Geobotany Studies
Basics, Methods and Case Studies

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Franco Pedrotti · Kevin Cianfaglione
John R. Akeroyd *Editors*

Human Impact on Danube Watershed Biodiversity in the XXI Century

Springer

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Contents

Introduction

Angela Curtean-Bănăduc, Kevin Cianfaglione, John Robert Akeroyd, Doru Bănăduc, and Franco Pedrotti

The largest European lotic systems, and their associated wetlands—streams, springs, marshes, forests, valleys, plains, bogs, ponds, lakes, deltas and estuaries—have been populated by humans for millennia. They have been and continue to be a significant driving force in many human cultures and civilizations. These human societies arose in such areas due to the fact that they were favourable in terms of natural resources, and were strategic localities in which to install human settlements. In general these areas have a great and wide ecological value, including a rich natural diversity in products and services, that make them very attractive with regard to economic, social, political and military issues.

But on the other hand, this wide interest is the basis of pollution, urbanization, deforestation, reclamation, logging, modification of land forms and water characteristics, and ecosystem dynamics: resulting in biodiversity loss, anthropization, hydrogeological disruption, simplification of biological communities and loss of productivity.

The second largest European river after the Volga is the Danube, one of the major rivers of our planet for its geographical and human history importance. The footprints of the first Danubian human communities date back to around 200,000 BC. In more recent history, the river has been a major international waterway and area of settlement, with numerous cities, including four capital cities, Belgrade, Bratislava,

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Budapest and Vienna, lying on its banks. The length of the Danube River is 2826 km and its watershed of 801,093 km^2 is shared today between 19 countries, from its springs in the Black Forest to its water outflow of an average of 827 km^3/year into the Black Sea.

The natural attractions of the Danube River basin for human societies throughout history favoured an extensive, intensive, significant, complex long-term human impact, in spite of the progress of modern ecology and green policies.

We need to remember that the Danubian Limes (comprising the Limes Germanicus-Raeticus) was an important sector of the Limes of the Roman Empire, in other word the fortification system that defended the Empire. It is no coincidence that the word “Limes” in Latin has a double meaning: in the first case, it means “boundary line”; and in the second case “way” or “road” that could be also the way to penetrate new territories to conquest or conquer. In later centuries the Danube River remained an important frontier zone fought over by different empires and nations.

Of particular importance is the azonal vegetation of the Danube, that can be divided into two groups: the vegetation of water (hydrophytes and helophytes) and the vegetation of shores, banks and terraces. The latter group corresponds mainly to forests of deciduous species, among them *Salix alba*, *Salix fragilis*, *Alnus incana*, *Alnus glutinosa*, *Pinus sylvestris*, *Populus alba*, *P. nigra*, *Ulmus minor, U. laevis*, *Prunus padus*, *Quercus robur*, *Fraxinus excelsior*, *Tilia cordata* and *Carpinus betulus*, with many associations that follow upon each other longitudinally from the mountains to the plains and transversely, from the center of the watercourse to the external terraces.

Forests, the vegetation of the banks and shores was progressively reduced by humans over the centuries, but in some countries of the Danube basin there are still significant testimonies to what they once was. The forest of Hasmacul Mare in the Danube delta is an extraordinary example of an alluvial forest. It covers about 500 ha on the island of Leita in the form of strips that occupy the sandy interdunal habitats, with impressively large trees, dominated by *Quercus robur*, *Q. pedunculiflora*, *Fraxinus pallisae*, *F. angustifolia*, *Populus alba* and *Tilia tomentosa*. The abundance of lianas (*Vitis sylvestris*, *Clematis vitalba*, *Hedera helix* and *Periploca graeca*) gives the impression of a tropical forest. Today, all the waterside vegetation needs to be conserved with a great care.

Other oaks, conifers and beech formations are mostly found on the valley slopes, in zonal forests.

In the Danube basin, deforestation has led to critical phenomena of hydrogeological instability, strong upstream erosion and strong downstream deposits. Loss of natural habitats and related biodiversity. Happened not only in the past, but also recently or actually (e.g.: in Serbia and Montenegro). The Danube is a summing up of environmental and social problems that develop along its course to the Sea. Classic examples are human settlements (urban-industrial) development causing Land artificialization, and ecosystems loss. Or the excessive stubborn hunting pressure that runs along its course causing huge disturbance and pollution; especially impacting in its Delta.

The goal of this publication is an attempt to describe and understand some Landscape (geographical, cultural and natural heritage) values interactions, to identify threats and the different types of human impact affecting this system, in all the countries of the Danube River Basin, based upon the scientific researches and points of view of a range of experienced naturalists, now at the beginning of the twenty-first century, a new century in which the human–nature relationship is still far from balanced.

A general introduction on the environment and vegetation of the Danube basin, by *Franco Pedrotti*, shows us that we can distinguish the following types of environment: mountains, hills, plains, swamps, lakes, rivers, mires, saline places, deltas and hydrographic network. For each of the environments the phytogeographic, chorological, ecological, floristic and vegetational features are illustrated.

The stretch of the Upper Danube in Germany was approached by *Erika Schneider-Binder* in the context of habitat changes due to human impact in terms of: basic ecological conditions on the German stretch of the Upper Danube River; hydrological characteristics; morphological dynamics; climate gradients; climatic-biogeographical differentiation; human impacts and their consequences; measures for improvement—studies, programmes and plans for restoration; present state of the habitats on the German Upper Danube; the Natura 2000 network on the Upper Danube; future perspectives.

In the headwater region in Switzerland of the Danube tributary the river Inn, *Conradin Adolf Burga* and *Elias Landolt*, in the context of a Swiss plant diversity hotspot and premium tourism region, reveal elements of: geography; climate; geology; glacier and vegetation history; flora; hotspots of flowering plants diversity; altitudinal vegetation zonation; tourism.

The riparian vegetation of the Danube in Austria was realized by *Erich Huebl* following these main categories: softwood flood plain (*Salicetum albae*, *Alnetum incanae*), hardwood flood plain (communities of *Quercus robur*, *Ulmus minor*, *Fraxinus excelsior*, *Carpinus betulus*) and paludification of stagnant old river branches (communities of hydrophythes and helophytes).

In the Danube Basin in Italy, in a landscape-environment-culture-management context, some elements are highlighted by *Kevin Cianfaglione* and *Franco Pedrotti*, mainly based on information related to geography; administration; altitudinal belts; plant landscape; thematic maps; fauna aspects; protected areas; history of the territory, land uses and anthropogenic impact.

In a part of the Danube Basin in Slovenia, *Andraž Čarni* and *Nina Juvan* integrate in this publication some aspects concerning forest vegetation along the Mura River basin, related to: geography; bedrock and soils; fauna; endangered flora; invasive species; overview of non-forest vegetation; forest vegetation.

In the area studied in *Czech Republic*, *Zdeněk Adámek*, *Zdenka Jurajdová*, *Michal Janác*, *Světlana Zahrádkova*, *Denisa Nemejcová* and *Pavel Jurajda*, based on a case study of fish assemblages in response to human impact, approached the subject on the basis of: general characteristics of the Morava River basin; current situation as regards habitat and water quality degradation along the lower Morava and Dyje;

physical habitat degradation; water quality development; history of ichthyological research; fish monitoring.

The contribution of *Marko Ćaleta*, *Perica Mustafić*, *Davor Zanella*, *Ivana Buj*, *Zoran Marčić* and *Milorad Mrakovčić* from *Croatia* is based, in the context of the Morava and Dyje basins on: hydrology; speleology; subterranean fauna; limnofauna; fish fauna; human impact.

The data studied from the River Vrbas tributaries area of Bosnia and Herzegovina by *Radoslav Dekić* and *Aleksandar Ivanc*, rely upon: geographical characteristics of the watershed; topography; climate; hydrology; zoobenthos; ichthyofauna.

The Szigetköz floodplain researched in *Hungary* by *Gábor Guti* sheds light on elements related to: hydrology; hydro-morphology; aquatic habitats; ecological processes; vegetation; aquatic invertebrates; fish; historical river utilisation and land use; river engineering; fisheries; agriculture; forestry; alterations of the river-floodplain ecosystem; hydrological and hydro-morphological dynamics; aquatic habitats; environmental objectives of river restoration.

Some anthropogenic pressures on watercourses of the Danube River basin approaches in Montenegro was carried out by *Vesna Dikanović*, *Miroslav Nikčcević*, *Branislav Mićković*, *Aleksandar Hegediš*, *Danilo Mrdak* and *Vladimir Pešić*, based on: anthropogenic pressures that affect surface waters; sources of watercourse pollution; biological indicators of water quality; macro-invertebrates; fish.

Mirjana Lenhardt, *Ivan Jarić*, *Stoimir Kolarević*, *Branka Vuković-Gačić*, *Jelena Knezević*, *Maria Smederevac-Lalić*, *Gorčin Cvijanović* and *Zoran Gačić* from Serbia, present the impact of some human activities on the status of the Danube River in Serbia, based on: microbiological and ichthyofaunistic data related with: water and sediment pollution; major pollution hotspots; impact of Danube pollution on aquatic biota and the state of scientific research; recent management and policy initiatives and future priorities; influence of the Djerdap I and Djerdap II dam construction on fish populations; impact of the fishery on ichthyofauna; microbiological and genotoxicity analyses.

For Slovakia, *Emília Mišiková Elexová* and *Jarmila Makovinská*, offer some conclusions regarding the aquatic ecosystems in the Danube River, based on: geographical characteristics; socio-economic data; water services; geomorphology; hydromorphology, benthic invertebrates; phytobenthos; diatoms; non-diatoms; phytobenthos biomass; phytoplankton; macrophytes; zooplankton; fish; invasive alien species; ecological status assessment.

For the state and changes of natural environment of the Danube River basin in Poland, *Weronika Maślanko*, *Beata Ferencz* and *Jarosław Dawidek*, reveal some elements regarding: geography; administration; climate; hydrography; geology; soil; water; land use; protected areas; fauna; flora; changes of natural environment; changes of water quality parameters; changes in the biosphere; potential threats.

For Ukraine, *Sergey Afanasyev*, *Artem Lyashenko*, *Alexei Iarochevitch*, *Olena Lietytska*, *Ekaterina Zorina-Sakharova* and *Olena Marushevska*, present data regarding the pressures and impacts on ecological status of surface water bodies in terms of: geography; hydromorphology; plankton; water plants; invertebrates; fish; organic and nutrient pollution; hazardous substances pollution; hydromorphological alterations; littering of the riverbeds and floodplains by communal waste; expansion of invasive species; ecological status assessment; aquatic biodiversity; pressures.

Rigers Bakiu from Albania, highlights some elements of interest of the Drina River (the Sava's tributary of the Danube River) and the related human impact, in relation to: geography; palaeogeography; climate; hydrology; biogeochemistry; flora; fauna; economy; environmental impact.

Some characteristics of the Danube Drainage in Republic of Macedonia, are presented by *Vasil Kostov*, *Valentina Slavevska-Stamenkovic*, *Milica Ristovska*, *Vasko Stojov* and *Saša Marić*, based on the following elements: geography; hydrology; geology; climate; vegetation; fauna; threats.

For Bulgaria, *Lyubomir Kenderov* and *Teodora Trichkova* reveal long-term changes in the ecological conditions of the Danube tributary the Iskar River, regarding: geography; geomorphology; climate; water use; hydrology; water chemistry; benthic macroinvertebrates; fish.

For the lowest Danubian country, with the major part of the Danube Basin, Romania, *Angela Curtean-Bănăduc* and *Doru Bănăduc*, bring to attention the Târnava River Basin, based on: geography; hydrology; human impact; aquatic and semi-aquatic biodiversity; management and conservation elements.

After the world wars, the iron curtean, and European Union, actually the Danube is still a Limes. But not a Limes to penetrate new territories and not a boundary. Finally, it represent a way that link the European Community and its People.

