSIC database) was developed at the Institute for Biological Research "Siniša Stanković", University of Belgrade, with the aim of assessing the status of water bodies in the context of biological invasions. The AISSIC database contains data on allochthonous species of the SIC (Danube and its main tributaries, and the Rhine-Main-Danube canal). It includes the donor and recipient areas, periods of investigation, year of the first record, pathways and vectors of introduction (Stefanović et al., 2008). At present, there are 3 243 records in the database. Another database is BAES (Biodiversity in Aquatic Ecosystems in Serbia, Simić et al. 2006) that was developed at the Institute of Biology and Ecology, Faculty of Science, University of Kragujevac. It is comprised of data about the attendance and distribution of species in aquatic ecosystems in Serbia (macroalgae, macroinvertebrates and fish), and is based on field research and bibliographic information.

The classification method of alien fish species was based on the date of the first record in the assessment unit, the native range, invasiveness, feeding and reproductive characteristics, mode of arrival, pathway and vector of introduction (Table 1). The mode of arrival was categorized as intentional or unintentional; the vector of introduction as intentional release, natural spread and escape; the pathways were categorized as aquaculture, stocking, accidental, ornamental, shipping activities, range expansion and sport fishing. The invasive status provided in the checklist was assumed to be the result of the economic impact or the negative effect of alien fish species on the native community and/or ecosystem. Different species were categorized as invasive and potentially invasive. An unknown status was assigned to species with insufficient data with respect to their effects. Scientific and common names of alien fish species are provided in Table 1.

The assessment units (AUs) on the Danube (SC 2, SC 3, SC 3a, SC 3b, SC 4; Table 2) were defined according to Panov et al. (2009). Reports from the Danube Delta, a separate and unique system, were not included in this study.

RESULTS

In total, 20 non-indigenous fish species were observed in the Danube (Table 1). Their contribution to the species richness of European ichthyofauna is about 8%, as regards to the total number of about 250 freshwater fish species listed in Europe (Maitland, 2000). Allochthonous fish species of the Danube originate from five different biographical units (Fig. 1). Six species originate from the Ponto-Caspian and Asian provinces of the Euro-Siberian subregion in

Table 1. List of alien species recorded in the Danube River basin and the year of first record.
Assessment unit: **SC 2** - Lower Danube, **SC 3** -- Middle Danube, **SC 3a** - the river Sava, **SC 3b** - the river Tisa, **SC 4** – Upper Danube. Abbreviations for the pathway/vector and invasiveness: AQ - Aquaculture, ST – Stocking, ACC – Accidental, SH – Shipping activities, OT – Ornamental trade, SF - Sport fishing, RE - Range expansion, INT – Intentional introduction, ND - Natural dispersal, ESC – Escape. Invasiveness: I – invasive, PI – potentially invasive, UN – unknown.

Species	Assessment Unit					Native Range	Likely Pathway/ Vector	Current Status	Invasiveness	References
	SC 2	SC 3	SC 3a	SC3b	SC4					
Ictaluridae										
Ameiurus melas Rafinesque, 1820 Black bullhead	1952	1905	1952	1952		North America	AQ, INT	widespread, established	I	Simonović et al., 2010b; Taler, 1954
Ameiurus nebulosus Lesueur, 1819 Brown bullhead	1952	1952	1953	1962		North America	ST, INT	widespread, established	I	SPUR Dunav IV, 2003; Freyhof, 2003; SPUR Sava I, 2003; Maletin et al., 1997
Gobiidae										
Babka gymnotrachelus Kessler, 1857 Racer goby	1991	2001			2001	Ponto-Caspian	SH, ND	widespread, established	PI	Hegediš et al., 1991; Smederevac et al., 2001; Anhelt et al., 2001
Neogobius fluviatilis Pallas, 1814 Monkey goby	early 1960's	1984	2007	1993		Ponto-Caspian	RE, ND	widespread, established	I	Bănărescu, 1964; Pintér, 1989; Simonović et al., 2010b; Harka, 1993
Neogobius melanostomus Pallas, 1814 Round goby	1997	2001	2011		2000	Ponto-Caspian	SH, ND	widespread, established	I	Simonović et al., 1998; Smederevac et al., 2001; Piria et al., 2011; Wiesner et al., 2000
Ponticola kessleri Günther, 1861 Bighead goby	1997	early 1990's	1997		1996	Ponto-Caspian	SH, ND	regionally established	PI	Simonović et al., 2010a; Kováč and Siryová, 2005; Simonović et al., 2001; Stráňai, 1997
Proterorhinus semilunaris Pallas, 1814 Tubenose goby		2001			2002	Ponto-Caspian	RE, ND	regionally established	UN	Simonović et al., 2001; Wiesner, 2005
Salmonidae										
Coregonus peled Gmelin, 1789 Peled					1974	Europe	ST, INT	widespread, established	UN	Holcík et al., 1981
Cyprinidae										
Carassius gibelio Bloch, 1782 Prussian carp	1912	1954	1975	1964	1961	Asia	AQ, INT	widespread, established	I	Pojoga, 1977; Csakany, 1958; Maletin and Budakov, 1982; Žitnan, 1965; Balon, 1962
Ctenopharyngodon idella Vallenciennes, 1844 Grass carp	early 1960's	1960's	unknown	unknown		Asia	AQ, INT	regionally established	I	Ciolac, 2004; Tóth, 1971; Janković, 1998
Hypophthalmichthys molitrix Vallenciennes, 1844 Silver carp	early 1960's	1969		1991		Asia	ST, INT	regionally established	I	Ciolac, 2004; Tóth, 1971; Hristić and Bunjevac, 1991

