Current Status of Fish Communities in the Danube

Vladimír Kováč

Abstract The Danube is a river with the highest fish species richness (102 species ever reported) in Europe. Nevertheless, it is also a river that faces various human pressures with serious negative impacts on its ecosystems, including fish communities. In this chapter, data from both the Joint Danube Survey 2 (2007) and the Gabčíkovo Hydroelectric Scheme Monitoring (1991–2011) are reanalysed briefly (data from JDS3 - 2013 are not included). A total of 69 species of fishes were recorded within the recent surveys of the Danube, a number that still suggest a high diversity of the Danubian fish community. However, as many as 12 of these species were not native in the Danube, at least not in its whole course, and a total of 18 non-native species have been ever recorded in the Danube. Concerning native species, cyprinids, especially bleak, highly predominated along the whole course of the Danube, though invasive species, such as gobies in the Upper and Middle Danube and gibel in the Lower Danube, were found to be extremely abundant. Biological invasions not only indicate deterioration of environments but also may result in an overall decline in biodiversity. Therefore, a predictive risk assessments and management strategies for introductions and invasions of non-native fishes should be developed for the Danube and applied subsequently at an international level. Human impacts on fish communities of the Danube are also briefly illustrated, with the Gabčíkovo Hydroelectric Scheme used as an example.

Keywords Diversity, Fishes, Gabčíkovo monitoring, Human impacts, Invasive gobies, Joint Danube Survey 2

V. Kováč (✉)
Comenius University, Faculty of Natural Sciences, Department of Ecology, Iľkovičova 6, Mlynská dolina, Bratislava, Slovakia
e-mail: kovac@fns.uniba.sk

I. Liska (ed.), *The Danube River Basin*, Hdb Env Chem (2015) 39: 359–388,
DOI 10.1007/698_2015_377,
Published online: 15 July 2015

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1 Introduction

With as many as 102 species of fishes recorded, the Danube is a river with the highest species richness in Europe. The first comprehensive review of the Danubian ichthyofauna was provided by Balon [1, 2] who also defined the Danube as the major migration route for a diverse Central Asian and Ponto–Caspian fauna [3]. Thanks to a high habitat diversity and dense ecotonal structure, the Danube provides diverse combinations of environmental conditions suitable for a great variety of different fish species [4, 5].

Nevertheless, the Danube is also a river with great international importance as a route for transport of goods across Europe, a vital resource for water supply, a strong source of hydro-energy, as well as a base for agriculture, industry, recreation, tourism and both recreational and commercial fisheries. Therefore, there have been various environmental pressures resulting from diverse human activities that have had serious negative impacts on the Danubian ecosystems, including its fish communities. That is why it is important to pay a constant attention to what is going on in the Danubian ecosystems, as well as what are the trends in the dynamics of fish communities. The ecological status and problems of the Danube and its fish fauna were recently reviewed by Schiemer et al. [5]. In the meantime, the Joint Danube Survey 2 (JDS2), which took place from 13 August to 28 September 2007, brought the most detailed and most comprehensive data on fish communities ever collected from the Danube [6, 7] (data from JDS3 2013 were not available when writing this chapter). Furthermore, since 1990, a continuous monitoring of fish fauna has been carried out in order to evaluate the impacts of the Gabčíkovo Hydroelectric Scheme (GHS) on fish communities in the Čunovo–Sap section (Middle Danube), including sidearms.

In this chapter, data from both JDS2 and GHS monitoring are reanalysed briefly, in order to provide the most recent update of the status of fish communities in the Danube. Of course, the Danube is a really large river, and thus the methodological constraints in the sampling protocols of both these sources of data [6, 8] do not allow to make scientifically undisputable conclusions. Nevertheless, a collection of samples taken within a short period of time from 45 sampling sites all along the Danube, combined with a collection of samples taken over a 20-year-long period but from sampling sites situated at one stretch of the Danube, provides a unique chance to get at least an overall picture on what is the current status of fish communities in the Danube.

2 Fish Community of the Upper Danube (JDS 2)

The upper section of the Danube runs from the Black Forest (Germany) to the Devín Gate (Slovakia, river km 1880), where the River Morava enters the Danube [5]. During the Joint Danube Survey sampling that took place in 2007, a total of 45 species of fishes were found in the Upper Danube [6]. Among these, 39 species were native, and 6 species were allochthonous, with 4 species considered invasive (Table 1).

Two species were found to be eudominant (relative density >10%), with an extremely high predominance of bleak (*Alburnus alburnus*) that covered more than 60% of all fish individuals collected in the upper section of the Danube. Bleak was followed by round goby (*Neogobius melanostomus*), a species that has recently invaded not only the whole Danube but also the River Rhine, as well as several other river systems in Europe (e.g. Copp et al. [9]). The following 9 species formed a slightly more than one fifth of the Upper Danube fish community, and the remaining 34 species were represented by less than 1% of relative density (Table 1).

Concerning native species, cyprinids, especially bleak, followed by nase (*Chondrostoma nasus*), roach (*Rutilus rutilus*), chub (*Leuciscus cephalus*), ide (*Leuciscus leuciscus*), common bream (*Abramis brama*) and barbel (*Barbus barbus*), highly predominated. Two further species – perch (*Perca fluviatilis*) and eel (*Anguilla anguilla*) – also exceeded 1% of relative density. Two non-native invasive gobies (round and bighead) formed a relevant part (13.1%) of the Upper Danube fish community, whereas the relative density of the other four non-native species attained only 1.5% (Table 1).

Most of the species recorded in the upper section of the Danube demonstrated high affinity to current velocity – 31 species were rheophilous. Nevertheless, these rheophils did not cover more than 27.53% of all individuals, because of bleak, which is eurytopic, and together with other ten eurytopic species formed as much as 72.4% of all fish specimens collected in the upper section of the Danube. Only three species, which represented together just 0.1% of the Upper Danube fish community, were limnophilous (Table 1).

Table 1 Species of fishes collected in the Upper Danube during JDS2 ([7], data reanalysed)

Species	Origin	Habitat preference	Reproductive guild	Relative density
Alburnus alburnus	Nat	EU	A.1.4	60.60
Neogobius melanostomus	Inv	RB	B.1.3	10.76
Chondrostoma nasus	Nat	RA	A.1.3	3.50
Rutilus rutilus	Nat	EU	A.1.4	3.09
Leuciscus cephalus	Nat	EU	A.1.3	2.67
Leuciscus idus	Nat	RB	A.1.4	2.49
Neogobius kessleri	Inv	RB	B.1.3	2.31
Perca fluviatilis	Nat	EU	A.1.4	2.30
Abramis brama	Nat	RB	A.1.4	1.84
Anguilla anguilla	Nat	EU	N/A	1.67
Barbus barbus	Nat	RA	A.1.3	1.50
Leuciscus leuciscus	Nat	RA	A.1.4	0.90
Aspius aspius	Nat	RB	A.1.3	0.79
Carassius gibelio	Inv	EU	A.1.5	0.79
Gasterosteus aculeatus	Non	EU	B.2.4	0.69
Lota lota	Nat	RB	A.1.2	0.64
Alburnoides bipunctatus	Nat	RA	A.1.3	0.61
Gymnocephalus cernuus	Nat	RB	A.1.4	0.44
Esox lucius	Nat	EU	A.1.5	0.36
Sander lucioperca	Nat	RB	B.2.5	0.36
Vimba vimba	Nat	RB	A.1.3	0.32
Blicca bjoerkna	Nat	RB	A.1.5	0.20
Silurus glanis	Nat	EU	B.1.4	0.16
Gymnocephalus schraetser	Nat	RA	A.1.4	0.11
Abramis sapa	Nat	RA	A.1.3	0.10
Proterorhinus marmoratus	Nat	EU	B.2.7	0.10
Zingel zingel	Nat	RB	A.2.3	0.09
Rutilus pigus	Nat	RA	A.1.5	0.08
Scardinius erythrophthalmus	Nat	LI	A.1.5	0.07
Cyprinus carpio	Nat	EU	A.1.5	0.06
Salmo trutta m. fario	Nat	RA	A.2.3	0.05
Barbatula barbatula	Nat	RA	A.1.6	0.03
Cottus gobio	Nat	RA	B.2.7	0.03
Hucho hucho	Nat	RA	B.2.3	0.03
Lepomis gibbosus	Inv	LI	B.2.2	0.03
Zingel streber	Nat	RA	A.2.3	0.03
Gobio albipinnatus	Nat	RA	A.1.6	0.02
Gymnocephalus baloni	Nat	RA	A.1.4	0.02
Rhodeus amarus	Nat	EU	A.2.5	0.02
Sander volgensis	Nat	RB	B.2.5	0.02
Thymallus thymallus	Nat	RA	B.2.3	0.02
Oncorhynchus mykiss	Non	RA	A.2.3	0.01

(continued)

Table 1 (continued)

Species	Origin	Habitat preference	Reproductive guild	Relative density
Phoxinus phoxinus	Nat	RA	A.1.3	0.01
Tinca tinca	Nat	LI	A.1.5	0.01
Gobio gobio	Nat	RA	A.1.6	0.01

Nat native species, *Non* non-native species, *Inv* invasive species, *EU* eurytopic species (i.e. without specialised affinity to current velocity), *RA* rheophils A (i.e. species that live in lotic habitats throughout their life circle), *RB* rheophils B (i.e. species that prefer lotic habitats but make seasonal habitat shifts between the river and backwaters), *LI* limnophils (i.e. species that prefer stagnant water). Reproductive guilds [10]: *A* nonguarders, *A.1* open substrate spawners, *A.1.1* pelagophils, *A.1.2* lithopelagophils, *A.1.3* lithophils, *A.1.4* phytolitophils, *A.1.5* phytophils, *A.1.6* psammophils, *A.2* brood hiders, *A.2.2* phytolitophils, *A.2.3* lithophils, *A.2.5* ostracophils, *B* guarders, *B.1* substrate choosers, *B.1.3* lithophils, *B.1.4* k phytophils, *B.2* nest spawners, *B.2.2* polyphils, *B.2.3* lithophils, *B.2.4* ariadnophils, *B.2.5* phytophils, *B.2.7* speleophils, *C* bearers, *C.1.5* pouch bearers. Relative density is expressed in percent of individuals of a species from the total number of individuals in the community

Concerning the affinity to spawning substrate, phyto-lithophilous fishes represented by nine species were the most abundant in the Upper Danube (71.8%), though lithophilous species prevailed in number (16 species covering 22.8% of relative density), followed by phytophils that were represented by ten species but covered only 2.1% of the Upper Danube fish community. The remaining ten species (3.2% of relative density) demonstrated affinity to various other substrata; three of them were psammophilous (Table 1).