Independent studies around the Danube Basin, high diversity approaches of 64 experienced researchers in the field, from 18 Danubian countries, highlight that the green strategies and actions in the Danube Basin are showing signs of progress. It is a good start but . . . it is a long scientific, administrative and policy way to go to have a basin which can offer, due to its as close as is possible natural dynamic equilibrium, the most beneficial natural long-term products and services.

These studies confirm how biodiversity, conservation and ecological related studies can provide a successful tool to promote mutual cooperation and integration of effort as they should to be in a responsible continent.

Overview of the Environment and Vegetation of the Danube Basin

Franco Pedrotti

The River Danube (in Latin *Danubius* or *Danuvius*, German *Donau*, Italian *Danubio*, Czech *Dunaj*, Slovenian *Donava*, Croatian *Dunav*, Hungarian *Duna*, Romanian *Dunărea*, Albanian *Danubi*, Serbian and Bulgarian *Дунав—Dunav*) rises in the Black Forest (Germany) and pours into the Black Sea (Romania), after a journey from west to east of 2860 km. Its water catchment area covers an area of 805,000 km^2 and is surrounded by mountain groups such as the Alps, the Tatra, the Carpathians and the Dinarids, which have many peaks that exceed 2000 m; the highest point is Pizzo Bernina, in the Alps, at 4050 m. In the central part lies the Pannonian plain and, further south, the Romanian plain, bordered to the north by the Carpathians, and the Bulgarian plain, bordered to the south by the two chains of Stara Planina and Rila Planina. This territory is characterized by a temperate macrobioclimate with the exception of a narrow strip along the coasts of the Black Sea, in Romania and Bulgaria, which possesses steppe characteristics (Rivas Martìnez 1996). Annual precipitation is between 2000 mm in the Black Forest (oceanic influence) and 500–800 mm on the Pannonian plain (continental influence), while exhibiting a strong decrease on the Black Sea coast, with 385 mm at Constanța.

1 Plant Geography

From the phyto-geographical point of view, the Danube basin belongs within two vegetation zones (Fig. 1), the nemoral zone to the north and the steppe zone to the south-east (Ivan et al. 1993; Postolache 1995; Ozenda and Borel 2000; Safronova 2005; Ogureeva 2005). The nemoral zone is characterized by deciduous forests and

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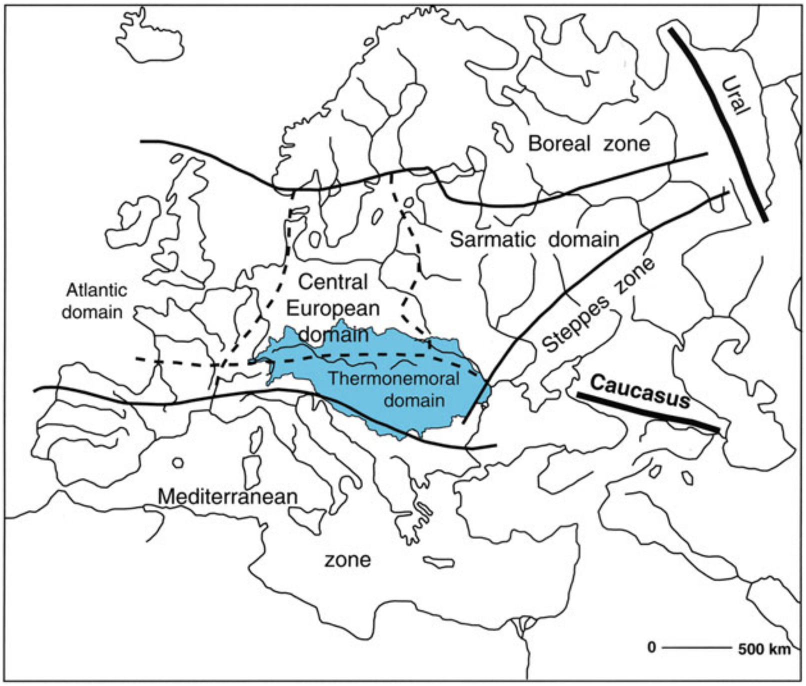

Fig. 1 The hydrographic basin of the Danube is located in the nemoral zone (thermonemoral domain) and in a small part of the steppe zone, to the east; in the south it is in contact with the Mediterranean area (from Ozenda and Borel 2000 *modified*)

is the most extensive, the steppe area being limited to part of Moldova and Muntenia and to Dobrogea, and having the vegetation of the steppes. At the contact between the two zones a transition band called silvosteppe is distinguished, distributed outside the Carpathian arc in the plains of Moldova, Dobrogea, Muntenia and Oltenia; *Quercus robur* forests are developed in northern Moldova and *Quercus pedunculiflora* and *Q. pubescens* in Muntenia and Oltenia. The northernmost extensions of silvosteppe in Moldova are those of the Forestry District of Gîrcina in the province of Piatra Neamț (Gafta 1991).

In the Danube basin the following types of environment can be distinguished: mountains and hills, plains, swamps, lakes, rivers, mires, saline places, deltas and hydrographic network.

Mountains and Hills The mountainous and hilly systems that delimit the Danube basin are as follows: the left side of the river basin, (1) Black Forest (Schwarzwald), to 1493 m; (1a) Svabian Alb, to 1009 m; (2) Bohemian Forest, to 1458 m; (3a) Sudetes, to 1491 m; (3) Tatra, to 2655 m; (4) Carpathians, with Retezat 2509 m; right hydrographic side: (6) Alps, with Bernina 4050 m; (7) Dinarides, with Bobotov Kuk 2523 m; (8a) Stara Planina, with Botew 2376 m; (8b) Rila Planina, with Moussala 2925 m; the chain of the Carpathians extends far into the river basin, forming the Carpathian arc. Other mountainous groups, which however reach lower altitudes than those listed above, occupy an isolated position within the greater Danube basin: (9) Little Carpathians, 768 m; (9c) Matra, 1014 m, and others in Hungary; (5) Apuseni, 1849 m; (11) Mecsek, 682 m, and others in Hungary; (14) reliefs of Slavonia, 894 m, and others in the Balkan Peninsula, (16) Kopaonik, 2017 m, and others in Serbia, (8b) Rila Planina. The reliefs outside the Carpathian arc (Moldova) are just over 500 m, (18) Dealu Mare, 587 m; (19) Colinele Tutovei, 562 m; (20) Bălăneşti, 430 m.

Plains (1) Bavaria, 500 m; (2) Lower Austria, 150–500 m; (3) Pannonian plain, also called Câmpia Dunării de Mijloc, divided into two parts as follows: (3a) Pannonian plain, to the left of the Danube, 100 m, and (3b) Pannonian plain, to the right of the Danube, 100 m, is the great central plain of the entire river basin, extended from Vienna to Budapest and Belgrade; (4) Podisul (Câmpia) Transilvaniei, 400 m; (5) Câmpia Română, also called Câmpia Dunării de Jos (Oltenia, Muntenia), 70–150 m; (6) Podisul Moldovei, 0–150 m; (7) Podisul Dobrogei, 0–89 m; (8) Southern Danube plain, Bulgaria, 0–100 m; (9) Southern Belgrade plain, 100–120 m; (10) Southern Zagreb plain, 100–120 m; (11) Ljubljana, Slovenia, 300–800 m; (12) Klagenfurt, Kärnten, 400 m.

Swamps At the Neusiedl and Balaton lakes (Austria and Hungary) and in some areas of the Tisza River basin (north-eastern Hungary).

Lakes In the Danube basin there are two large lakes, Neusiedl and Balaton, and many small lakes, especially in the mountains, which are not represented on the map.

Mires Peat bogs are not depicted on the map, because they are small.

Coastal Halophilous Environments The coastal halophile environments are limited to some sandy stretches on the Black Sea (Dobrogea).

Continental Halophilous Environment The continental halophile environments are those of the Pannonian plain (Hungarian *puszta*) and of the Oltenia and Muntenia plains, but areas of small extent are frequent, as in Romania, where they are called sărături.

Deltas The Danube's course ends in the Black Sea, forming a delta of 4300 km^2.

Hydrographic Network The hydrographic network of the Danube and its tributaries can be distinguished into two sectors, the mountain and the plains. On the mountain ranges, the watercourses have a more or less accentuated slope and usually have a bed between the slopes of the valleys, with a linear pattern, so that the riparian vegetation forms a rather narrow band (Fig. 2). The slope becomes gradually reduced towards the lowland areas, where the riparian vegetation has the possibility to form very wide bands (Fig. 3). In the plain section, along the Danube are frequent meanders (Fig. 4) and river islands (Fig. 5), with considerable growth of both herbaceous and shrubby and woody vegetation.

Up until just below Vienna, the Danube resembles a mountain river and only from this point onward begins to present the characteristics of a large river plain.

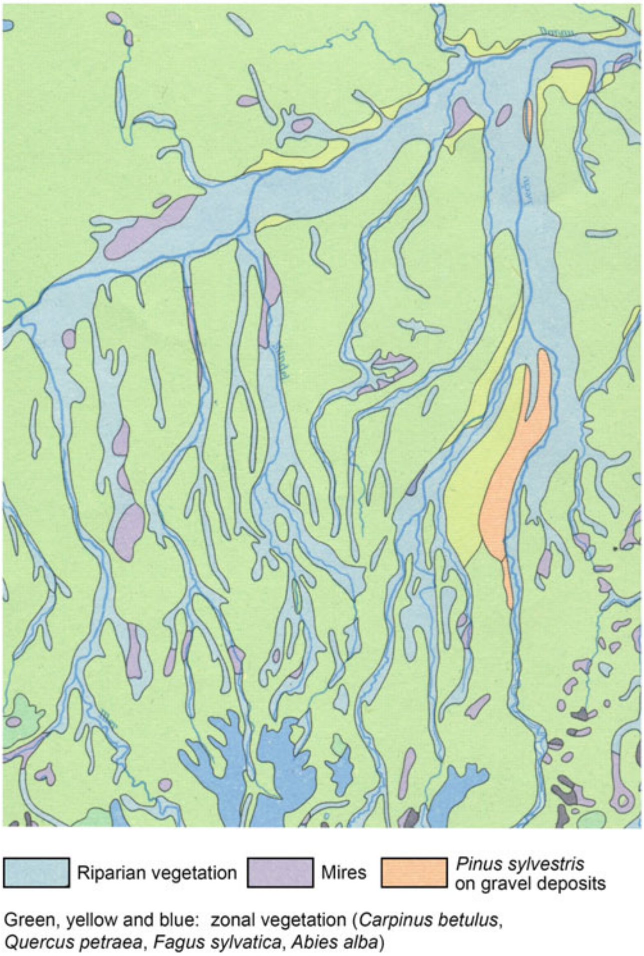

Fig. 2 Hydrographic network of the Danube and its tributaries in a mountain area, Bavarian Alps (from Wagner 1989)

2 Biodiversity

In a territory so wide and ecologically very differentiated, the plant biodiversity is very high at the phytocoenotic level and results in a large number of plant associations, as shown by publications dedicated to the vegetation of Austria, Hungary and Romania (Mucina et al. 1993a, b; Grabherr and Mucina 1993; Borhidi 2003; Coldea 2007, 2012, 2015) and other Danubian states.