Table 1. Continued

Species	Assessment Unit SC 2	SC 3	SC 3a	SC3b	SC4	Native Range	Likely Pathway/ Vector	Current Status	Invasiveness	References
Pseudorasbora parva Temnick and Schlegel, 1846 Topmouth gudgeon	1961	1963		1982		Asia	AQ, INT	regionally established	I	Bănărescu and Nalbant, 1965; Biró, 1972; Žitnan and Holčik, 1976
Centrarchidae										
Lepomis gibbosus Linnaeus, 1758 Pumpkinseed		1952	1953	1930		North America	OT	regionally established	I	Taler, 1954; Ristic, 1940
Micropterus salmoides Lacepede, 1802 Largemouth bass		1984			1957	North America	SF, INT	regionally established	I	Maletin, 1988; Lusk et al., 2010
Polyodontidae										
Polyodon spatula Walbaum, 1792 Mississippi paddlefish	2000					North America	ESC, ACC	regionally established	UN	Kutsarov, 2005
Gasterosteidae										
Gasterosteus aculeatus Linnaeus, 1758 Three-spined stickleback	1995	1960				North America, Europe	ESC, OT	regionally established	UN	Cakic et al., 2000; Berinkey, 1960
Loricariidae										
Pterygoplichthys pardalis Castelnau, 1855 Amazon sailfin catfish	2009					South America	ESC, ACC	regionally established	UN	Simonović et al., 2010a
Odontobutidae										
Perccottus glenii Dybowski, 1877 Amur sleeper	2003		2008	1997		Asia	ESC, ACC	regionally established	UN	Šipoš et al., 2004; Ćaleta et al., 2010; Hoščo et al., 2003
Syngnathidae										
Syngnathus abaster Risso 1827 Short-snouted pipefish	1998					Ponto-caspian	SH, ND	regionally established	UN	Sekulić et al., 1999

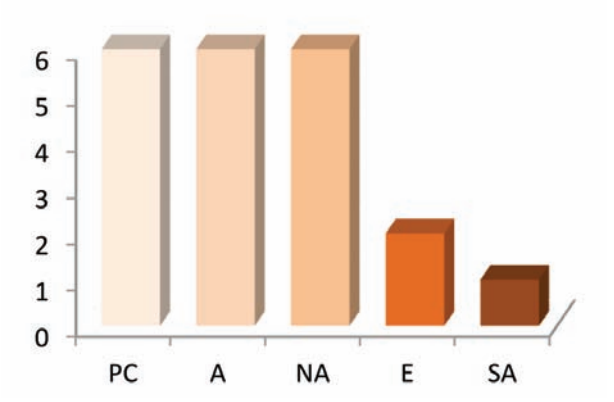

Fig. 1. Distribution of non-indigenous fish species per donor area: PC - Ponto-Caspian; A - Asia; NA - North America; E - Europe without the Ponto-Caspian region; SA - South America. Species whose native range includes two or more geographical units were counted more than once.