3 Fish Community of the Middle Danube (JDS 2)

The middle section of the Danube starts just below the Devín Gate, where it still has a character of a submontane river, and ends at the Iron Gate reservoir (river km 1075; [5]). In 2007, a total of 51 species of fishes were recorded in this section of the Danube [6], though only 40 species belonged to native fauna, whereas 11 species were non-native, with 9 species considered invasive (Table 2).

Two species were found to be eudominant, again with an extremely high predominance of bleak that covered more than 44% of all fish individuals collected in the middle section of the Danube, followed by the Ponto–Caspian invader, round goby. The subsequent ten species formed approximately one third of the Middle Danube fish community, and as many as 37 species were represented by less than 1% of relative density (Table 2).

Concerning native species, cyprinids, such as bleak, followed by roach, asp (*Aspius aspius*), dace (*Leuciscus idus*), silver bream (*Blicca bjoerkna*) and common bream highly predominated, accompanied with burbot (*Lota lota*) and perch in the group of species exceeding 1% of relative density. However, almost one quarter of the Middle Danube fish community was found to be formed by non-native species,

Table 2 Species of fishes collected in the Middle Danube during JDS2 ([7], data reanalysed)

Species	Origin	Habitat preference	Reproductive guild	Relative density
Alburnus alburnus	Nat	EU	A.1.4	44.13
Neogobius melanostomus	Inv	RB	B.1.3	10.90
Rutilus rutilus	Nat	RA	A.1.5	7.93
Neogobius kessleri	Inv	RB	B.1.3	5.43
Aspius aspius	Nat	RB	A.1.3	4.45
Carassius gibelio	Inv	EU	A.1.5	3.86
Lota lota	Nat	RB	A.1.2	3.17
Leuciscus idus	Nat	RB	A.1.4	2.39
Blicca bjoerkna	Nat	RB	A.1.5	2.20
Neogobius fluviatilis	Inv	RB	B.1.3	1.68
Perca fluviatilis	Nat	EU	A.1.4	1.58
Abramis brama	Nat	RB	A.1.4	1.19
Gobio albipinnatus	Nat	RA	A.1.6	1.00
Esox lucius	Nat	EU	A.1.5	1.00
Lepomis gibbosus	Inv	LI	B.2.2	0.92
Chondrostoma nasus	Nat	RA	A.1.3	0.77
Gymnocephalus schraetser	Nat	RA	A.1.4	0.75
Sander lucioperca	Nat	RB	B.2.5	0.75
Neogobius gymnotrachelus	Inv	RB	B.1.3	0.72
Barbus barbus	Nat	RA	A.1.3.	0.69
Rhodeus amarus	Nat	EU	A.2.5	0.67
Gymnocephalus baloni	Nat	RA	A.1.4	0.42
Proterorhinus marmoratus	Nat	EU	B.2.7	0.40
Ameiurus melas	Inv	LI	B.2.3	0.39
Eudontomyzon mariae	Nat	RA	A.2.3	0.39
Leuciscus cephalus	Nat	EU	A.1.3	0.30
Gymnocephalus cernuus	Nat	RB	A.1.4	0.27
Cyprinus carpio	Nat	EU	A.1.5	0.26
Scardinius erythrophthalmus	Nat	LI	A.1.5	0.26
Abramis sapa	Nat	RA	A.1.3	0.25
Vimba vimba	Nat	RB	A.1.3	0.21
Rutilus pigus	Nat	EU	A.1.4	0.11
Silurus glanis	Nat	EU	B.1.4	0.09
Sander volgensis	Nat	RB	B.2.5	0.08
Pseudorasbora parva	Inv	EU	A.2.2	0.07
Zingel zingel	Nat	RA	A.2.3	0.07
Pelecus cultratus	Nat	EU	A.1.1	0.05
Alburnoides bipunctatus	Nat	RA	A.1.3	0.04
Abramis ballerus	Nat	RB	A.1.4	0.03
Tinca tinca	Nat	LI	A.1.5	0.03
Anguilla anguilla	Nat	EU	N/A	0.02
Gobio gobio	Nat	RA	A.1.6	0.02

(continued)

Table 2 (continued)

Species	Origin	Habitat preference	Reproductive guild	Relative density
Cobitis elongatoides	Nat	RB	A.1.5	0.02
Misgurnus fossilis	Nat	LI	A.1.5	0.02
Leuciscus leuciscus	Nat	RA	A.1.4	0.01
Sabanejewia sp.	Nat	RA	A.2.3	0.01
Acipenser ruthenus	Nat	RA	A.1.2	0.01
Ameiurus nebulosus	Non	LI	B.2.7	0.01
Carassius carassius	Nat	LI	A.1.5	0.01
Hypophthalmichthys molitrix	Non	LI	A.1.1	0.01
Perccottus glenii	Inv	LI	B.2.5	0.01

Nat native species, *Non* non-native species, *Inv* invasive species, *EU* eurytopic species (i.e. without specialised affinity to current velocity), *RA* rheophils A (i.e. species that live in lotic habitats throughout their life circle), *RB* rheophils B (i.e. species that prefer lotic habitats but make seasonal habitat shifts between the river and backwaters), *LI* limnophils (i.e. species that prefer stagnant water). Reproductive guilds [10]: *A* nonguarders, *A.1* open substrate spawners, *A.1.1* pelagophils, *A.1.2* lithopelagophils, *A.1.3* lithophils, *A.1.4* phytolitophils, *A.1.5* phytophils, *A.1.6* psammophils, *A.2* brood hiders, *A.2.2* phytolitophils, *A.2.3* lithophils, *A.2.5* ostracophils, *B* guarders, *B.1* substrate choosers, *B.1.3* lithophils, *B.1.4* k phytophils, *B.2* nest spawners, *B.2.2* polyphils, *B.2.3* lithophils, *B.2.4* ariadnophils, *B.2.5* phytophils, *B.2.7* speleophils, *C* bearers, *C.1.5* pouch bearers. Relative density is expressed in percent of individuals of a species from the total number of individuals in the community

and almost every fourth specimen collected was invasive (Table 2). Among these, Ponto–Caspian gobies, especially round goby, bighead goby (*Neogobius kessleri*) and monkey goby (*Neogobius fluviatilis*), formed a major part of the invaders, providing together 18% of the total fish community.

The submontane character of the middle section of the Danube was also reflected in the species composition, concerning their affinity to current velocity. A majority of the 51 species (30 species represented by 38.1% of all individuals) were rheophilous, followed by 12 eurytopic species (60.3% of all individuals) and 9 limnophilous species (only 1.6% of all individuals). Unfortunately, approximately a half of the rheophils was covered by invasive gobies.

Thanks to the predominance of bleak, phyto-lithophilous species were the most abundant in the Middle Danube (58.8%, 11 species), though lithophils were represented by the highest number of species (15 species, 26.3%), followed by phytophils (14 species, 8.7%). Other reproductive guilds were represented by 11 species contributing by 6.3% of relative density from the total fish community (Table 2).

4 Fish Community of the Lower Danube (JDS 2)

The lower section of the Danube starts below the Iron Gate reservoir and continues up to the delta, where the Danube enters the Black Sea [5]. A total of 46 species of fishes were found in the Lower Danube in 2007 [6]. In contrast to the previous two sections of the Danube, the species composition in this fish community contained a highest proportion of native species (41), and only five species were non-native, with four species being invasive (Table 3).

Two species were found to be eudominant, with the same leader as in the upper and middle sections (bleak) that covered more than 40% of all fish individuals, though the population of the second most abundant species (gibel; *Carassius gibelio*) was also very dense (24.8%). Fifteen other species with more than 1% of relative density contributed to the Lower Danube fish community with 29% of all individuals, and the remaining 29 species were represented by less than 1% of relative density (Table 3).