These associations are represented on the vegetation maps of the states crossed by the Danube: Alps, including Italy, Switzerland, Austria, Germany and Slovenia (1: 2,250,000, Ozenda 1983), Switzerland (1: 200,000, Schmid 1961), Germany (1:

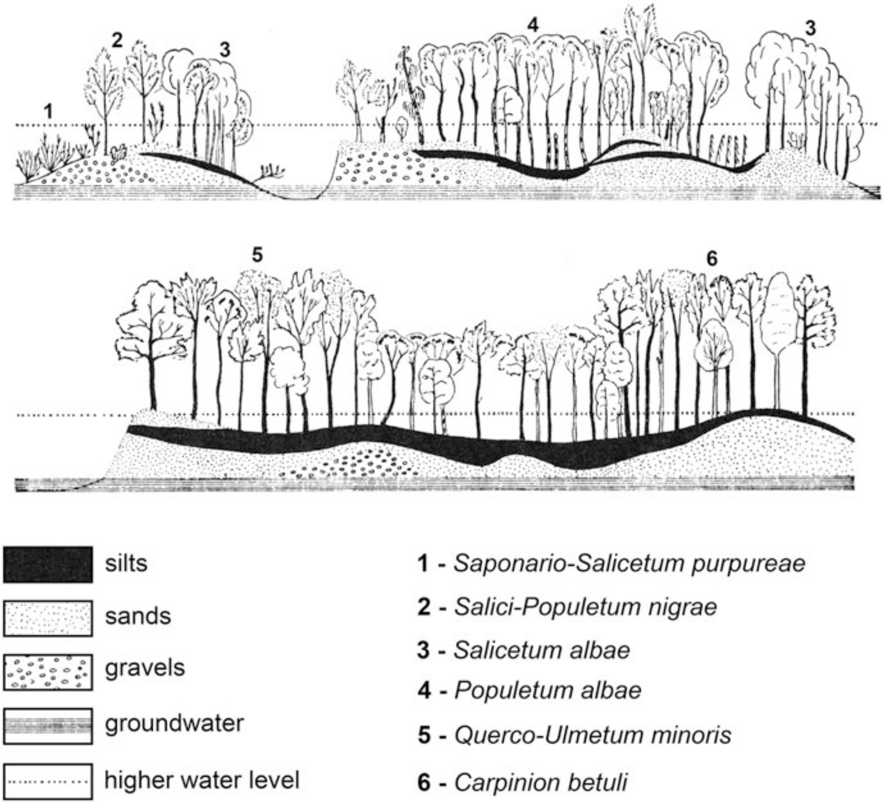

Fig. 3 Cross zoning of the riparian vegetation of the Danube downstream of Vienna (da Margl 1971)

5,000,000, Bundesamt Naturschutz 2011), Austria (1: 500,000, Wagner 1989), Czech Republic (1: 500,000, Neuhäuslová 2001), Slovenia (1: 400,000, Marinček and Čarni 2002), Croatia (1: 100,000, Trinajstić et al. 1992), Hungary (1: 1,500,000, Zolyomi 1968), Romania (Doniță and Roman 1979, 1: 1,000,000; Ivan et al. 1993, 1: 2,500,000) and Bulgaria (1: 600,000, Bondev 1991).

A first mapping summary of the phytocoenotic biodiversity of the entire Danube basin is that of *The natural vegetation map of the Danubian countries*, scale 1: 2,000,000, by Niklfeld (1974), which was followed by the *European Natural Vegetation Map*, scale 1: 2,500,000, by Bohn et al. (2003), which also includes the Danubian countries.

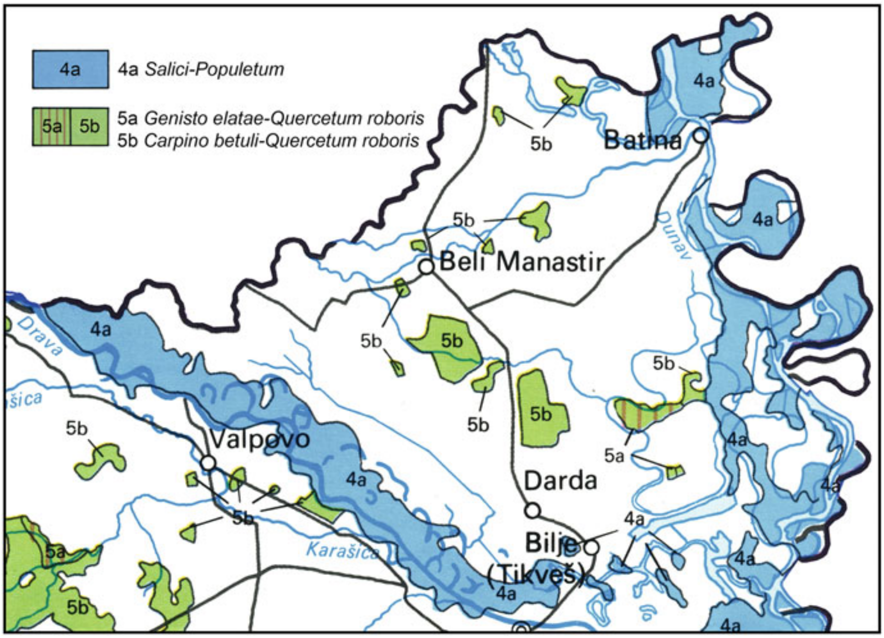

Fig. 4 Hydrographic network of the Danube and its tributaries in a lowland area, Beli Manastir, Croatia, with meanders (from Trinajstić et al. 1992)

3 Vegetation

The vegetation of the Danube basin is described with reference to the General Map of Europe's vegetation at 1: 10,000,000 scale by Bohn and Katenina (2000) (Fig. 6); this map, in turn, has been deduced from the Natural Vegetation Map of Europe by Bohn et al. (2003), previously cited.

Vegetation units derive from the aggregation of related plant associations; for each the following data are reported: reference code (the same as appears on the paper by Bohn and Katenina 2000), definition, main tree species, main phytosociological units of reference (class, order, alliance or association), chorology; in some cases the quotes of monographs and specific contributions are reported.

4 Mountains and Hills (Fig. 7)

The vegetation of the mountains and hills and distribution in altitudinal belts (nival, alpine, subalpine, mountain and hill), is as follows:

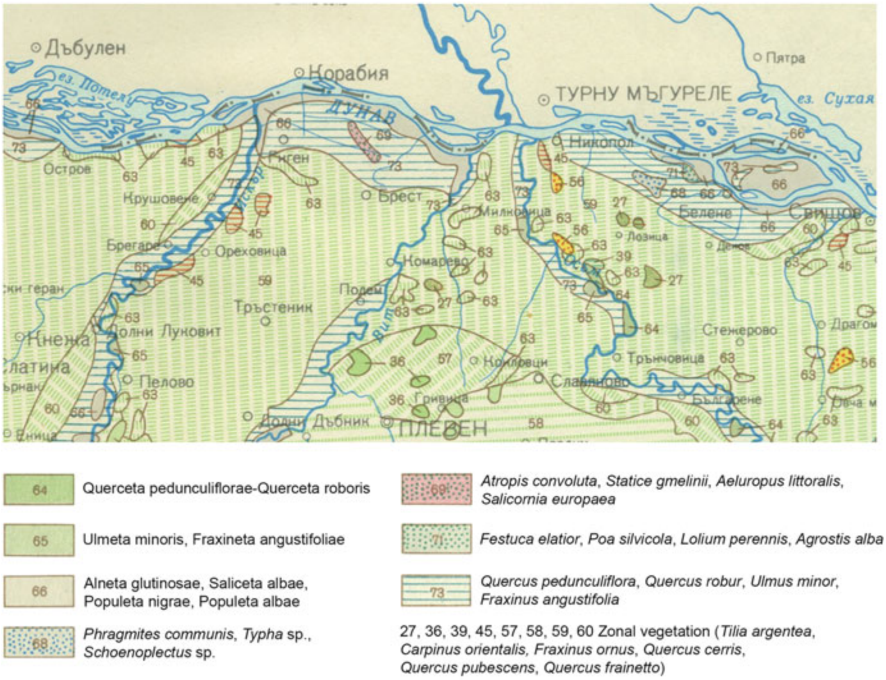

Fig. 5 Hydrographic network of the Danube and its tributaries in a lowland area, Bulgaria, with river islands (from Bondev 1991)

A2 Subnival vegetation of high mountains, pioneer vegetation of alliances *Arabidion caeruleae*, *Salicion herbaceae*, *Thlaspion rotundifolii*, *Androsacion alpinae*, Alps.

B5 Alpine vegetation, primary grasslands of the alliances *Seslerion albicantis*, *Caricion ferrugineae*, *Festucion variae*, *Caricion curvulae*, *Oxytropido-Elynion* (Alps), *Seslerion tenuifoliae*, *Oxytropidion dinaricae*, *Festucion pungentis*, *Edraianthion nivei* (Dinarides), *Seslerion tatrae*, *Festucion tatrae*, *Caricion curvulae* (Carpathians and Tatra) and *Seslerion comosae* (Dinarides and Rila Planina, Roussakova 2000).

C3 Subalpine vegetation (forests, scrub and dwarf shrub communities in combination with grasslands and tall-forb communities) of *Piceion abietis*, *Pinion mugo*, *Rhododendro-Vaccinion*, *Loiseleurio-Vaccinion*, *Juniperion nanae*, *Erico-Pinion sylvestris*, *Erico-Pinion mugo*, *Alnion viridis*, *Calamagrostion villosae*, *Rumicion alpini*, *Cirsion appendiculati* (Alps, Tatra, Carpathians, Dinaric Alps, Rila Planina, Stara Planina).

D9 Montane to altimontane, partly submontane fir and spruce forests in the nemoral zone (*Picea abies*, *Abies alba*, *Larix decidua*, *Pinus cembra* and other species); alliance: *Piceion excelsae*, *Dicrano-Pinion*, *Chrysanthemo rotundifolii-Piceion*, *Abieti-Piceion*.

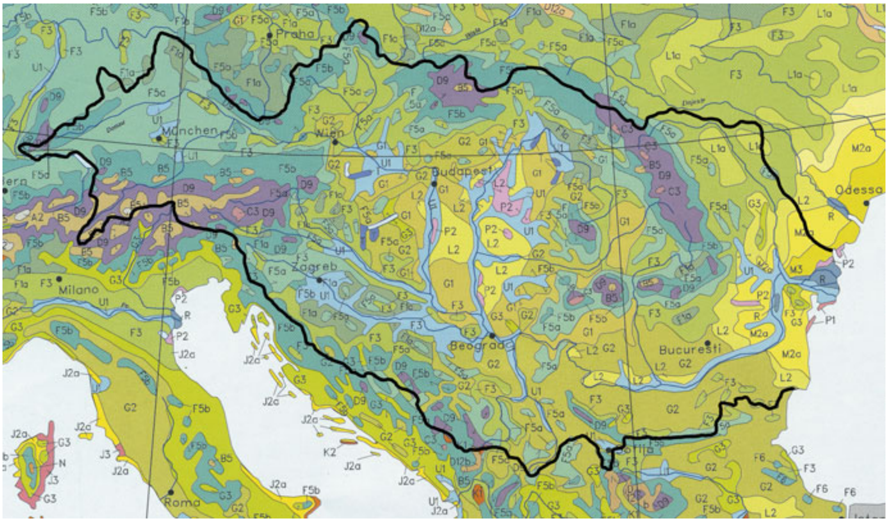

Fig. 6 Vegetation map of Danube basin. *Vegetation of the mountains*: **A2** Subnival vegetation of high mountains; **B5** Alpine vegetation; **C3** Subalpine vegetation; **D9** Montane to altimontane, partly submontane fir and spruce forests; **F1a** Acidophilous oak and mixed oak forests, poor in species, submontane; **F5a/I** Beech and mixed beech forests, lowland types; **F5a/II** Beech and mixed beech forests, submontane types; **F5b** Beech and mixed beech forests, montane to altimontane types, partly with fir and spruce; **K1** Nemoral, sub- and oro-mediterranean pine forests. *Vegetation of the plains*: **F1a** Acidophilous oak and mixed oak forests, poor in species, lowland; **F3** Mixed oak-hornbeam forests; **G1** Subcontinental thermophilous (mixed) pedunculate oak and sessile oak forests; **G2** Sub-Mediterranean-subcont. thermophilous bitter oak forests, as well as mixed forests; **G3** Sub-Mediterranean and meso-supra-Mediterranean downy oak, as well as mixed forests; **L2** Sub-Mediterranean-subcontinental lowland to montane herb-grass steppes, partly meadow steppes; **P2** Inland halophytic vegetation; **M2a** Herb grass steppes, lowland colline types; **L1a** Subcontinental meadow-steppes and dry grassland with oak forests or scrub; **M3** Grass steppes. *Others*: **P1** Coastal halophytic vegetation; **T** Swamp and fen forests (from Bohn and Katenina 2000)

F1a Acidophilous oak and mixed oak forests, poor in species, lowland to submontane types (*Quercus petraea*) (*Quercetea robori-petraeae*, *Vaccinio myrtilli-Quercion petraeae*, *Agrostio capillaris-Quercion petraeae*) (p.p.).