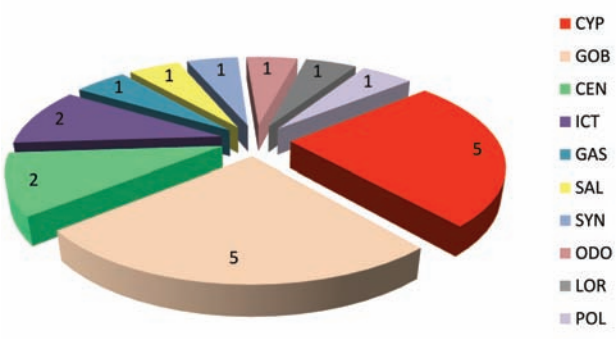

Fig. 2. Participation of families: CYP – Cyprinidae, GOB – Gobiidae, GAS –Gasterosteidae, ICT – Ictaluridae, SAL –Salmonidae, CEN – Centrarchidae, ODO – Odontobutidae, LOR – Loricariidae, POL – Polyodontidae, SYN – Syngnathidae, COB – Cobitidae, PER – Percidae.

the Palearctic region. Five species are from the North American Arctic-Atlantic area, the Pacific subregion in the Nearctic region. The native dispersal areas of the remaining alien species are the Neotropical region and Mid-European provinces of the Euro-Siberian subregion in the Palearctic region. One species is from the Euro-Siberian subregion and the North American Holarctic area.

The alien fish species presented in this study were classified into ten different families. The most numerous are representatives from the families

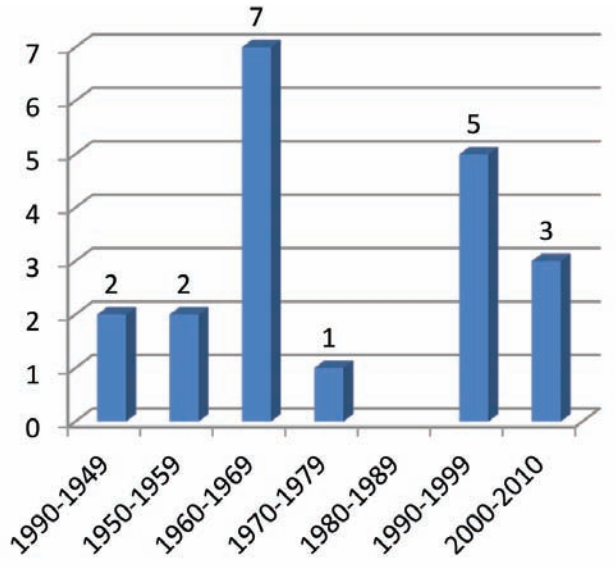

Fig. 3. Number of alien fish species introduced to the Danube River over a 10-year period (except from 1900-1949).

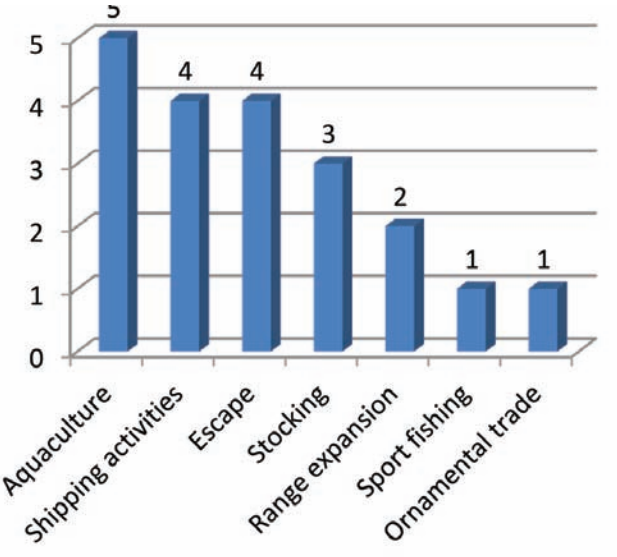

Fig. 4. Pathways involved in the introduction of alien fish species to the Danube.

Cyprinidae and Gobiidae, while the remaining families (Ictaluridae, Centrarchidae, Gasterosteidae, Salmonidae, Loricariidae, Syngnathidae, Polyodontidae and Odontobutidae) contribute smaller numbers of species (Fig. 2).

Table 2. List of assessment units on the Danube.

AU name	Latitude, N	Longitude, E	Ecosystem/water body
SC2	43°30' - 45°30'	22°30' - 28°30'	Lower Danube
SC3	44°00' - 49°00'	16°00' - 22°30'	Middle Danube
SC3a	44°00' - 45°20'	17°00' - 20°30'	Sava River
SC3b	45°30' - 49°00'	18°30' - 19°30'	Tisa River
SC4	47°00' - 49°10'	11°50' - 16°00'	Upper Danube

The introduction of new fish species into the Danube began at the end of the 19th century with the introduction of rainbow trout into German waters in 1882 (Freyhof, 2003). This was followed by the introduction of the gibel carp and black bullhead at the beginning of the 20th century. The process peaked in the 1960s and 1990s, when a total of ten species were introduced. After 2000, only two species were introduced (Fig. 3).