Similar to the previous two sections, cyprinids, and especially bleak, again, highly prevailed among the native species. Silver bream (*Blicca bjoerkna*), roach, white-eye bream (*Abramis sapa*), bitterling (*Rhodeus amarus*), common bream, white-finned gudgeon (*Romanogobio vladykovi*), asp and ide also exceeded 1% of the Lower Danube fish community. Further five species – sterlet (*Acipenser ruthenus*), pikeperch (*Sander lucioperca*), round goby, perch and monkey goby (*Neogobius fluviatilis*) – also contributed to the Lower Danube fish community with more than 1% of all individuals. Three non-native invasive species (gibel, pumpkinseed and topmouth gudgeon) formed a considerable part (27.4%) of the Lower Danube fish community, whereas the relative density of the other two non-native species was rather negligible (only 0.1%; Table 3).

Even in the lower section of the Danube, most species (24) demonstrated high affinity to current velocity, though the cumulative relative density of the rheophils covered only 23.2% of the fish community. On the other hand, eurytopic fishes, represented by 15 species, prevailed, since almost three quarters of all fish specimens collected in the lower section of the Danube were indifferent to current velocity. Finally, seven species, that represented 2.5% of the Lower Danube fish community, were limnophilous (Table 3).

Approximately a half all of the fishes (49%) collected in the Lower Danube (represented by ten species) were phyto-lithophilous. Concerning species composition, lithophils prevailed with 13 species that covered 9.1% of relative density, followed by phytophils that were represented by 12 species and, thanks to the invasive gibel, covered about one third (33.6%) of the Lower Danube fish community. Other reproductive guilds were represented by 11 species contributing by 8.4% of relative density from the total fish community (Table 3).

Table 3 Species of fishes collected in the Lower Danube during JDS2 ([7], data reanalysed)

Species	Origin	Habitat preference	Reproductive guild	Relative density
Alburnus alburnus	Nat	EU	A.1.4	40.03
Carassius gibelio	Inv	EU	A.1.5	24.80
Blicca bjoerkna	Nat	RB	A.1.5	4.94
Rutilus rutilus	Nat	EU	A.1.4	2.87
Abramis sapa	Nat	RA	A.1.3	2.39
Rhodeus amarus	Nat	EU	A.2.5	2.31
Acipenser ruthenus	Nat	RA	A.1.2	2.11
Abramis brama	Nat	RB	A.1.4	1.93
Sander lucioperca	Nat	RB	B.2.5	1.80
Gobio albipinnatus	Nat	RA	A.1.6	1.64
Neogobius melanostomus	Nat	RB	B.1.3	1.56
Lepomis gibbosus	Inv	LI	B.2.2	1.49
Aspius aspius	Nat	RB	A.1.3	1.35
Perca fluviatilis	Nat	EU	A.1.4	1.35
Neogobius fluviatilis	Nat	RB	B.1.3	1.15
Pseudorasbora parva	Inv	EU	A.2.2	1.11
Leuciscus idus	Nat	RB	A.1.4	1.00
Neogobius kessleri	Nat	RB	B.1.3	0.69
Gymnocephalus schraetser	Nat	RA	A.1.4	0.67
Scardinius erythrophthalmus	Nat	LI	A.1.5	0.65
Leuciscus cephalus	Nat	EU	A.1.3	0.58
Cyprinus carpio	Nat	EU	A.1.5	0.57
Neogobius gymnotrachelus	Nat	RB	B.1.3	0.49
Neogobius eurycephalus	Nat	RB	N/A	0.41
Esox lucius	Nat	EU	A.1.5	0.36
Chondrostoma nasus	Nat	RA	A.1.3	0.33
Barbus barbus	Nat	RA	A.1.3.	0.31
Pelecus cultratus	Nat	EU	A.1.1	0.16
Vimba vimba	Nat	RB	A.1.3	0.15
Perccottus glenii	Inv	LI	B.2.5	0.14
Silurus glanis	Nat	EU	B.1.4	0.14
Proterorhinus marmoratus	Nat	EU	B.2.7	0.09
Syngnathus abaster	Nat	LI	C.1.5	0.09
Carassius carassius	Nat	LI	A.1.5	0.09
Cobitis elongatoides	Nat	RB	A.1.5	0.06
Benthophiloides brauneri	Nat	EU	B.2.3	0.04
Benthophilus nudus	Nat	EU	B.1.3	0.03
Gymnocephalus cernuus	Nat	RB	A.1.4	0.03
Tinca tinca	Nat	LI	A.1.5	0.02
Acipenser stellatus	Nat	A	A.1.2	0.01
Mugil cephalus	Nat	EU	A.1.6	0.01
Zingel zingel	Nat	RA	A.2.3	0.01

(continued)

Table 3 (continued)

Species	Origin	Habitat preference	Reproductive guild	Relative density
Abramis ballerus	Nat	RB	A.1.4	0.01
Ameiurus nebulosus	Non	LI	B.2.7	0.01
Gymnocephalus baloni	Nat	RA	A.1.4	0.01
Sander volgensis	Nat	RB	B.2.5	0.01

Nat native species, *Non* non-native species, *Inv* invasive species, *EU* eurytopic species (i.e. without specialised affinity to current velocity), *RA* rheophils A (i.e. species that live in lotic habitats throughout their life circle), *RB* rheophils B (i.e. species that prefer lotic habitats but make seasonal habitat shifts between the river and backwaters), *LI* limnophils (i.e. species that prefer stagnant water). Reproductive guilds [10]: *A* nonguarders, *A.1* open substrate spawners, *A.1.1* pelagophils, *A.1.2* lithopelagophils, *A.1.3* lithophils, *A.1.4* phytolitophils, *A.1.5* phytophils, *A.1.6* psammophils, *A.2* brood hiders, *A.2.2* phytolitophils, *A.2.3* lithophils, *A.2.5* ostracophils, *B* guarders, *B.1* substrate choosers, *B.1.3* lithophils, *B.1.4* k phytophils, *B.2* nest spawners, *B.2.2* polyphils, *B.2.3* lithophils, *B.2.4* ariadnophils, *B.2.5* phytophils, *B.2.7* speleophils, *C* bearers, *C.1.5* pouch bearers. Relative density is expressed in percent of individuals of a species from the total number of individuals in the community

5 Twenty Years of Monitoring the Čunovo–Sap Section (Middle Danube)

Since 1990, a continuous monitoring of fish fauna has been carried out in order to evaluate the impacts of the Gabčíkovo Hydroelectric Scheme (GHS) on fish communities in the Čunovo–Sap section (river km 1851–1815, including sidearms). Electroshocking with a handheld anode, both wading and from a boat, has been used to collect the samples three times per year, usually in April–May, July–August and September–October [8].

In total, 41 species of fishes were recorded in this stretch of the Danube (Table 4) during the period 1991–2011. Two eudominant species (roach and bleak) were the most abundant, followed by pumpkinseed, tubenose goby, perch and gibel. Nevertheless, the fish community has been undergoing changes over the two decades after the GHS was put into operation. To evaluate these changes, the Fish Index of Slovakia (FIS) developed in terms of Water Framework Directive has been used. FIS is a multimetric index that calculates the deviation of observed values from the expected values. For each stream type, a hypothetical reference fish community has been defined based on a thorough analysis of historical data. Such a reference community provides the expected values for each metric of FIS. Most of these metrics are based on the classification of fishes into ecological guilds [11]. Trends and changes in the Middle Danube fish community can be best illustrated by the following seven metrics expressed in relative abundance (deviation of observed from expected values): phytophilous species, lithophilous species, benthic species, rheophilous species, potamodromous species, piscivorous species and invasive species.

Table 4 Species of fishes collected over 20 years of monitoring the Čunovo - Sap section (Middle Danube; data by J. Černý [8])

Species	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total
Rutilus rutilus	14.35	34.08	34.34	1.61	20.35	18.71	14.55	15.44	16.91	12.13	9.20	15.98
Alburnus alburnus	0.00	10.33	0.64	15.40	24.19	11.66	20.96	6.84	8.05	7.46	4.36	13.53
Lepomis gibbosus	0.11	3.78	2.48	13.61	11.80	9.61	2.52	4.30	2.50	3.41	28.07	9.69
Proterorhinus marmoratus	2.16	2.99	3.51	0.72	2.36	12.68	14.89	26.08	28.53	36.03	19.35	9.61
Carassius auratus	19.42	7.43	12.27	3.94	3.54	8.26	6.19	8.86	9.93	10.24	13.24	8.05
Perca fluviatilis	7.80	8.99	27.53	20.05	16.81	13.39	7.33	9.11	11.90	6.06	4.92	7.82
Rhodeus sericeus	0.00	3.05	0.25	0.90	4.42	4.23	5.38	1.77	1.16	7.60	4.60	4.62
Neogobius melanostomus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.87
Leuciscus idus	1.17	0.81	0.71	28.11	0.88	1.54	8.02	5.82	5.28	3.34	2.06	3.32
Esox lucius	1.11	5.55	1.08	3.76	6.78	7.56	7.10	5.82	2.86	3.55	3.17	3.30
Ameiurus melas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.08
Scardinius erythrophthalmus	0.00	2.82	0.28	0.72	0.00	1.41	2.29	0.25	0.27	3.07	0.24	2.29
Leuciscus cephalus	5.02	2.83	0.14	6.44	3.54	2.43	1.83	1.77	2.77	1.11	1.11	2.16
Cottus gobio	23.00	11.15	6.96	0.00	0.00	0.83	0.57	2.03	0.54	0.00	0.71	2.08
Blicca bjoerkna	7.08	0.63	4.54	2.86	0.88	3.01	3.89	4.05	4.20	3.69	1.43	1.88
Neogobius kessleri	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.54	1.76
Chondrostoma nasus	0.80	0.14	0.00	1.18	0.29	0.19	0.57	0.51	2.24	0.00	0.08	1.52
Aspius aspius	0.08	0.04	0.43	0.72	0.29	0.77	0.92	0.76	0.00	0.00	0.32	1.30
Lota lota	1.17	0.57	2.54	0.00	0.00	0.38	0.34	0.76	0.45	0.56	2.70	1.27
Barbus barbus	6.24	0.79	0.21	0.00	0.88	0.77	1.37	0.51	1.43	0.00	0.08	0.57