F5a Beech and mixed beech forests, lowland to submontane types; **F5b** Beech and mixed beech forests, montane to altimontane types, partly with fir and spruce (*Fagus sylvatica*) (*Deschampsio flexuosae-Fagion*, *Fagion moesiacum*, *Galio odorati-Fagion*, *Lonicero alpigenae-Fagion*, *Aremonio-Fagion*, *Symphyto cordatae-Fagion*). In the mountainous reliefs of Mount Măcin (467 m) in Dobrogia, at an altitude of just 100 m, there is a beech forest of *Fagus taurica* which was attributed to the association *Symphyto taurici-Fagetum tauricae* (Oprea et al. 2011).

K1 Xerophytic coniferous forests, nemoral, sub- and oro-Mediterranean pine forests with *Pinus sylvestris*, *Pinus engadinensis*, *Pinus uncinata*, *Pinus nigra* subsp. *nigra*, *Pinus nigra* subsp. *pallasiana*, *Pinus heldreichii*; (*Erico-Pinion*

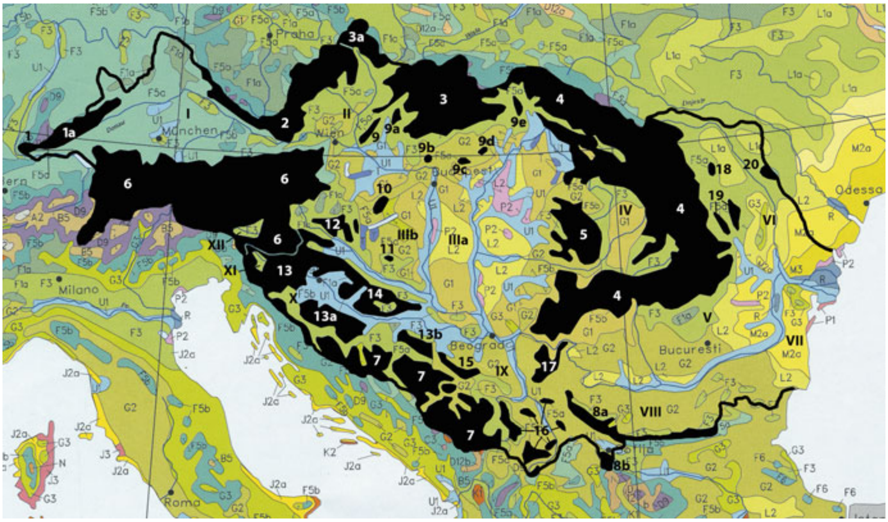

Fig. 7 Mountains and plains of the Danube basin. *Mountains*: (**1**) Jura (Crêt de la Neige, 1720 m); (**2**) Bohemian Forest (Grosser Arber, 1456 m); (**3**) Tatra (Gerlachovský štít, 2655 m); (**3a**) Sudetes (Hrubý Jeseňk, 1491 m); (**4**) Carpathians (Retezat, 2509 m); (**5**) Apuseni (Cucurbăta Mare, 1849 m); (**6**) Alps (Pizzo Bernina, 4050 m; Silvretta, 3244 m); (**7**) Dinaric Alps (Bobotov Kuk, 2523 m); (**8**) Stara Planina (Botew, 2376 m); (**8a**) Nikolska Planina (1120 m); (**8b**) Vitosa (2290 m), Rila Planina (Moussala, 2925 m); (**9**) Little Carpathians (Zarubry, 768 m); (**9a**) Ivonec Povalžký (1042 m); (**9b**) Börsöny (938 m); (**9c**) Matra (1014 m); (**9d**) Bükk (958 m); (**9e**) Kojšovská hoľa; (**10**) Northern Forest of Bacony (Köris-Hegy, 796 m); (**11**) Mecsek Mountains (682 m); (**12**) Orségi Mountain (372 m); (**13**) Sljeme mountains (Plešivica, 1657 m); (**13a**) Hills southern of Zagreb (500 m); (**13b**) Gučevo (779 m); (**14**) Slavonian Mountains (Psuný, 984 m); (**15**) Valjevo Mountain range (Povlen, 1347 m); (**16**) Kopaonik Mountain range (Pančić's Peak, 2017 m) and others; (**17**) Homoljske (963 m), Deli Jovan (1555 m), Miroc (768 m), Beljanica (1337 m); (**18**) Dealu Mare (587 m); (**19**) Colinele Tutovei (562 m); (**20**) Bălăneşti (430 m). *Plains*: (**I**) Bavaria (500 m); (**II**) Lower Austria (150–500); (**IIIa**) Pannonian plain, to the left of the Danube (100 m; (**IIIb**) Pannonian plain, to the right of the Danube (100 m); (**IV**) Podisul Transilvaniei (400 m); (**V**) Câmpia Română (Oltenia, Muntenia) (70–150 m); (**VI**) Podisul Moldovei (0–150 m); (**VII**) Podisul Dobrogei (0–89 m); (**VIII**) Southern Danube plain, Bulgaria (0–100 m); (**IX**) Southern Belgrade plain; (**X**) Southern Zagreb plains (110 m); (**XI**) Ljubljana (280 m); (**XII**) Klagenfurt. Kärnten (400 m) (from Bohn and Katenina 2000 *modified*)

sylvestris, *Ononido-Pinion, Pinion nigrae*, *Orno-Ericion*, *Pinion leucodermis*); in Engadina *Carici humilis-Pinetum engadinensis* and *Erico-Pinetum uncinata*e (Braun-Blanquet 1946; Reinalter 2003); Eastern Alps *Orno-Pinetum nigrae*, Dinarides and Balkans *Staehelino-Pinetum pallasianae*, *Seslerio robustae-Pinetum pallasianae.*

The mountain ranges of the Danube basin are very similar as regards the physiognomy of the vegetation (primary prairies, sub-alpine vegetation, beech forests, forests of white fir, spruce forests, etc.) and for the orders of vegetation, which are the same, sometimes also for the alliances, but not for the associations that are almost always different. They can be grouped into the following categories, based on the altitude above sea level:

(a) reliefs with complete altitudinal zonation of vegetation, those exceeding 4000 m altitude (Alps);
(b) reliefs with incomplete altitudinal zonation of the vegetation, as they reach lower altitudes; we can distinguish reliefs between 2509 and 2925 m (Tatra, Carpathians, Dinaric Alps, Rila Planina); reliefs that slightly exceed 2300 m (Stara Planina); reliefs between 1120 and 1849 m (Apuseni, Sudetes, Jura, Bohemian Forest); reliefs between 372 and 1657 m (Matra, Mecsek, Bacony, Little Carpathians, Dealu Mare, Colinele Tutovei, Bălăneşti, etc.); in all these cases one or more altitudinal planes are missing.

5 Plains (Fig. 7)

The vegetation is distributed in the plains as follows:

F3 Mixed oak-hornbeam forests; *Carpinus betulus*, *Quercus robur*; *Carpinion betuli* and *Erythronio-Carpinion*; main associations: Germania and Austria: *Galio sylvatici-Carpinetum Betuli*, *Melampyro Nemorosi-Carpinetum*, *Fraxino Pannonici-Carpinetum*, *Carici pilosae-Carpinetum*, *Primulo veris-Carpinetum*, *Asperulo odoratae-Carpinetum*, *Helleboro nigri-Carpinetum*; Ungheria: *Fraxino pannonicae-Carpinetum*, *Helleboro dumetorum-Carpinetum*, *Anemoni trifoliae-Carpinetum*, *Asperulo taurinae-Carpinetum*, *Circaeo-Carpinetum*, *Carpesio abrotanoides-Carpinetum*, *Cyclamini purpurascentis-Carpinetum*, *Waldsteino-Carpinetum*, *Carici pilosae-Carpinetum*, *Aceri campestris-Quercetum roboris*; Romania: *Carpino-Fagetum*, *Tilio tomentosae-Carpineum betuli*.

F5a Beech and mixed beech forests, lowland to submontane types (*Fagus sylvatica*).

G1 Subcontinental thermophilous (mixed) pedunculate oak and sessile oak forests; **G2** Sub-Mediterranean- subcontinental thermophilous bitter oak forests, as well as mixed forests; **G3** Sub-Mediterranean and meso-supra-Mediterranean downy oak, as well as mixed forests (*Quercus pubescens*, *Q. cerris*, *Q. frainetto*, *Q. pedunculiflora*, *Q. polycarpa*, *Q. dalechampii*, *Q. petraea*, *Fraxinus ornus*, *Ostrya carpinifolia*, *Carpinus orientalis*, *Acer tataricum*, *Tilia tomentosa*): many associations of the alliance *Quercion pubescentis-sessiliflorae*, *Aceri tatarici-Quercion*, *Fraxino orni-Ostryon carpinifoliae*, *Orno-Cotinion*, *Genisto germanicae-Quercion*, *Castaneo-Quercion*, *Quercion petraeae*, *Quercion farnetto*.

L1a Subcontinental meadow steppes and dry grassland alternating with oak forests or scrub, lowland colline types (*Festuca rupicola*, *F. valesiaca*, *Stipa tirsa*, *S. pennata*) Moldavia: *Stipo ucrainicae-Festucetum valesiacae*, *Festucetum stenophyllae* (Ivan et al. 1993).

L2 Sub-Mediterranean-subcontinental lowland to montane herb-grass steppes, partly meadow steppes; *Festuca valesiaca*, *Bothriochloa ischaemum*, *Chrysopogon gryllus*, *Corynephorus canescens* and other species; classes *Festuco-Brometea* and *Koelerio-Corynephoretea*, with many associations in Romania and Hungary (Ivan et al. 1993; Borhidi 2003).

M2a Herb grass steppes, lowland colline types; **M3** Grass steppes (*Stipa ucrainica*, *S. zalesskii*, *S. anomala*, *S. lessingiana*, *Festuca valesiaca*); Moldova and Ucraine: *Scabioso ucrainicae-Caricetum ligericae* (Ivan et al. 1993).

The plains are distributed between sea level (Dobrogea and Moldova) and the maximum altitude of 400–500 m (Carinthia, Transylvania and Bavaria). The forests of *Carpinus betulus*, alliance of the *Carpinion*, constitute a common element for all the plains of the Danube basin, with different associations but very similar from the ecological and floristic point of view. The plains at the highest altitudes (Carinthia, Transylvania and Bavaria) also host *Fagus sylvatica* forests, while those of the lower altitudes are characterized by various oak species (*Quercus*), and also *Ostrya carpinifolia*, *Acer tataricum* and other species (order *Quercetalia pubescentis-petraeae*). The steppe meadows are typical of the plains of Hungary and Moldova.