As to the mode of arrival, intentional (9 species) and unintentional (11 species) introduction are almost equally represented. The dominant pathways of introduction include aquaculture, escape, shipping activities and stocking (Fig. 4).

According to the negative effects, the alien species were categorized as invasive or potentially invasive. Among the 20 species listed, eleven species were classified as invasive, and two species as potentially invasive (Table 1). Thus, the percentage of invasive and potentially invasive species among the total number of alien species is 65%. An unknown status was assigned to the remaining seven species due to insufficient data.

DISCUSSION

An increase in the interest for introduced alien species is obvious from the recently published reports which describe the first appearance of alien fish species, or extension of the dispersal area in which the alien fish species have been detected. Over the last decades, fish species new to the fauna of the Danube have been recorded and traced. Some of them, such as racer and round gobies, have established themselves throughout the whole stretch of the Danube; some are established in fish communities in still waters in inshore areas of the Danube and in its backwaters (the Amur sleeper). Paddlefish has not yet established itself in the section of the Danube River upstream of the Iron Gate II dam, although Vasilev and Pehlivanov (2005) observed juvenile organisms in the lower section of the Danube. This suggests that paddlefish have spawned, i.e., that they have passed through the acclimatization phase in that part of the Danube, suggesting that a similar outcome could occur upstream.

Certain fish species with a cryptogenic status have not been included in the list of non-indigenous species presented here, despite human involvement in their spread. The native Ponto-Caspian, and therefore Danubian distribution of the common carp, *Cyprinus carpio*, has been dated to 6000-7000 BC (Tsepkin, 1995), although its dispersal to Western Europe about 2000 years ago was most probably facilitated first by the Romans, and in the Middle Ages by Cistercian monks (Balon, 1995). However, human-mediated dispersal of goldfish and gibel carp (*Carassius* spp.), which began in Western Europe during the late Middle Ages (Lozano-Rey, 1935; Almaça, 1995), does not leave any doubt as to their invasive character in the whole drainage area of the Danube.

Pathways of transmission of alien fish species in the Danube

Intentional introduction of alien fish species in aquaculture appears is often associated with fish es-

cape and dispersal in natural aquatic habitats. The gibel carp (Pojoga, 1977) and topmouth gudgeon (Banarescu, 1964) have quickly acclimatized and become naturalized in the surrounding environment after introduction, displaying the character of an invasive species. One of the most prominent pathways of introduction of new fish species is by intentional fish stocking. This has mainly been carried out by fishery managers for both angling and commercial fishing. Stocking with non-indigenous fish species in order to enhance a fishery, e.g., in newly formed highland reservoirs, has been a regular and common practice for a long time. It has led to the deterioration of fish communities initially inhabited by native fish species, such as gudgeon *Gobio gobio*, chub *Squalius cephalus*, brook barbel *Barbus balcanicus*, minnow *Phoxinus phoxinus*, riffle minnow *Alburnoides bipunctatus*, stone loach *Barbatula barbatula* and spined loach *Cobitis* spp. For fish species from the family Gobiidae with a native distribution in the Ponto-Caspian region, the basic pathway of introduction was range expansion, in particular to neighboring areas. For most, the direction of spread has been upstream on the Danube. Transport in the ballast water of vessels is the most recent route of non-deliberate introduction of invasive fish species (Jude et al., 1992; Skora and Stolarski, 1993; Grigorovich et al., 2003). Cryptic fish species, such as several gobies and short-snouted pipefish, have managed to survive in ballast water until entry into the environment. Wiesner (2005) revealed the relationship between ships, industrial harbors in the vicinity of Vienna, and the distribution patterns of Ponto-Caspian gobies which have colonized the Danube in Austria.

The impact of alien fish species in the Danube

In general, the impact of non-indigenous fish species in new surroundings is manifold. The direct effects of naturalized invasive fish species on aboriginal species in the Danube are difficult to estimate due to the lack of precise data about the structure and productivity of fish communities prior to the reported introductions. The most adverse effects are competition for food resources, invasion of habitats and spawning sites used by native fish species (*Ameiurus melas, A. nebulosus, Carassius gibelio, Pseudorasbora parva* and *Lepomis gibbosus*). Maletin et al. (1997) stated that the appearance and rapid increase in abundance of the gibel carp in the Serbian part of the Danube was followed by the decrease in numbers of native and syntopic common carp, tench and crucian carp, due to the adaptive advantages of the gibel carp, which were both reproductive (gynogenetic reproduction, early maturation, high fertility, portion spawning), and environmental (better tolerance to pollution). The introduction of *Ctenopharyngodon idella* that was undertaken in order to control aquatic vegetation resulted in the complete removal of vegetation from the water system, and consequent reduction of spawning zones for phytophilic spawners that make up the vast majority of native fish in the Danube River area.