(continued)

Table 4 (continued)

Species	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total
Gymnocephalus baloni	5.11	1.00	1.21	0.00	0.29	0.13	0.11	0.51	0.00	0.00	0.08	0.42
Gasterosteus aculeatus	0.00	0.00	0.00	0.00	0.29	0.58	0.34	0.76	0.81	0.35	0.56	0.29
Cyprinus carpio	2.11	0.00	0.00	0.00	0.29	0.32	0.00	0.76	0.09	0.28	0.00	0.22
Leuciscus leuciscus	0.00	0.00	0.00	0.00	1.18	0.13	0.11	0.25	0.00	0.00	0.95	0.21
Silurus glanis	0.33	0.00	0.57	0.00	0.00	0.51	0.23	0.51	0.00	0.00	0.24	0.20
Gymnocephalus cernuus	0.08	0.25	0.00	0.00	0.59	0.70	0.34	1.27	0.00	0.00	0.00	0.17
Abramis brama	0.22	0.81	0.11	0.00	0.00	0.00	0.00	0.76	0.00	0.00	0.00	0.15
Vimba vimba	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12
Misgurnus fossilis	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.11	0.00	0.10
Gobio albipinnatus	0.19	1.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08
Gobio kessleri	1.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
Tinca tinca	0.00	0.00	0.00	0.00	0.29	0.19	0.11	0.25	0.00	0.00	0.00	0.06
Zingel streber	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
Zingel zingel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
Stizostedion lucioperca	0.97	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
Abramis ballerus	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Cobitis taenia	0.00	0.14	0.11	0.00	0.00	0.00	0.00	0.25	0.09	0.00	0.00	0.03
Barbatula barbatula	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Carassius carassius	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Stizostedion volgense	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Neogobius gymnotrachelus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Species	2002	2003	E2004	2004	2005	2006	2007	2008	2009	2010	2011	Total
Rutilus rutilus	18.09	14.34	3.39	1.76	13.59	15.49	25.62	20.54	13.71	20.58	12.83	15.98
Alburnus alburnus	12.77	17.46	1.69	18.64	32.07	15.40	24.95	18.68	18.97	13.89	13.20	13.53
Lepomis gibbosus	9.19	14.77	0.00	0.59	16.04	20.38	9.88	17.60	16.34	13.27	12.91	9.69
Proterorhinus marmoratus	17.66	13.64	8.90	2.85	8.07	3.94	1.15	0.72	1.23	1.12	2.80	9.61
Carassius auratus	2.48	5.99	41.95	1.85	2.66	4.23	1.62	2.78	1.86	4.65	3.69	8.05
Perca fluviatilis	4.59	6.69	3.81	9.24	2.76	3.00	1.86	0.87	1.54	2.67	1.18	7.82
Rhodeus sericeus	12.77	8.51	5.08	18.89	0.51	1.31	0.33	2.01	7.81	5.27	5.75	4.62
Neogobius melanostomus	0.00	0.00	4.66	6.21	5.41	5.07	8.97	14.72	10.35	14.26	15.56	3.87
Leuciscus idus	2.19	2.26	2.12	0.00	0.61	0.38	1.34	0.67	0.82	2.60	2.43	3.32
Esox lucius	2.99	3.21	3.39	2.69	2.76	3.00	1.48	1.18	1.18	1.55	0.81	3.30
Ameiurus melas	0.00	0.00	0.00	0.00	4.09	17.00	9.69	7.21	14.16	3.41	12.32	3.08
Scardinius erythrophthalmus	3.65	4.60	1.27	0.34	2.96	4.60	1.38	3.91	7.22	3.60	5.53	2.29
Leuciscus cephalus	2.55	0.61	8.05	1.26	0.31	0.09	0.76	0.98	0.00	3.22	0.66	2.16
Cottus gobio	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.08
Blicca bjoerkna	1.60	1.13	0.00	0.00	0.00	0.00	0.62	0.82	0.00	0.87	0.00	1.88
Neogobius kessleri	6.42	4.00	5.93	1.68	4.70	2.72	2.15	2.06	0.95	2.98	2.51	1.76
Chondrostoma nasus	0.00	1.04	0.42	24.94	0.00	0.00	0.00	0.62	0.00	0.25	0.07	1.52
Aspius aspius	0.14	0.00	0.85	1.60	3.06	1.78	6.20	1.90	1.68	3.53	3.47	1.30
Lota lota	1.09	0.09	1.27	7.47	0.00	0.47	1.00	1.03	1.32	1.36	3.32	1.27
Barbus barbus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.57
Gymnocephalus baloni	0.00	0.00	0.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42

(continued)

Table 4 (continued)

Species	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total
Gasterosteus aculeatus	0.22	0.43	2.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29
Cyprinus carpio	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.41	0.31	0.15	0.22
Leuciscus leuciscus	0.07	1.13	0.85	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.21
Silurus glanis	0.14	0.00	0.00	0.00	0.31	0.38	0.24	0.62	0.14	0.12	0.15	0.20
Gymnocephalus cernuus	0.00	0.00	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17
Abramis brama	0.14	0.00	0.00	0.00	0.10	0.00	0.29	0.21	0.32	0.12	0.29	0.15
Vimba vimba	1.09	0.00	0.00	0.00	0.00	0.00	0.38	0.87	0.00	0.19	0.00	0.12
Misgurnus fossilis	0.00	0.00	0.00	0.00	0.00	0.75	0.00	0.00	0.00	0.06	0.15	0.10
Gobio albipinnatus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08
Gobio kessleri	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
Tinca tinca	0.00	0.00	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
Zingel streber	0.00	0.00	1.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
Zingel zingel	0.00	0.00	1.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
Stizostedion lucioperca	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.05
Abramis ballerus	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.59	0.03
Cobitis taenia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Barbatula barbatula	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Carassius carassius	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Stizostedion volgense	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Neogobius gymnotrachelus	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00

E2004 special expedition [9]

During 1991–2011, the most important changes in the fish community of the Čunovo–Sap section were observed in relative abundance of benthic, rheophilous, lithophilous and invasive species (Figs. 1, 2, 3 and 4). In contrast to benthic, rheophilous and lithophilous species, in which the trend was mainly decreasing

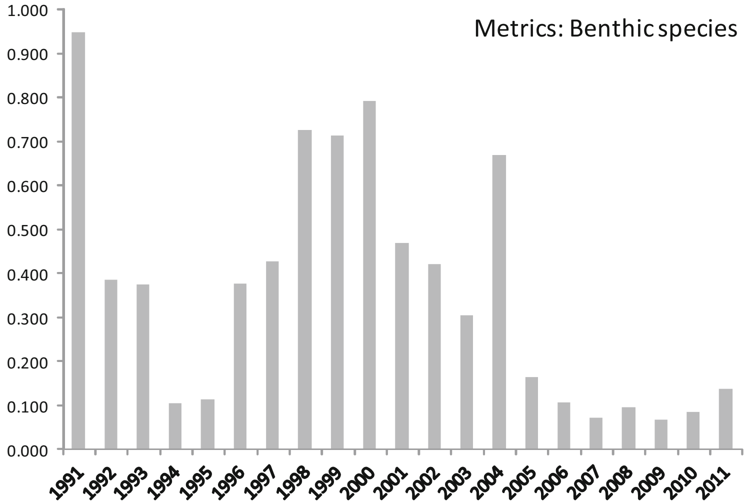

Fig. 1 Variation of benthic species in the Čunovo–Sap fish community in the 1991–2011 period. Values of the metrics are calculated from relative density and express the deviation from the expected value, i.e. 1.000. Native species are considered only

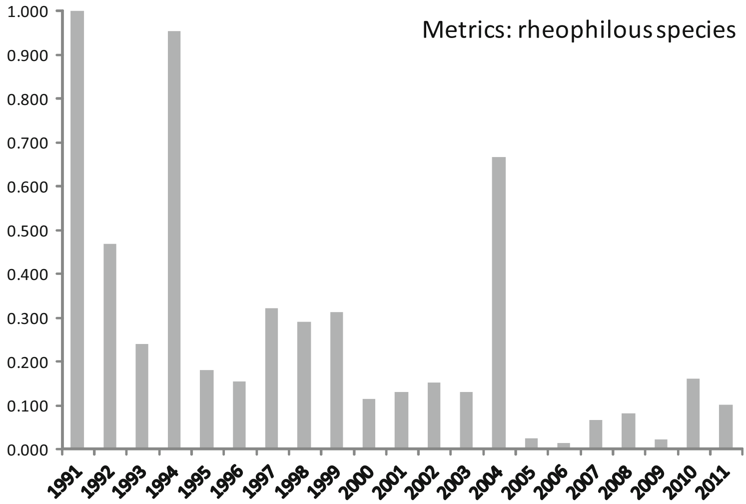

Fig. 2 Variation of rheophilous species in the Čunovo–Sap fish community in the 1991–2011 period. Values of the metrics are calculated as described in Fig. 1