5.1 Swamps

T Fen and swamp with forests; flora: *Alnus glutinosa*, *Salix cinerea*, *S. pentandra*, *S. aurita*, *Betula pubescens*; associations: *Carici elongatae-Alnetum glutinosae, Angelico sylvestris-Alnetum glutinosae*, *Fraxino pannonicae-Alnetum glutinosae*, *Sphagno squarrosi-Alnetum glutinosae*, *Salici pentandrae-Betuletum pubescentis*, *Salicetum auritae*, *Calamagrostidi-Salicetum cinereae*, *Salici cinereae-Sphagnetum recurvi*, *Betulo pubescentis-Sphagnetum recurvi*.

5.2 Lakes (Including Ponds and Marshes)

Flora: *Lemna* spp., *Riccia fluitans*, *Ricciocarpus natans*, *Salvinia natans*, *Chara* spp., *Nitella* spp., *Isoëtes lacustris*, *Isoëtes hystrix*, *Littorella uniflora*, *Eleocharis acicularis*, *Juncus bufonius*, *Potamogeton* spp., *Nymphaea alba*, *Nuphar luteum*, *Phragmites vulgaris*, *Carex elata*, *C. gracilis*, *C. rostrata*, *C. vesicaria*; vegetation classes: *Lemnetea*, *Potametea*, *Utricularietetea intermedio-minoris*, *Charetea fragilis*, *Isoëto-Littorelletea*, *Isoëto-Nanojuncetea*, *Bidentetea*, *Phragmito-Magnocaricetea*.

5.3 Mires

In the Danube basin, especially in the mountain systems, there are low and transitional bogs (*Scheuchezerio-Caricetea fuscae*) with the alliances *Caricion fuscae*, *Caricion davallianae*, *Rhynchosporion albae* and *Caricion lasiocarpae*, and high bogs (*Oxycocco-Sphagnetea*) with the *Sphagnion* alliance average. In some peat bogs, the vegetation is also formed by an arboreal layer of *Pinus rotundata*, *P. silvestris*, *B. pubescens*, *B. humilis* and *Picea abies*, which form the following associations *Pinetum rotundatae* (*Pino mugo-Sphagnetum* syn.), *Vaccinio uliginosi-Pinetum sylvestri*s, *Vaccinio uliginosi-Betuletum pubescentis*, *Betuletum humilis*, *Sphagno girgensohnii-Piceetum* and others.

5.4 Coastal Halophilous Environments

P1 Vegetation of coastal sand dunes: *Elymetum gigantei*, *Aperetum maritimi* and others.

5.5 Continental Halophilous Environments

P2 Inland halophytic vegetation; belongs to the following vegetation classes: *Puccinellio-Salicornietea* (Mucina 1997); for Hungary, Borhidi (2003) lists numerous associations; for Moldova, Oltenia, Dobrogea: *Artemisio-Festucetum pseudovinae*, *Achilleo-Festucetum pseudovinae*, *Agropyro pectinatae-Kochietum prostratae* (Ivan et al. 1993).

5.6 Danube Delta (Fig. 8)

R Tall reed and tall sedge swamps. Aquatic vegetation; *Lemna* spp., *Nymphaea alba*, *Nuphar luteum*, *Potamogeton* spp., *Nymphoides peltata*, *Trapa natans*, *Phragmites vulgaris*, *Schoenoplectus lacustris*, *Juncus maritimus*, *J. acutus*; *Lemnetea*, *Potametea*, *Juncetea maritimi*, *Phragmito-Magnocaricetea*. The vegetation of the Danube delta is formed by a complex of environments that condition the formation of many associations, as is clear from a recent map of the Danube delta on a scale of 1: 100,000 (Hanganu et al. 1994), of which three fragments are reported here related to an internal element with numerous ponds and meanders (Fig. 9) and to two elements close to the sea, one with sandy strips (Fig. 10), the other with marsh areas of different types (Fig. 11). The most extensive association is of *Phragmitetum australis*, which occupies most of the delta; within are water

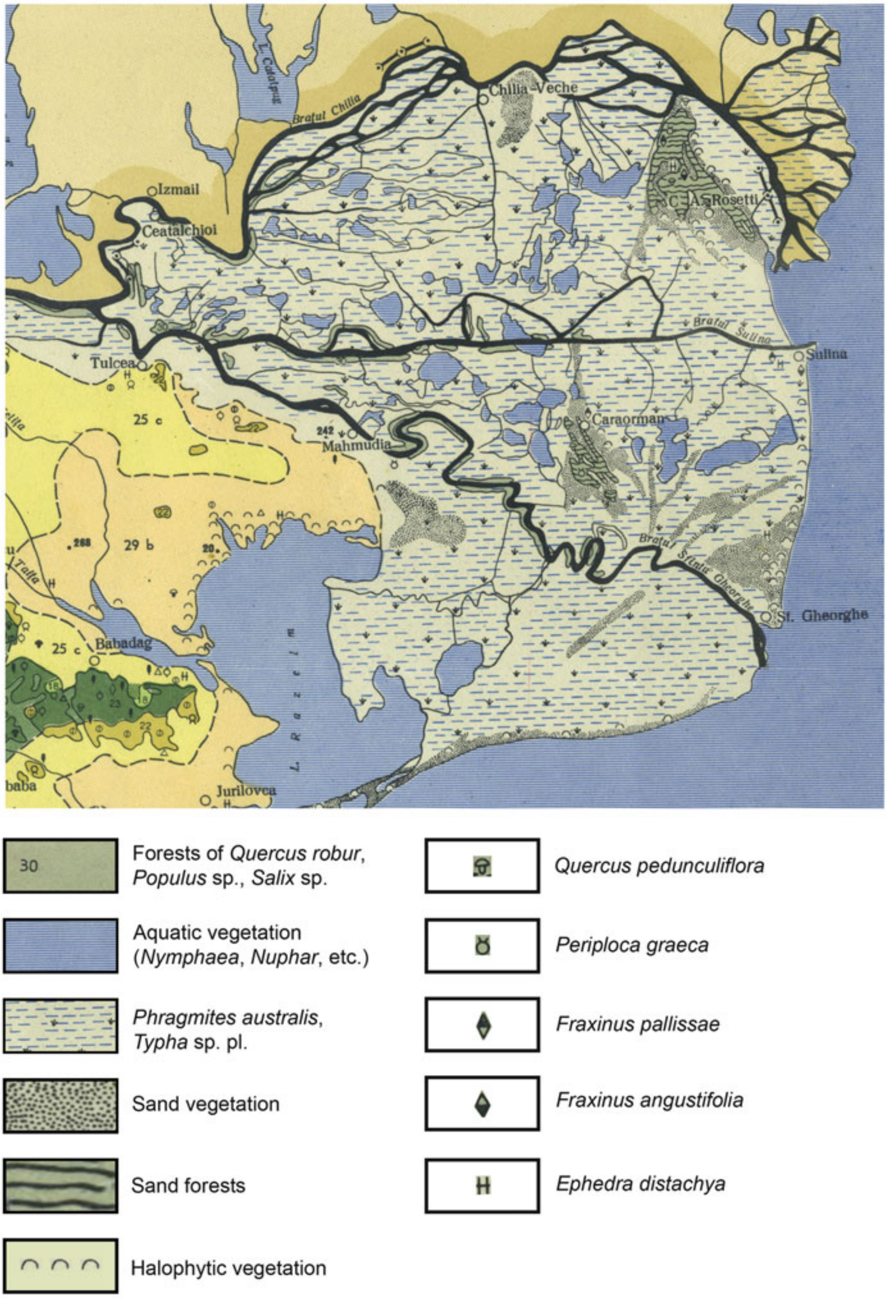

Fig. 8 Vegetation of the Danube delta (from Doniță and Roman 1979)

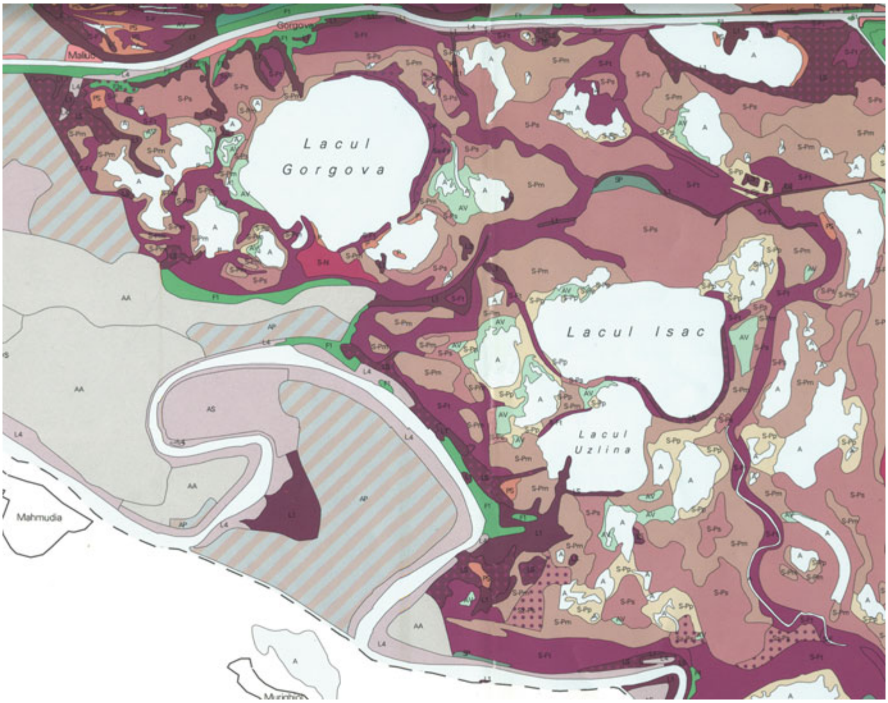

Fig. 9 Vegetation of the Danube delta, sector with ponds and meanders (from Hanganu et al. 1994)

bodies with associations formed of aquatic macrophyte species (*Nymphoidetum peltatae*, *Myriophyllo-Nupharetum*, *Trapetum natantis* and others). Within are also pools with the association *Juncetum acuti-maritimi*, which has a halophilous character, as well as *Puccinellietum distantis* and *Salicornietum ramosissimae* (Ivan et al. 1993). On the beach deposits of the delta various associations are developed: *Caricetum colchicae*, *Festucetum arenicolae*, *Aeluropetum litoralis* and *Aeluropo-Salicornietum*. The riparian vegetation is represented by the tree associations *Quercetum robori-pedunculiflorae*, *Fraxinetum pallisae* and *Salicetum albae*. The shrub association *Calamagrosti-Tamaricetum ramosissimae* is also reported. The typical association of the Danube Delta is the *Fraxinetum pallisae*; in Fig. 12 a profile is shown that highlights its vertical structure (Schnitzler et al. 2003).