Another negative effect of the introduction of non-indigenous species on aboriginal species is associated with the introduction of exotic parasitic species and pathogens. The unfavorable consequences of parasitism have been linked to the introduction of non-native fish species. The spread of parasites to native taxa was previously reported (Nikolić and Simonović, 1998; Nikolić et al., 2007; Gozlan et al., 2005). The import of exotic pathogens that are not group-specific has also had a huge impact on the native fish community, because pathogens are frequently more dangerous in atypical hosts (native fish), than in typical hosts (Elvira, 2001).

Ecological aspects important for invasive success

Certain ecological characteristics of alien species have an important role in their invasive potential. A cryptic way of life in weeded (e.g., pipefish, Amur sleeper, topmouth gudgeon, tubenose goby), stony (e.g., bighead goby) and mosaic (e.g., round, racer and sand goby) habitats enables the successful acclimatization and naturalization of non-native species in recipient areas. Certain alien fish species (*Ameiurus melas, A. nebulosus* and *Carassius gibelio)* have low environmental requirements and are very tolerant to many physical and chemical variables of wa-

ter quality, especially low oxygen content and high pollution levels. Certain successful invaders display parental care (roe and fry), with males guarding offspring prior to and after hatching, fanning the clutch, and defending the nest aggressively (stickleback, gobies and Amur sleeper). Other reproductive features advantageous to invaders are batch spawning, observed in topmouth gudgeon, and sac brooding of short-snouted pipefish. The majority of alien fish species in the Danube combine some or most advantageous biological characteristics. The topmouth gudgeon and gibel carp are successful due to their broad feeding niche, early attainment of maturity and reproductive features (Gozlan et al., 2002). The feeding characteristics of alien species may also contribute to the successful invasiveness in new areas. Some species with a narrow but specific feeding niche, such as the predominantly mollusc-eating round goby, are probably more competitive in a narrow and specific feeding niche. However, the example of the non-invasive short-snouted pipefish, which is also a narrow feeder, suggests that feeding is not the only determining feature. In contrast, omnivorous fish species with diets that range from plankton and insect larvae to plants, crustaceans and small fish, are numerous among non-native fish species in the Danube River. Seven out of the 20 indigenous species feed in this way: *Ameiurus melas, A. nebulosus*, *Ctenopharyngodon idella, Gasterosteus aculeatus, Pseudorasbora parva, Micropterus salmoides, Ponticola kessleri*. Certain alien species have limitations that decrease their invasive potential. This is illustrated by the largemouth bass and short-snouted pipefish that have become naturalized in the Danube; these two species have not spread beyond their initial microhabitats in the recipient area, despite their advantageous reproductive features (nest guarding and sac brooding, respectively). Similarly, the Amur sleeper is susceptible to the high diversity of the original fish community that is held responsible for food shortage, and to strong currents in eddies and in the side arms of the Danube (Bogutskaya and Naseka, 2002; Simonović et al., 2006b). It seems that establishing invasiveness in the Danube and in general is a very complex process that is linked to many factors in the physical environment, such as the habitat. In addition to the ability of certain fish species to utilize a broad range of habitat types (racer goby), certain alien species can reveal their invasive effect by altering the habitat when modifying it for their own needs, as for example the Amazon sailfin catfish, which digs holes in dykes (Simonović et al., 2010a). On the other hand, various types of human-assisted habitat modifications can contribute to the water body becoming a suitable recipient area. According to Paunović et al. (2006, 2007, 2012), this describes the situation in the area around the Iron Gate and most downstream stretches of the main tributaries of the Danube in Serbia (the rivers Sava and Tisa), where the introduction and acclimatization of invertebrate species has occurred.

CONCLUSIONS

The conclusions presented herein are based on the information currently available in the database. Additional research will be beneficial as it will complete and further improve knowledge in this field. In spite of the generally low predictability of biological invasiveness (Williamson and Fitter, 1996), some invasions can provide clues as to their further development, dispersal patterns and spread. This suggests that more research is needed in order to identify potential invaders, and to define programs and measures for alien species. This is clearly not a national problem, and future actions should be coordinated with related activities at the regional level.

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