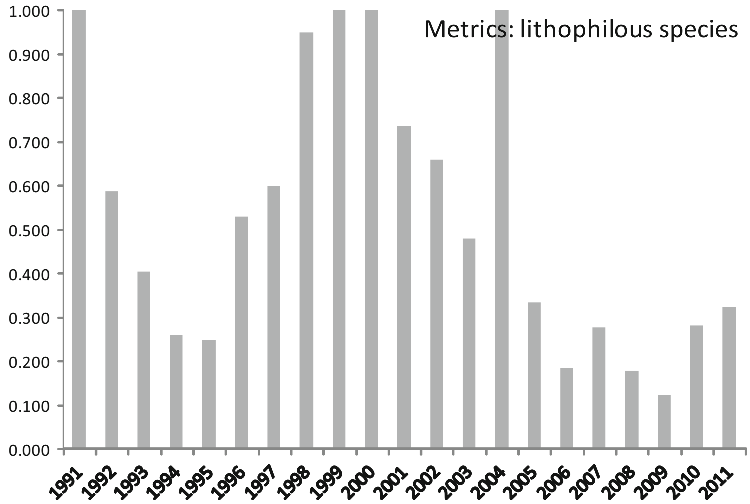

Fig. 3 Variation of lithophilous species in the Čunovo–Sap fish community in the 1991–2011 period. Values of the metrics are calculated as described in Fig. 1

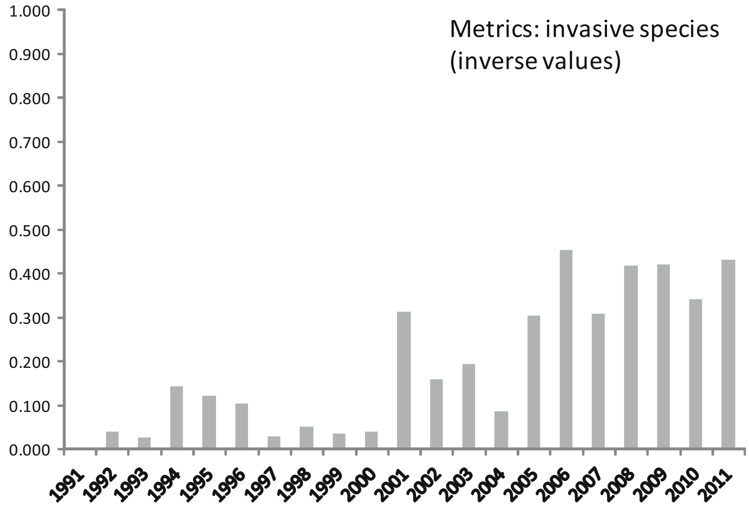

Fig. 4 Variation of invasive species in the Čunovo–Sap fish community in the 1991–2011 period. Values of the metrics are calculated from relative density and express the deviation from the expected value, i.e. 0.000

during the second half of the monitoring period, the relative abundance of invasive species was increasing. Since 2005, i.e. soon after the appearance of round goby in this section of the Danube, the inverse value of this metric oscillated around 0.4 (Fig. 4), which indicates a very serious contamination of native fish community with invasive species.

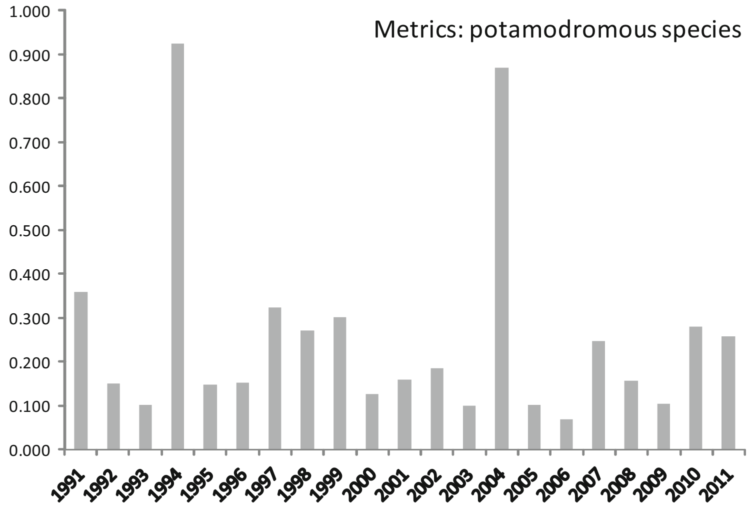

Fig. 5 Variation of potamodromous species in the Čunovo–Sap fish community in the 1991–2011 period. Values of the metrics are calculated as described in Fig. 1

Concerning potamodromous species, no apparent changes and/or trends were observed between 1991 and 2011, because even before GHS was put into operation, the relative abundance of this ecological group was rather low, ranging from 15 to 35% of the expected values. Nevertheless, some temporary fluctuations were also observed, especially in 1994 and 2004, when their relative abundance jumped to 92.5% and 87%, respectively (Fig. 5). On the other hand, phytophilous species appear to have been present in the fish community in expected relative abundances (metrics = 1.000) throughout the whole period, except 1993, when the metric of phytophilous species decreased to 0.59, temporarily.

Piscivorous species passed through apparent fluctuations, peaking in a periodicity of 10 years, approximately (Fig. 6). In 1990s (1994–1998), the peak resulted from increasing abundance of pike (*Esox lucius*), whereas asp (*Aspius aspius*) became the most abundant piscivorous species in 2007 (Table 4).

At the species level, the changes in the Čunovo–Sap fish community resulted mainly from the fact that such rheophilous species as bullhead (*Cottus gobio*), wild carp (*Cyprinus carpio*), white-finned gudgeon (*Gobio albipinnatus*) and/or Kessler's gudgeon (*Gobio kessleri*) disappeared from the eupotamal habitats monitored, and the abundance of Balon's ruffe (*Gymnocephalus baloni*) and breams (*Abramis brama*, *A. sapa*, *A. ballerus* and even *B. bjoerkna*) also reduced considerably. All these species appear to have been replaced by more plastic, especially invasive species, such as pumpkinseed (*Lepomis gibbosus*) and round goby (Table 4).

Nonetheless, these trends can be related exclusively to the littoral habitats of the main channel and sidearms of the Danube that have been monitored, since the limitations of the sampling protocol applied in the monitoring of fish community must be considered. Most of the species present in eupotamal of the Danube before

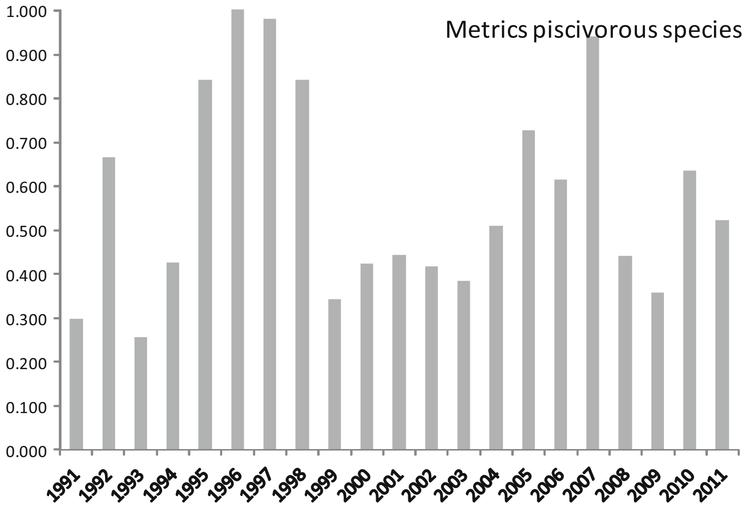

Fig. 6 Variation of piscivorous species in the Čunovo–Sap fish community in the 1991–2011 period. Values of the metrics are calculated as described in Fig. 1

GHS operation have not disappeared completely, though their abundance has reduced. This is obvious from the JDS 2 results (see Table 2). Reophilous species still find their habitats in the middle of the main channel of the Danube, as well as in deeper parts of its littoral zone (personal observation, August 2011, electroshocking bottom trawling performed by *B. Csány* and his team). The only exception seems to be the bullhead that attained as high relative abundance as 23% in 1991, but its population declined afterwards to disappear completely from this stretch of the Danube in 2002 (Table 4; see also Table 2).

The overall abundance of the Čunovo–Sap fish community appears to have stabilised, but the Catch per unit effort (CPUE) values remain very low. Another problem is the absence of individuals from older age classes, as well as the reduction of economically important species, such as perch, pike, pikeperch and wels, especially larger individuals [12].