5.7 Hydrographic Network

U1 Flood plain vegetation and moist lowland forests; *Salix purpurea*, *S. elaeagnos*, *S. triandra*, *S. daphnoides*, *S. alba*, *S. fragilis*, *Populus alba*, *P. nigra*, *Ulmus*

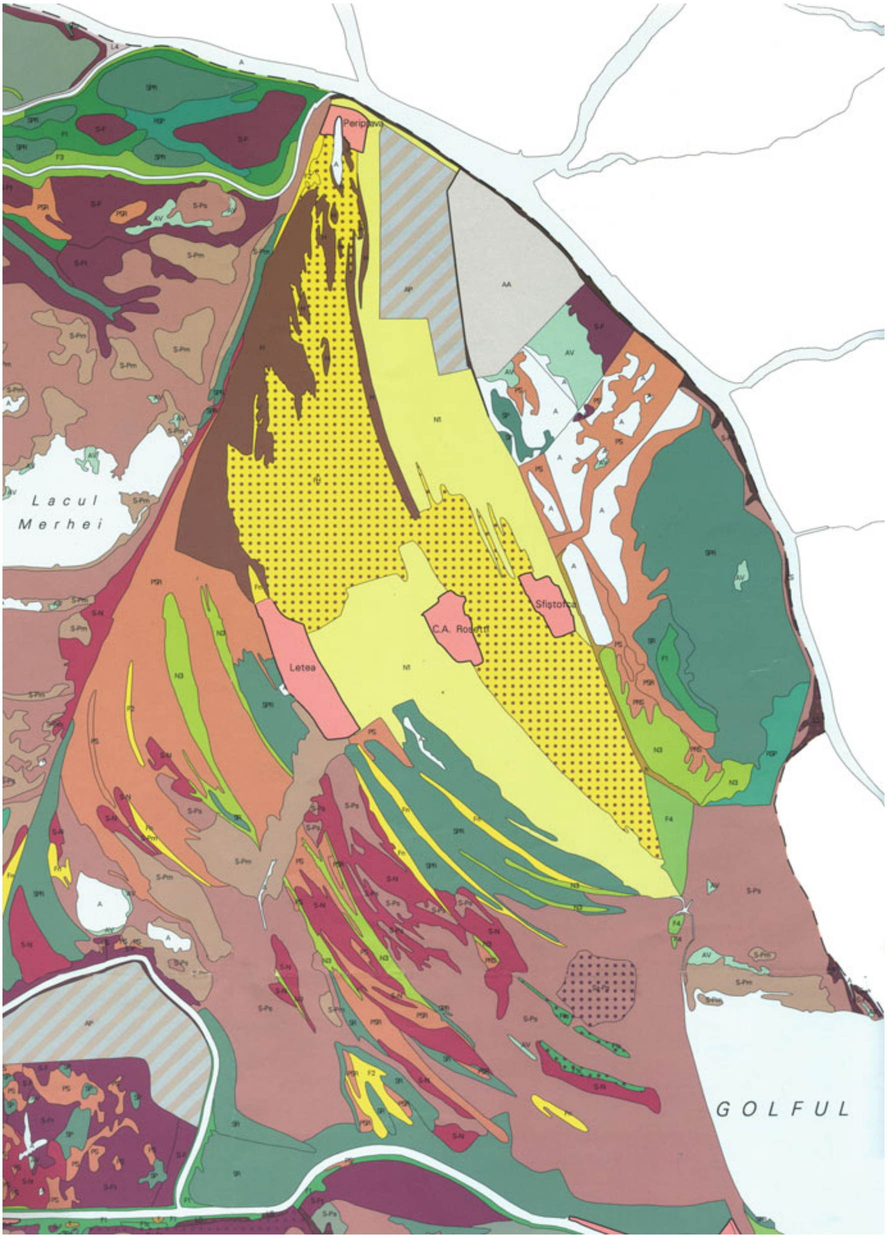

Fig. 10 Vegetation of the Danube delta, sector with sandy deposits (from Hanganu et al. 1994)

minor, *U. laevis*, *U. scabra*, *Alnus incana*, *A. glutinosa*, *Padus avium*, *Fraxinus excelsior*, *Quercus robur*, *F. angustifolia* subsp. *pannonica*. The vegetation belongs to the following classes: *Salicetea purpureae* with the alliances *Salicion*

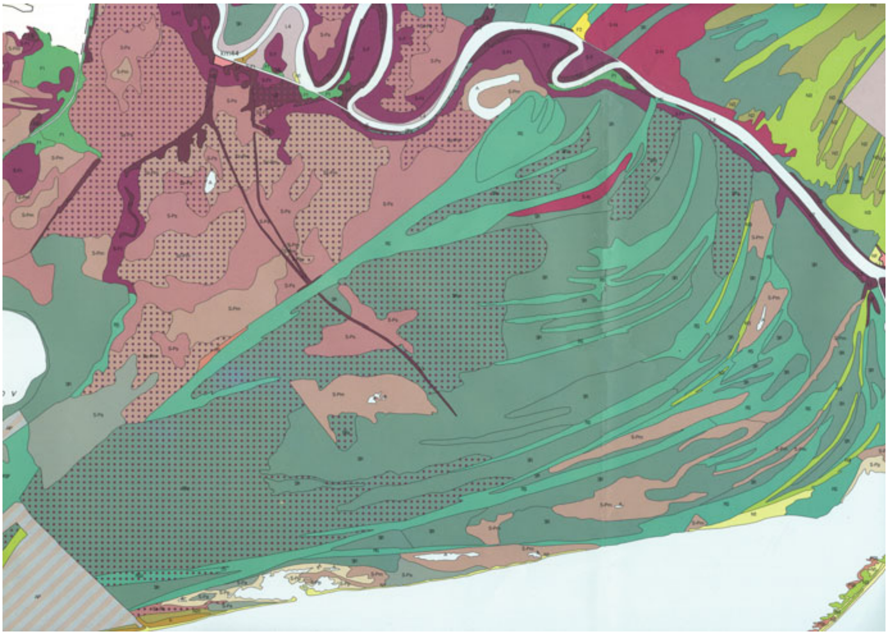

Fig. 11 Vegetation of the Danube delta, sector with marsh areas of different types (from Hanganu et al. 1994)

triandrae, *Salicion elaeagno-daphnoidis* and *Salicion albae* and *Querco-Fagetea* with the alliance *Alnion incanae*. The vegetation of the watercourses, going from the source to the mouth, is distributed according to a longitudinal or altitudinal zonation. The *Salicion elaeagno-daphnoidis* alliance is characteristic of the upper part of the watercourses (with the *Salici-Myricarietum* associations, *Salici incanae-Hippophaetum*, *Salicetum incano-purpureae*), but can also descend to lower altitudes on stony and pebbly beds; the alliance *Salicion albae* is predominantly of the plain, with the associations *Salicetum triandrae*, *S. albae* and *S. fragilis*; the *Alnion incanae* from the mountainous tract (*Alnetum incanae*, *Stellario nemorum-Alnetum glutinosae* and others) to that of the plain. Main associations; in Austria: *Stellario bulbosae-Fraxinetum*, *Pruno-Fraxinetum*, *Carici-remotae-Fraxinetum*, *Querco-Ulmetum*, *Fraxino pannonicae-Ulmetum*, *Fraxino-Populetum* (Mucina et al. 1993a, b); in the Pannonian plain: *Rumici crispi-Salicetum purpureae*, *Polygono hydropiperi-Salicetum triandrae*, *Senecioni sarracenici-Populetum albae*, *Carduo crispi-Populetum nigrae*, *Leucojo aestivi-Salicetum albae*, *Querco-Ulmetum*, *Fraxino pannonicae-Ulmetum*, *Pimpinello majoris-Ulmetum*, *Scillo vindobonensis-Ulmetum*, *knautio drymeiae-Ulmetum* (Borhidi 2003); in the plain of Oltenia: *Salicetum albae*, *Fraxino angustifoliae-Ulmetum*, *Quercetum pedunculiflorae* (Ivan et al. 1993). General contributions on riparian forests throughout Europe, with reference also to the Danube, are those of Yon and Tendron (1981), Carbiener (1984), Yon

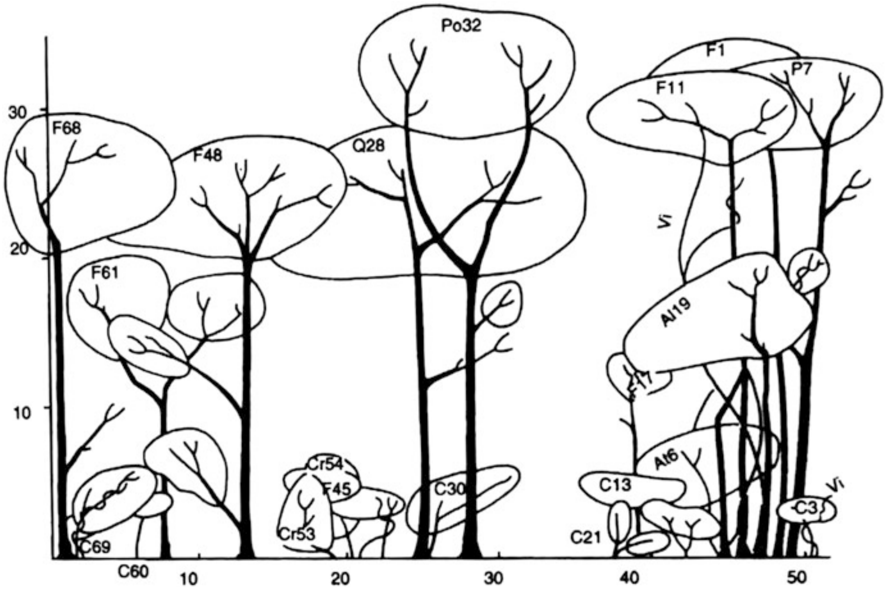

Fig. 12 Vertical structure of the *Fraxinetum pallissae*, Letea, Danube delta; F *Fraxinus pallissae*, Q *Quercus robur*, Po *Populus alba*, Al *Alnus glutinosa*, At *Acer tataricum*, C *Cornus sanguinea*, Cr *Crataegus monogyna* (from Schnitzler et al. 2003)

(1984) and Falinski (2002), which examines the ecology of genera *Salix* and *Populus*. Many monographs cover the riparian vegetation of the Danube and its tributaries; for Austria, Wendelberger-Zelinka 1952, Margl (1971), Hübl (1972), Wendelberger (1984); for Hungary, Karpati and Karpati (1974), Karpati (1982, 1984); for Romania, Danube delta, Hanganu et al. (1994).

6 Conclusions

The River Danube crosses 19 European states during its journey from the Black Forest to the Black Sea: Albania, Austria, Bosnia-Herzegovina, Bulgaria, Croatia, Germany, Italy, Macedonia, Moldova, Montenegro, Poland, Czech Republic, Romania, Serbia, Slovakia, Slovenia, Switzerland, Ukraine and Hungary. The regions that are part of its catchment area have an extraordinary environmental, landscape and biological richness, which translates into a great biodiversity, as can be seen on the map of the Danube basin vegetation (Fig. 6), referring only to the vegetable cover.

For thousands of years, in this ecological and geographical context has lived Man, who over the centuries has exerted a great influence on it and caused major changes both to the river axis and to its hinterland. It is sufficient to say that the Danube has been an important navigation route for decades, that hydroelectric power plants have been built throughout its basin and that deforestation has been intense and extensive. For the protection of the Danube ecosystem, the "*Convention for the Protection of the Danube River*" was signed in Sofia in 1994, followed in 1998 by the establishment of the "*International Commission for the Protection of the Danube River*", with the purpose of the promotion and coordination of a sustainable and equitable management of the waters of the Danube river and its tributaries and tributaries. Beyond the economic, social and political problems, the need to protect the natural environment and its vegetation, which in many cases has been completely eliminated or severely damaged, must be reaffirmed. In 1980 an international scientific congress was convened in Strasbourg on "*La végétation des forets alluviales*", followed by a Council of Europe synthesis report on the same theme (Yon and Tendron 1981; Géhu 1984). The measures envisaged by the EU Habitats Directive are therefore followed. In addition, the various protected areas (parks and nature reserves) established in various areas of the Danube river basin must be remembered, each state having one or more reserves; among them, the Danube Delta, which enjoys a triple state of international protection, stands out: the *Biosphere Reserve*, designated at international level by UNESCO's "Man and the Biosphere" Committee, a *Wetland of International Importance*, designated by the Secretariat of the Ramsar Convention and *UNESCO World Heritage Site*. All laws and declarations approved for the protection of the Danube are of great importance, but they will be useful for the preservation of the Danube—especially in the future—only if the management that follows will be effective and concrete.

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The Habitats Along the Upper Danube in Germany and Changes to Them Induced by Human Impacts

Erika Schneider-Binder

1 The Upper Danube Stretch in Germany: General Remarks

The Upper Danube extends from its two main source rivers, the Breg (45.6 km long) and Brigach (40.2 km long) in the Black Forest (Schwarzwald) to the gap called the Devin Gate or Porta Hungarica upstream of Bratislava, crossing over some 975 km various landscapes of Germany and Austria. The beginning of the Danube is also frequently denoted from the confluence of the rivers Breg and Brigach at Donaueschingen, at an altitude of 672 m NHN, where too the small Danube stream ("Donauquelle") flows in from the Fürstenberg castle area.