All the negative trends in the Čunovo–Sap fish community are clearly reflected in the FIS values over the period 1991–2011. Since 1991, the FIS values dropped down from 0.731 (indicating class 1 of ecological status) up to values oscillating around 0.200 after 2005 (indicating class 5 of ecological status Fig. 7). Interestingly, FIS demonstrated an increasing tendency soon after the GHS began working, and this tendency persisted for a period of 4 years (1995–1998). However, since 1998, FIS started declining to reach class 5 in 2005. The only exception occurred in 2004, when FIS jumped up to 0.574 (class 2). This is very likely to be associated with the extremely high discharge of the Danube in August 2002, which overflooded the whole sidearm system and increased thus the spawning and nursery grounds for most of the fish species. On the other hand, low FIS values corresponding to bad ecological status of this stretch of the Danube coincide with

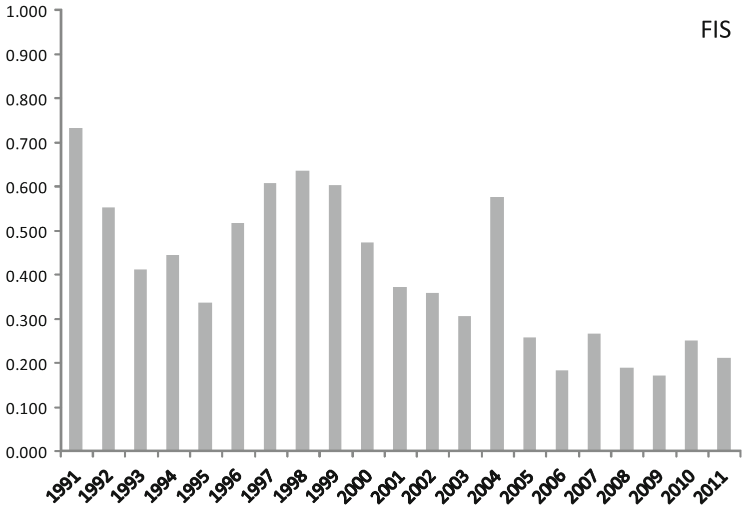

Fig. 7 Variation of the Fish Index of Slovakia in the Čunovo–Sap fish community in the 1991–2011 period. Values of FIS express the deviation from the expected value, i.e. 1.000. Please note that FIS values as well as values of all metrics are biased by the constraints of the sampling methods used during the GHS monitoring that do not meet the WFD requirements, because the Danube falls into the category of large rivers. Therefore, the ecological status, in terms of WFD, cannot be derived from the presented FIS values, though they illustrate the trends and changes in the Čunovo–Sap fish community over the last two decades

the increase of invasive species that form a separate metric of FIS and as such have the power to push FIS values to lower levels.

6 Human Impacts

Major impacts of human activities on the ecosystems of the Danube comprise pollution, i.e. deterioration of water quality, regulations, construction of dams and reservoirs and navigation. As reviewed recently by Schiemer et al. [5], fish communities can also be heavily affected by inappropriate management of fisheries and illegal fishing (see also Černý [12]). Water quality of the Danube is a subject of other chapters; therefore, it is not discussed here.

6.1 River Regulations

Hydromorphological alterations, including regulations of rivers, have been identified as one of the four basin-wide significant water management issues that result in substantial environmental impacts. Hydromorphological alterations result, for example, in the decline of both species diversity and species abundance, in alterations in the structure of populations and/or in limited migrations, which make reproduction of some species impossible [13].

Regulations of the River Danube have not been an issue of recent times, exclusively. For example, already in the thirteenth century, local dams in the form of circular forts were built in separate villages at the middle section of the Danube. In 1424, the King Žigmund (Sigismund of Luxemburg) ordered to interconnect these dams. In the seventeenth century, organised construction of dams along the inundation zone of the Danube began, followed by intensive damming in the nineteenth century, arranged by water unions in the cities of Šamorín and Komárno. As a result, the original course of the Danube, with a dense network of anastomosing sidearms and waste inundation area, was channelised into an area that was 1–3 km wide, and most of the discharge was concentrated in one main stream.

In the Upper Danube, the process of intensive engineering also began in the nineteenth century, with the aim to create a single, straightened channel, stabilised by riverside embankments and rip-raps [5]. Similar to the Middle Danube, the sidearms of the original braided system were cut off. To retain the water level in wetlands, weirs were built in the sidearms. These regulations changed the hydromorphology of the Danube considerably, especially its slopes and transport of bed sediments, as well as runoff characteristics [5].

One of the main reasons for these regulations, both in the Upper and Middle Danube, was to improve navigation. As the upper and lower ends of the sidearms were closed, a new main channel of the river with a more straight stream formed, which was further supported by construction of weirs to direct the stream into a channel suitable for navigation. This has had detrimental impacts on the original habitats – the inshore habitats reduced considerably, large floodplain areas disappeared and the connectivity between the river and floodplains became limited [5, 12]. The geomorphological processes also altered as the erosive forces were suddenly concentrated in the main channel that resulted in deepening of the riverbed. In the 1980s and early 1990s, massive excavation of gravel at Bratislava just speeded up these processes, and as a result not only the bottom of the main channel sank down but the communication between the sidearm system of the inundation area and the main channel got very limited. The last natural flood in the inundation area below Bratislava, so important for reproduction of fishes, occurred in 1992 [12].

Thus, the river regulations initiated trends that still continue: lowering of the water table and deepening of the riverbed, combined with sedimentation processes in sidearms leading to permanent changes and a loss of aquatic habitats [5].

6.2 Dams and Reservoirs

Another ecological concern is associated with the construction of hydropower dams. The Danube has a high hydroelectric potential that has been largely exploited by 52 power dams in the Upper Danube and three major barrages in the Middle Danube – Gabčíkovo, Iron Gates 1 and 2 [5].

The Gabčíkovo Hydroelectric Scheme (GHS) has affected the fish communities in the Slovak stretch (Middle Danube), considerably. However, GHS was not the first construction that had such a detrimental impact on the Danubian fish communities. Iron Gate (Serbia/Romania), as well as numerous dams in Germany and Austria, had been built up earlier. Nevertheless, diverting the former Danube main stream into the new artificial canal in 1992 interrupted and/or damaged natural processes in the inland delta of the Danube. Soon after the GHS started to work, the communication between the sidearm system and the former main stream was blocked and the hydrological regime changed, dramatically. The network of sidearms was divided into isolated sections and their character changed from lotic to lenitic. A number of smaller oxbows also became isolated. At present, some of the main branches are permanently fed by water from the new channel and thus have again a predominantly lotic character. However, a uniform littoral zone has emerged in the original riverbed of the Danube, with strongly reduced water levels. The littoral zone has shifted towards the middle of the riverbed, and therefore, many natural shelters as well as spawning grounds disappeared. As a result, both abundance and species diversity have decreased in the littoral zone of the former main stream [12]. The relative abundance of eurytopic, mostly phytophilous species with a wide ecological tolerance, increased. In contrast, rheophilous species, predominant in the sidearms in the past, have become subdominant or recedent. Abundance of almost all species of fishes, especially predators, has decreased considerably.

However, this is not only a consequence of the environmental changes associated with GHS but also a consequence of high pressure from anglers and poachers violating the fishery legislation in 1990s. The age structure of many populations has also changed – specimens of higher age classes are now very rare and the rate of reproduction rather low. The relative abundance declined mainly in such species as pike, pikeperch and wels. In contrast, species as burbot (*Lota lota*) and/or zingel (*Zingel zingel*) benefit from the presence of invasive gobies that have become their dominant prey. Recently, there have been several attempts to revitalise the former sidearm system of the inland delta, and there is a hope that many of the former habitats will be restored. Nonetheless, it will take decades to re-establish or at least to approach the original diversity in local fish communities.

In Lower Danube, construction of Iron Gate 1 (river km 942.5) in 1970 and Iron Gate 2 (river km 863) in 1984 interrupted longitudinal connectivity of the river and resulted in a physical separation from the Middle Danube [5]. Subsequently, side levees separated the main channel of the river from its floodplain, which lead to a serious impact on the overall environmental situation and fisheries. The area of the former floodplain saturated by natural floods was reduced to 15% of its original size (approximately 5000 km^2). The discharge regime, the transport of suspended sediments and bed load as well as the daily water level fluctuation in the Bulgarian and Romanian stretches of the Danube also changed, considerably. The negative impacts of these changes as well as impacts of other dams in the Danube on fish communities and fisheries have been discussed by Schiemer et al. [5].

6.3 Navigation

Several recent studies from all the three sections of the Danube have addressed the essential role of the littoral zone, including the shoreline, for long-term survival of native fish communities and for keeping their natural composition, diversity and structure [14–16].

The results from the JDS2 suggest that navigation has a negative impact on fish community, and this is probably most intensive in the Upper Danube [7]. Moving vessels generate large waves that can drift larvae or beach out juveniles and affect thus the reproductive success of some species, such as barbel and nase. Heavy navigation can therefore result in changes in population structure of species that depend on the littoral zone. For example, Wiesner et al. [7] have reported clear differences between the population structure of barbel and nase at Kelheim (a site without navigation) and Jochenstein (a site with a narrow channel and navigation). It also appears, however, that further downstream, the negative impact of navigation decreases, probably due to the increasing width of the Danube [7].

7 Non-native and Invasive Species

A total of 69 species of fishes were recorded within the recent surveys of the Danube [6, 12], a number that suggests a high diversity of the Danubian fish community. However, as many as 12 of these species are not native in the Danube, at least not in its whole course, and a total of 18 non-native species have been ever recorded in the Danube (Table 5).

All of these species have been introduced to the Danube by humans, some of them intentionally, but most of them unintentionally. When assessing ecological status of a river, it is important to distinguish between non-native species and those that have become invasive. There have been numerous debates on what it means to be invasive, and various definitions have been proposed (e.g. Copp et al. [9]). Very often, invasive organisms are considered "native or alien species that spread, with or without the aid of humans, in natural or seminatural habitats, producing a significant change in composition, structure, or ecosystem processes, or cause severe economic losses to human activities" (see Paunović et al.). However, to assess whether a change in composition, structure or ecosystem processes is significant or not depends on how we define what is "significant" and what is not, which is often a subjective judgement rather than a scientific analysis. Similarly, what is the boundary between severe and less than severe economic losses to human activities may also vary from opinion to opinion. Finally, assessments of the impacts of non-native species to ecosystems and/or economies, supported by scientific data, are not always available. Therefore, in this chapter, non-native species are considered those that had not occurred in the Danube prior to introduction by humans, whereas invasive species are considered only those from them that

Table 5 A list of species of fishes (+) ever reported from the Danube (data from Schiemer et al. [5]), found recently in the Austrian, Hungarian and Romanian parts of the Danube [5], found during JDS2 in the Upper, Middle and Lower Danube [7], found during the monitoring of the Čunovo–Sap section in 1991–2011 (data from J. Černý [8]) and confirmed recently, i.e. collected recently, in any section of the Danube (results from JDS2 and monitoring together)

Species	reported ever	Sch. et al. (2004)	JDS2 Upper	JDS2 Middle	JDS2 Lower	1999-2011	confirmed recently
Abramis ballerus (Linnaeus, 1758)	+	+	-	+	+	+	+
Abramis brama (Linnaeus, 1758)	+	+	+	+	+	+	+
Abramis sapa (Pallas, 1814)	+	+	+	+	+	-	+
Acipenser gueldenstaedtii Brandt et Ratzeburg, 1833	+	+	-	-	-	-	-
***Acipenser nudiventris* Lovetzky, 1828**	**+**	**-**	**-**	**-**	**-**	**-**	**-**
Acipenser ruthenus Linnaeus, 1758	+	+	-	+	+	-	+
Acipenser stellatus Pallas, 1771	+	+	-	-	+	-	+
***Acipenser sturio* Linnaeus, 1758**	**+**	**-**	**-**	**-**	**-**	**-**	**-**
Alburnoides bipunctatus (Bloch, 1782)	+	+	+	+	-	-	+
Alburnus alburnus (Linnaeus, 1758)	+	+	+	+	+	+	+
Alosa immaculata Bennett, 1835	+	+	-	-	-	-	-
Alosa maeotica (Grimm, 1901)	+	+	-	-	-	-	-
Alosa tanaica (Grimm, 1901)	+	+	-	-	-	-	-
Ameirurus melas (Rafinesque, 1820)	+	+	-	+	-	+	+
Ameiurus nebulosus (Lesueur, 1819)	+	+	-	+	+	-	+
Anguilla anguilla (Linnaeus, 1758)	+	+	+	+	-	-	+
Aspius aspius (Linnaeus, 1758)	+	+	+	+	+	+	+
Atherina boyeri Risso, 1810	+	+	-	-	-	-	-
Barbatula barbatula (Linnaeus, 1758)	+	+	+	-	-	+	+
Barbus barbus (Linnaeus, 1758)	+	+	+	+	+	+	+
Barbus peloponnesius Valencienns, 1842	+	+	-	-	-	-	-
Benthophiloides brauneri Belling et Iljin, 1927	+	+	-	-	+	-	+
Benthophilus stellatus (Sauvage, 1874)	+	+	-	-	+	-	+
Blicca bjoerkna (Linnaeus, 1758)	+	+	+	+	+	+	+
Carassius carassius (Linnaeus, 1758)	+	+	-	+	+	+	+
Carassius gibelio (Bloch, 1782)	+	+	+	+	+	+	+
Clupeonella cultriventris (Nordmann, 1840)	+	+	-	-	-	-	-
Cobitis elongatoides Bacescu et Mayer, 1969	+	+	-	+	+	+	+
Coregonus albula (Linnaeus, 1758)	+	+	-	-	-	-	-
Coregonus peled (Gmelin, 1788)	+	+	-	-	-	-	-
Coregonus renke (Schrank, 1783)	+	+	-	-	-	-	-
Cottus gobio Linnaeus, 1758	+	+	+	-	-	+	+
***Cottus poecilopus* Heckel, 1836**	**+**	**-**	**-**	**-**	**-**	**-**	**-**
Ctenopharyngodon idella (Valenciennes, 1844)	+	+	-	-	-	-	-
Cyprinus carpio Linnaeus, 1758 (wild form)	+	+	+	+	+	+	+
Esox lucius Linnaeus, 1758	+	+	+	+	+	+	+
Eudontomyzon mariae (Berg, 1931)	+	+	-	+	-	-	+
Gasterosteus aculeatus (Linnaeus, 1758)	+	+	+	-	-	+	+
Gobio albipinnatus Lukasch, 1933	+	+	+	+	+	+	+
Gobio gobio (Linnaeus, 1758)	+	+	+	+	-	-	+
Gobio kesslerii Dybowski, 1862	+	+	-	-	-	+	+
Gobio uranoscopus (Agassiz, 1828)	+	+	-	-	-	-	-
***Gobius ophiocephalus* (Pallas, 1814)**	**+**	**-**	**-**	**-**	**-**	**-**	**-**
Gymnocephalus baloni Holčík et Hensel, 1974	+	+	+	+	+	+	+
Gymnocephalus cernuus (Linnaeus, 1758)	+	+	+	+	+	+	+
Gymnocephalus schraetser (Linnaeus, 1758)	+	+	+	+	+	-	+
Hucho hucho (Linnaeus, 1758)	+	+	+	-	-	-	+
Huso huso Linnaeus, 1758	+	+	-	-	-	-	-
Hypophthalmichthys molitrix (Valenciennes, 1844)	+	+	-	+	-	-	+
Hypophthalmichthys nobilis (Richardson, 1845)	+	+	-	-	-	-	-
***Chalcalburnus chalcoides* (Gueldenstaedt, 1772)**	**+**	**-**	**-**	**-**	**-**	**-**	**-**
Chondrostoma nasus (Linnaeus, 1758)	+	+	+	+	+	+	+
Ictalurus punctatus (Rafinesque, 1818)	+	+	-	-	-	-	-
Knipowitschia cameliae Nalbant et Otel, 1995	+	+	-	-	-	-	-
Knipowitschia caucasica (Berg, 1916)	+	+	-	-	-	-	-
Lepomis gibbosus (Linnaeus, 1758)	+	+	+	+	+	+	+
Leucaspius delineatus (Heckel, 1843)	+	+	-	-	-	-	-
Leuciscus borysthenicus (Kessler, 1859)	+	+	-	-	-	-	-
Leuciscus cephalus (Linnaeus, 1758)	+	+	+	+	+	+	+
Leuciscus idus (Linnaeus, 1758)	+	+	+	+	+	+	+

(continued)

Table 5 (continued)

Leuciscus leuciscus (Linnaeus, 1758)	+	+	+	+	-	+	+
Liza aurata (Risso, 1810)	+	+	-	-	-	-	-
Liza saliens (Risso, 1810)	+	+	-	-	-	-	-
Lota lota (Linnaeus, 1758)	+	+	+	+	-	+	+
Micropterus salmoides (La Cepéde, 1802)	+	+	-	-	-	-	-
Misgurnus fossilis (Linnaeus, 1758)	+	+	-	+	-	+	+
Mugil cephalus Linnaeus, 1758	+	+	-	-	+	-	+
Neogobius eurycephalus (Kessler, 1874)	+	+	-	-	+	-	+
Neogobius fluviatilis (Pallas, 1814)	+	+	-	+	+	+	+
Neogobius gymnotrachelus (Kessler, 1857)	+	+	-	+	+	+	+
Neogobius kessleri (Gunther, 1861)	+	+	+	+	+	+	+
Neogobius melanostomus (Pallas, 1814)	+	+	+	+	+	+	+
Neogobius syrman (Nordmann,1840)	+	+	-	-	-	-	-
Oncorhynchus mykiss (Walbaum, 1792)	+	+	+	-	-	-	+
Pelecus cultratus (Linnaeus, 1758)	+	+	-	+	+	-	+
Perca fluviatilis Linnaeus, 1758	+	+	+	+	+	+	+
Percarina demidoffi (Nordmann, 1840)	+	+	-	-	-	-	+
Perccottus glenii Dybowski, 1877	+	-	-	+	+	-	+
Phoxinus phoxinus (Linnaeus, 1758)	+	+	+	-	-	-	+
Platichthys flesus (Linnaeus, 1758)	+	+	-	-	-	-	+
Proterorhinus Marmoratus (Pallas, 1814)	+	+	+	+	+	+	+
Pseudorasbora parva (Temminck et Schlegel, 1842)	+	+	-	+	+	-	+
Pungitius platygaster (Kessler, 1859)	+	+	-	-	-	-	-
Rhodeus sericeus (Pallas, 1776)	+	+	+	+	+	+	+
Rutilus meidingeri (Heckel, 1851)	+	+	-	-	-	-	-
Rutilus pigus (La Cepéde, 1803)	+	+	+	+	-	-	+
Rutilus rutilus (Linnaeus, 1758)	+	+	+	+	+	+	+
Sabanejewia sp.	+	+	-	+	-	-	+
Sabanejewia bulgarica Drensky, 1928)	+	+	-	-	-	-	-
Salmo trutta m. fario (Linnaeus, 1758)	+	+	+	-	-	-	+
Salvelinus fontinalis (Mitchill, 1814)	+	+	-	-	-	-	-
Sander lucioperca (Linnaeus, 1758)	+	+	+	+	+	+	+
Sander volgensis (Gmelin, 1788)	+	+	+	+	+	+	+
Scardinius erythrophthalmus (Linnaeus, 1758)	+	+	+	+	+	+	+
Silurus glanis Linnaeus, 1758	+	+	+	+	+	+	+
Syngnathus abaster Risso, 1859	+	+	-	-	+	-	+
Thymallus thymallus (Linnaeus, 1758)	+	+	+	-	-	-	+
Tinca tinca (Linnaeus, 1758)	+	+	+	+	+	+	+
Umbra krameri Walbaum, 1792	+	+	-	-	-	-	-
Vimba vimba (Linnaeus, 1758)	+	+	+	+	+	+	+
Zingel streber (Siebold, 1863)	+	+	+	-	-	+	+
Zingel zingel (Linnaeus, 1766)	+	+	+	+	+	+	+
Total number	102	96	45	51	46	42	69