Characteristic landscape elements are, on the one hand, various basins and marginal depressions and, on the other hand, highland breaches such are those of the Swabian and Franconian Jura, Alpine foothills and crystalline mountains (WWF-DCP & WWF-AI 1999; Schneider et al. 2009). The Upper Danube ends according to Lászlóffy (1967) not exactly at the breach through the Carpathians at the Devin Gate, but further downstream with 90 km in the area of Szigetköz, where an inland delta existed and large fan gravel deposits of the river enter the adjacent plain.

The German stretch of the Upper Danube begins from the longest source river Breg (Fig. 1), at an altitude of 1078 m NHN in the area of Kolmenhof and Martinskapelle/Black Forest near to the town of Furtwangen, and reaches to the mouth of river Inn, an alpine right tributary of the Danube, at Passau on the Austrian

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Fig. 1 The source of Breg, the longest source river of the Danube

border. This stretch is represented by a length of 618 km, including about two thirds of the whole Upper Danube. From the river's springs to the Ulm locality the Upper Danube River is part of Baden-Württemberg State and from Neu-Ulm to the Austrian border part of Bavaria federal state.

The German part of the Danube River basin (Fig. 2) comprises 56.113 km^2 and represents 7% of the total Danube Basin area, including the sub-basins of tributaries from right and left banks of the river. On the right bank are the alpine tributaries, the rivers Iller, Lech (with Wertach) Isar (with the inflowing Amper), the Inn (with Tiroler Achen, Alz, Salzach and Saalach). The tributaries on the left bank are the rivers Wörnitz, Altmühl, Naab and Regen (Brunotte et al. 2009; Fig. 2).

2 Basic Ecological Conditions on the German Stretch of the Upper Danube River

2.1 Hydrological Characteristics

Over its considerable length the Danube shows varying hydrological characteristics in some sections, depending on the slope, the grain size of sediments and the regime of its tributaries as can be followed from hydrological statistics (Regionale

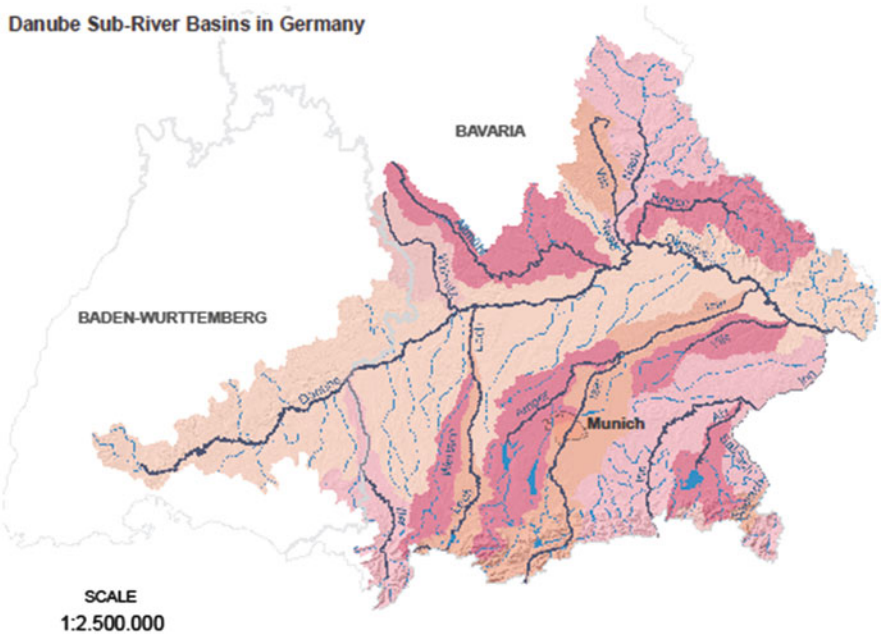

Fig. 2 The German Danube river basin with Sub-basins of the tributaries (Brunotte et al. 2009, with kind permission of the authors)

Zusammenarbeit der Donauländer 1986). Apart from the altitude differences of 400 m from upper sector of rivers Breg and Brigach to Donaueschingen, the slope from Donaueschingen area to the mouth of Lech River has a mean value of 101 cm/km. From the Lech to the Mosonyi branch of the Danube River on the Hungarian territory the slope is c. 40 cm/km (Lászlóffy 1967).

The higher Upper Danube up to the Iller mouth is a highland river and shows a correspondingly characteristic hydrological regime with winter maxima (Dister 1985). Conditioned by its right-bank tributaries Lech (discharge 118 cm^3/s), Isar (176 m^3/s), Inn (760 m^3/s), it transforms into an alpine river, the maxima shifting into summer (Dister 1994). From the mouth of Inn River the alpine character of the hydrological regime is predominant and controls the latter up as far as the Pannonian lowland (Lászlóffy 1967; Regionale Zusammenarbeit der Donauländer 1986; Dister 1985; Somogyi et al. 1983).

The Danube's mean annual runoff data show a distinct classification in three sections that do also point up the influence of the tributaries on the flow regime of the Danube River. The upper section extends up to the Isar mouth in Bavaria. The second section between the Isar and Drava mouths distinctly shows the dominating influence of the Inn river with a discharge of 760 m^3/s. The third and lowest section of the Danube reveals the definite influence of the Tisza and Sava rivers (Lászlóffy 1967).

The water levels dynamics and discharge, duration, period, height and the periodicity of floods as also determinant for the habitats and vegetation of the neighbouring floodplain (Schneider et al. 2009).

2.2 Morphological Dynamics

The Danube River reveals a significant morphological variability closely related to its hydrological variability. Only on the uppermost stretch in the Black forest is little bedload transported (Schwarz et al. 2008), but from the mouth of Iller the situation is changing and a considerable bedload supply originating from its alpine tributaries in particular Lech, Isar and Inn could thus be registered. As a result of this bedload supply, in its broad alluvial basin the Danube developed a widely braided river bed with many channels, which was modified during most flooding events; huge talus fans formed in the mouth of the alpine rivers where characteristic pioneer species colonised dependent upon the particle size of the substrate (Müller 1991a, b; Bayerisches Landesamt für Umwelt 2011). As a result of the Upper Danube's development until upstream of Vienna and in parts also of its tributaries, bedload transport and supply have been widely halted (Schwarz et al. 2008).

3 Climate Gradients in the Danube River Basin

Hydrological and morphological dynamics are decisive for the succession and spatial spreading of life communities and define the characteristics of the floodplain vegetation occurring along the Danube River. The Danube shows a considerable West-Southeast extension and thus its vegetation composition is not only affected by these ecologically determining factors, the hydrological and morphological dynamic, with changing water levels and related to the slope and grain size of sediments, but also by climatic continentality gradients (Schneider 2003; Schneider et al. 2009). The general climatic and hydrological factors affect the biocoenoses of the Danube floodplains in different ways, explaining the differences as for their species composition, communities and zoning along the river (Schneider 2003). This becomes obvious from the comparison of the floodplain vegetation occurring along the varying sections of the Danube River (Table 1). Whereas the influence of the subcontinental-central European climate prevails on the Upper Danube, (abundant summer precipitation and moderately cold winters) the downstream stretch of the Danube in the Pannonian area already shows a continental influence, with moderately poor winter precipitation and relatively frequent years with a dry late summer (Walter and Lieth 1964; Horvat et al. 1974; Neuwirth 1980; Steinhauser 1973, 1977).

Table 1 Vegetation units of Danube floodplains/river banks, upstream to downstream

Designation of soft and hardwood stands/ communities along the Danube	Upper Danube	Middle Danube	Lower Danube	Danube Delta
Scrub vegetation/habitats				
Salici-Myricarietum	(x)			
Ass. of *Hippophae rhamnoides*	xx			
Salicetum purpureae	xx	xx	x	
Salicetum triandrae	xxx	xxx	xxx	xx
Tamaricetum ramosissimae			xx	xxx
Hippophae rhamnoides-Elaeagnus angustifolia				xxx
Softwood forests				
Alnetum incanae	xxx			
Ass. *Alnus incana-Salix alba*	xxx			
Ass. *Salix alba-Populus nigra-Alnus incana*		x		
Salici albae-Populetum nigrae		xxx	xxx	xx
Ass. *Populus nigra-Populus alba*		xxx	xxx	
Populus alba gallery forest			xxx	
Salicetum albae-fragilis, *Salicetum albae*	xx	xxx	xxx	xxx
Transition forest: softwood-hardwood forest				
Ass. *Alnus incana-Fraxinus excelsior*	xxx			
Ass. *Populus nigra-Populus alba-Ulmus minor*		xx	xxx	
Hardwood forests				
Querco-Ulmetum, *Fraxino-Ulmetum*	xxx	xxx	xx	x
Galio-Carpinetum	xxx			
Fraxino pannonicae-Ulmetum		xxx		
Leucojo (aestivalis)-Fraxinetum		xxx	xx	
Genisto elatae-Quercetum robori		xxx		
Asparago-Quercetum pedunculiflorae			xxx	xxx
Fraxinetum pallisae				xxx

(x) = mentioned from the Danube alpine tributaries, but, due to river straightening, embankment and consequent loss of hydro-morphodynamics, reduced and in danger of extinction (according to Schneider 2003, with modifications)

4 Climatic-Biogeographical Differentiation of the Danube Sections

The influence of the above factors on the azonal floodplain vegetation results in a very concise classification of the Danube floodplains. This specific classification differentiates, with an increasing continentality in the eastward direction, by the occurrence of species specific to particular stretches. These influences reflect increasingly in the species composition of hardwood floodplain forests and may be anticipated from the occurrence of geographically differential species. However, the softwood floodplain stands, sometimes still gallery-like, are more azonal (Schneider et al. 2009).

The alpine-prealpine Upper Danube (in Baden-Württemberg) is characterized by the occurrence of alpine species in the riparian vegetation that is frequently reduced to a small fringe. The importance of calcareous beech forests is emphasized by the occurrence of alpine species such as *Carex alba* and *Lunaria rediviva*. In some specific rare places Olive willow (*Salix elaeagnos*) and Grey alder (*Alnus incana*), characteristic of dynamic, alpine floodplains, occur as well (Schneider 2003).

The central European moderately continental Upper Danube area is mainly characterized by European respectively central European species of the highland level. Most characteristic of the whole pre-alpine area of the Upper Danube are also numerous alpine plants that have been washed ashore in the lowlands from tributaries such as the Lech, Isar and Inn rivers (Bayerisches Landesamt für Umwelt 2011; Bayrisches Landesamt für Umwelt LFU & Bayerische Landesanstalt für Wald und Forstwirtschaft LWF 2010; Müller 1991a, b; Markgraf 2005). These are partly species of dynamic pioneer stands with large-grained sediments, among others Olive willow (*Salix elaeagnos*), German Tamarisk (*Myricaria germanica*) and Grey alder (*Alnus incana*). These species are characteristic of the alpine tributaries of the Danube (Oberdorfer 2001, Ellenberg and Leuschner 2010). Moreover, the hardwood floodplain forests comprise a number of alpine calcareous beech forests species such as *Carex alba*, Spring pea (*Lathyrus vernus*), in some places the less frequent Lady's Slipper orchid (*Cypripedium calceolus*), Mezereon (*Daphne mezereum*), Pleurospermum (*Pleurospermum austriacum*), Monkshood (*Aconitum napellus*), Yellow Monkshood (*A. anthora*), Great masterwort (*Astrantia major*) and Moschatel (*Adoxa moschatellina*) (see also Janssen and Seibert 1986; Birkel and Maier 1992; Margl 1971). Characteristic for hardwood floodplain forests are on the Upper Danube near Ingolstadt the geophytes Alpine Squill (*Scilla bifolia*), Spring snowflake (*Leucojum vernum*), Ramsons (*Allium ursinum*) and also *Primula leucophylla*, which covers large area in springtime. Under the influence of the growing continentality Cornelian cherry (*Cornus mas*), characteristic of the much more continental stretch of the Danube area, is also present in the hardwood floodplain forests near Ingolstadt. The species forms stands on dryer, more elevated sites, with gravel and sand, called "Heißlände" ("hot area").