Species in bold are considered extinct or not present in the Danube any longer, light grey indicates non-native species and their presence and dark grey indicates invasive species and their presence have established viable populations, achieved high abundance and tend to spread actively into new areas of distribution. Thus, the current list of invasive species of fishes in the Danube contains nine species (black bullhead, gibel, pumpkinseed, monkey goby, racer goby, bighead goby, round goby, Amur sleeper and topmouth gudgeon), though not all of them demonstrate the above invasive attributes in their Danubian habitats, and not all of them are invasive throughout the whole course of the river.

The black bullhead (*Ameiurus melas*) was introduced to Europe in the late nineteenth and early twentieth centuries and is now established in many European countries [9, 17]. With its tendency to overpopulate and spread rapidly, black bullhead is considered to be a species with a notable invasive potential [18]. Nevertheless, a recent study suggests that, in the Danubian area, black bullhead has been spreading, thanks to increased propagule pressure (i.e. continuing introductions by humans) rather than on its own [19]. This is also supported by the fact that during JDS2 black bullhead was recorded in the Middle Danube but not in the Upper or Lower Danube (Tables 1, 2 and 3). On the other hand, once a population has been established locally, its abundance has the potential to grow very fast (see Table 4, 2005–2011).

Gibel (*Carassius gibelio*) is reported to have appeared in the Lower Danube in the first quarter of the last century and to have invaded the Middle and Upper Danube, afterwards [20]. Its invasion was facilitated by its gynogenetic reproduction – the entire population contained females, exclusively. Gibel females used males of other cyprinid species for reproduction (e.g. Balon [21] and Holčík [22]). In the Slovak part of the Danube, the first males were observed in 1992, and since then the population of gibel, being well established, consists of both sexes. It appears that in the Middle Danube the abundance of gibel has stabilised at much lower levels compared to Lower Danube, where the species still keeps extremely high relative abundance (Tables 2 and 3).

One of the most successful of the non-native fish species in Europe is pumpkinseed *Lepomis gibbosus* [23, 24], which was first introduced around 1880 [25] and during the nineteenth and twentieth centuries became established in many European countries [26]. Pumpkinseed has been reported to be very common in the Slovak stretch of the Danube, especially the floodplain areas and the lower parts of the Danube's tributaries [27, 28]. Indeed, pumpkinseed appears to be the third most abundant species of fish in the Gabčikovo–Sap section (Table 4), and it has been recorded in all three sections of the Danube during JDS2 (Tables 1, 2 and 3).

Over the last two decades, four species of gobies, native to Lower Danube, have invaded the Middle and Upper Danube: bighead goby, racer goby, monkey goby and round goby. The expansion of these species was facilitated by human activities (e.g. Wiesner [29]), and all these species spread rapidly [9].

Bighead goby originally inhabited the brackish zone in northern and western shores of the Black Sea and lower parts of rivers entering the sea between the rivers Danube and Dnepr [30]. The species appeared in the Middle Danube in the early 1990s, first found in Hungary [31] and then (in 1994) in eastern Austria [32, 33].

The first records of bighead goby in the Slovak part of the Danube were in June 1996 [34, 35].

However, bighead goby, the first Ponto–Caspian gobiid invader of the Middle and Upper Danube and previously the most abundant and widely distributed of the invading gobiids, has been recently outnumbered in both abundance and distribution dynamics by a subsequent invader, the round goby [36]. Indeed, round goby has recently greatly extended its native range from the Black Sea, Caspian Sea and surrounding waters and invaded not only the Middle and Upper Danube but also the River Moscow and ultimately the Baltic Sea [9] as far as the German coast [37]. Round goby has invaded not only across Europe but also Great Lakes in North America. In the Danube, Bănărescu [20] reported the upriver expansion of round goby since the 1960s, but it had been known earlier as far upstream as Vidin [38, 39]. In 1997, the species was found for the first time in the Serbian part of the Danube [40]. By 2000, it was present in the main Danube near Vienna, Austria. Since then, it has been observed in modest abundance, mainly in industrial harbours and to a lesser extent along the banks of the main channel [29]. In 2003, round goby was detected as the fourth new gobiid species in the Slovak catchment of the Danube [9, 41].

Monkey goby established populations in Hungary already in the 1980s (Lake Balaton and River Tisza; [42]). In Slovakia, monkey goby was first observed in 2001 in the Danube and its tributaries, including the River Hron [43]. However, the current distribution and habitat preferences of monkey goby in the Middle and Upper Danube differ from the other two invasive goby species [44]. Also, monkey goby has not achieved the same high densities as the bighead and round gobies [45], and because of high habitat specialisation, it appears that monkey goby will not be so widespread and abundant as round and/or bighead goby.

Racer goby has also invaded both the Middle and Upper Danube and, similar to round goby, has reached the River Rhine, where it was first recorded in 2010 [46]. In the Danube, both distribution and abundance of racer goby have been rather limited, especially compared to round and bighead gobies (Tables 1, 2, 3 and 4).

Amur sleeper (*Perccottus glenii*), highly invasive elsewhere (e.g. Grabowska et al. [47]), has been recorded only sporadically in the middle section of the Danube (Table 2). Nevertheless, its extremely high invasive potential makes Amur sleeper a hot candidate to become a highly invasive species in the inundation area across all sections of the Danube. Therefore, this species deserves special attention, with the emphasis to risk assessment and prevention.

One of the most successful invasive species in Europe in recent times has been the topmouth gudgeon *Pseudorasbora parva*, a cyprinid native to East Asia that has achieved an almost pan-Eurasian distribution within less than 40 years [48, 49]. The species was accidentally introduced as a contaminant of imported fish consignments, such as grass carp, which arrived in Romania in 1961 and 1962 [50]. Topmouth gudgeon subsequently dispersed through most of Europe, again as a contaminant of fish consignments and by natural dispersal via watercourses [9, 51, 52]. A detailed recent review has even assigned topmouth gudgeon to be the most compelling fish invasion in the world [53]. Therefore, even if this species was recorded only in the Lower Danube during JDS2, it is also present in the Upper and Middle Danube and certainly represents a great risk for the native fish communities, especially because topmouth gudgeon is a host of two highly pathogenic parasites – *Anguillicola crassus* and the rosette agent *Sphaerothecum destruens* [54, 55].

Biological invasions may lead to the extirpation of native species, resulting in an overall decline in biodiversity [56]. Indeed, for example, in the Slovak part of the Middle Danube, invasive species of fishes, especially two species of gobies (round and bighead), topmouth gudgeon and black bullhead, have become a major problem for native fish communities. Small benthic native species, e.g. bullhead, white-finned gudgeon and stone loach, virtually disappeared from the local fish communities [12]. However, a wide-scale analysis of the impact of invasive species on Danubian fish communities is still lacking. Accidental introductions, which should be regarded as biological pollution [57], can often lead to irreversible ecological impacts on native ecosystems [53]. Therefore, a predictive risk assessments and management strategies of introductions and invasions of non-native fishes should be developed for the Danube and applied subsequently at an international level.

8 Conclusions

A total of 69 species of fishes that were recorded within the recent ichthyological surveys of the Danube may seem to demonstrate a high diversity of the current Danubian fish community. However, the structure of this community, especially species composition (high predominance of bleak and high relative densities of invasive species), does not provide an ideal picture at all. Indeed, environmental pressures resulting from human activities have serious negative impacts on the Danubian ecosystems. River regulations, constructions of dams and reservoirs, deterioration of water quality, navigation, etc., these all have reduced most of the native populations of fishes, and several species have been even extinct. To prevent further deterioration of the Danubian fish community, the human activities with potential negative impacts should be reconsidered, and programmes of restorations should be developed. Occasional high water levels, such as that in August 2002, clearly demonstrate that the sidearm systems have vital importance for fish in the Danube, as they serve as spawning and nursery grounds for most species. Therefore, special attention should be paid to restoration of both longitudinal and transversal connectivities between the sidearms and the main channel of the river, especially in the Upper and Middle Danube. Finally, because of serious ecological as well as economic and social threats posed by biological invasions, a predictive risk assessments and management strategies for introductions and invasions of non-native fishes should be developed for the Danube and applied subsequently at an international level.

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