In the area of the mouth of the Isar the presence of Veronico longifoliae-Euphorbietum lucidae Bal.-Tul. et Knez 1973, an association of subcontinental species of more Eastern distribution documents the growing subcontinental character of the vegetation in the area (Oberdorfer 1983). Also some other river valley species characteristic of eastern Europe ("Stromtalarten"), among them *Thalictrum lucidum*, reach the western limit of their distribution on the Bavarian Danube. More eastwards in the area of Salzach river, Snowdrop (*Galanthus nivalis*) appears locally with high abundance-dominance in the hardwood floodplain forest accompanying the Upper Danube and is present also in the forests of the Danube National Park east of Vienna (Fig. 3).

Fig. 3 Snowdrop (*Galanthus nivalis*) in the Austrian stretch of the Upper Danube's hardwood floodplain forest (Photo: Erika Schneider, March 2004)

5 Human Impacts and Their Consequences

From the most ancient times the Upper Danube has been a lifeline for people and an important communication corridor. Although some hydrotechnical works with weirs and intervention by extraction of water and derivation canals for mills, locally bank reinforcements as well as some deforestation for agricultural use, the interventions remained small and without large consequences for the integrity and functioning of the interdependent ecosystem complex of the river and its floodplains (Konold 1994; Konold and Schütz 1996). Only in the nineteenth century the Danube was exposed to increasing intervention and change from straightening measures, construction of weirs, construction of dykes along the river and drainage of the floodplain for agricultural use (Konold 1994; Kaiser 2005). In Baden-Württemberg the main hydrotechnical works were realised between 1820 and 1889. Following these modifications the Danube River received a uniform river bed with a trapezoidal cross section and reinforced banks. Also in the nineteenth century in Bavaria started preliminary hydrotechnical works, with river correction and cutting of meanders. As a consequence, between Regensburg and Vilshofen the Danube course has been shortened by 15% (Konold and Schütz 1996). Only after 1907 following the enacting of a new water law a more intensive development of the Danube began, with construction of flood protection dykes and subsequently the use of hydropower. In 1927 the first barrage for shipping was finished near Vilshofen (Markgraf 2005).

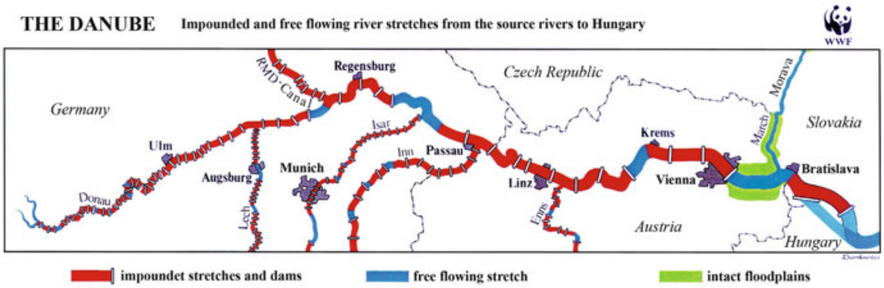

Fig. 4 Impounded and free-flowing stretches of Upper Danube (Auen-Institut/Rastatt)

Table 2 Comparison of the extension of morphological and recent floodplains along the Danube River (WWF-DCP & WWF-Auen-Institut 1999; Schneider et al. 2009)

River section	Morphological floodplain (M) (km^2)	Recent floodplain (R) (km^2) and river	Loss (%)
Upper Danube (De, A)	1762	95	95
Central Danube	8161	2002	75
Lower Danube	7862	2200	72
Danube Delta	5402	3799	30

Danube river basin 817,000 km^2 length of the river 2840 km (2880 as from the source of longest source river Breg)

This was the beginning of the changing of the Danube River due to barrages and hydropower stations (Fig. 4), by ecological changes and disturbances for the Danube floodplains ecosystems with far reaching consequences. The construction of barrages intensified between 1962 and 1992 (Markgraf 2005).

As a consequence of human interventions large changes took place in the ecosystem complex of the river and its surrounding area. As on the Upper Danube River and some of its tributaries the extension of the morphological floodplain is rather small, and the present human impact had as a result large loss of areas neighbouring to the river with all their site-typical ecosystems and species (Tables 2 and 3).

If we compare the size of the morphological floodplain to that of the recent floodplain which is also subject to water level fluctuations such as flooding and drying out, the loss of floodplain area becomes clearly apparent and so does the extent of human interventions and alterations that has occurred on this river and in its floodplains (WWF-DCP & WWF-Auen-Institut 1999; Brunotte et al. 2009; Schwarz 2010). Over the whole Upper Danube (Germany and Austria), slightly (Table 3) more than 95 km^2 of the former floodplain area have been preserved, mainly on the Austrian Danube east of Vienna in the Donau-Auen National Park. As for the German Danube, in Baden-Württemberg the section between Sigmaringen and Ulm merely comprises twelve 1-km stretches that have not been regulated (see Konold and Schütz 1996; Gewässerdirektion Donau/Bodensee/IDP 1999; Schneider 2003; Klepser 2005). On the Bavarian Danube (with a length of 385 km) as well,

Table 3 Overview of the proportion of water surfaces, recent and old, i.e. former floodplains along the German part of the Upper Danube and its tributaries (according to data from Brunotte et al. 2009)

River	Tributary from	Water body in ha (%)	Recent floodplain ha (%)	Old floodplain ha (%)
Danube		6810 (6.1)	28,911 (26)	75,356
Iller	Right	678 (4.2)	2223 (13.7)	13,314 (82.1)
Wörnitz	Left	102 (7.9)	1006 (77.6)	189 (14.6)
Lech	Right	3920 (10.4)	1944 (5.2)	31,722 (84.4)
Wertach	Right	102 (1.4)	137 (1.9)	6800 (96.6)
Altmühl	Left	506 (10.6)	2837 (59.4)	1430 (30)
Naab	Left	635 (8.1)	4756 (61)	2402 (30.8)
Regen	Left	613 (12.5)	3502 (71.6)	773 (15.8)
Isar	Right	2318 (5)	6904 (14.8)	37,337 (80.2)
Amper	Right	299 (3.2)	5658 (60.5)	3388 (36.3)
Vils	Right	86 (3)	2083 (73)	686 (24)
Inn	Right	4070 (15)	5243 (19.3)	17,875 (65.7)
Tiroler Achen	Right	7792 (45.7)	2142 (12.6)	7126 (41.8)
Alz	Right	290 (7.3)	1680 (42.5)	1979 (50.1)
Salzach	Right	651 (14.4)	1872 (41.3)	2005 (44.3)
Saalach	Right	183 (11.1)	427 (25.8)	1043 (63.1)

only few areas of the recent floodplain have persisted along the last natural 70-km river section between Straubing and Vilshofen (see Weiger 1994; Brunotte et al. 2009 and Fig. 5).

If we compare the size of the morphological floodplain to that of the recent floodplain which is also subject to water level fluctuations such as flooding and drying out, the loss of floodplain area becomes clearly apparent and so does the extent of human interventions and alterations that has occurred on this river and in its floodplains (WWF-DCP & WWF-Auen-Institut 1999; Brunotte et al. 2009; Schwarz 2010). Over the whole Upper Danube (Germany and Austria), slightly more than 95 km^2 of the former floodplain area have been preserved, mainly on the Austrian Danube east of Vienna in the Donau-Auen National Park. As for the German Danube, in Baden-Württemberg the section between Sigmaringen and Ulm merely comprises twelve 1-km stretches that have not been regulated (see Konold and Schütz 1996; Gewässerdirektion Donau/Bodensee/IDP 1999; Schneider 2003; Klepser 2005). On the Bavarian Danube (with a length of 385 km) as well, only few areas of the recent floodplain have persisted along the last natural 70-km river section between Straubing and Vilshofen (see Weiger 1994; Brunotte et al. 2009 and Fig. 5).

With the hydro-technical measures and the large loss of floodplains considerable loss of habitats and species has taken place on the Upper Danube. The loss refers to the habitats on the river banks and the whole floodplain areas, but as well to site-typical aquatic habitats. Changes in the hydrological regime, loss of

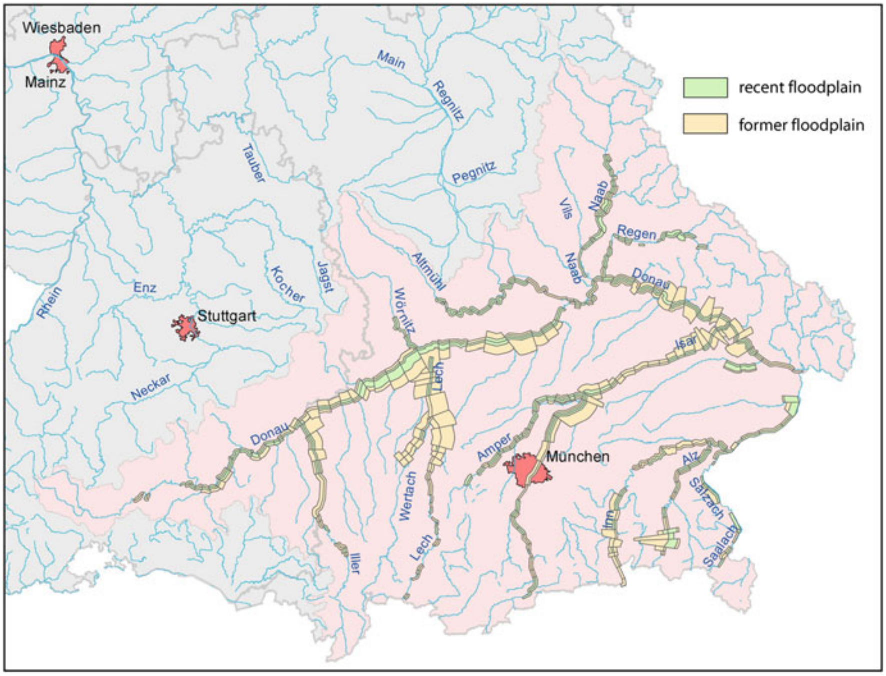

Fig. 5 The relation between former and recent floodplain on the German stretch of the Upper Danube (Brunotte et al. 2009; with kind permission of the authors)

morphodynamics, changes of groundwater table dynamic and the related groundwater supply, loss of longitudinal and lateral connectivity have been the main consequences for complete loss and for alterations in the aquatic, semi-aquatic and surrounding terrestrial ecosystems and habitats with loss of site-typical species diversity.

Due to the loss of morphodynamics as a consequence of hydrotechnical works, plant species closely associated with gravel banks, such as *Myricaria germanica*, *Salix elaeagnos*, *S. myrsinifolia*, *Hippophae rhamnoides*, *Rumex aquaticus* and *Epilobium dodonaei* have disappeared in many locations from where they were mentioned in earlier decades (Häupler and Schönfelder 1988; Müller 1991a, b).

The lack of flooding and the decrease of groundwater table led to visible degradation of the Grey Alder (*Alnus incana*) stands, for example on the Lech River (Müller 1991a, b). As a consequence of the lack of floods, the grey alder stands are replaced in time by an ash-elm floodplain forests.

For some aquatic macrophytes such *Potamogeton perfoliatus*, *P. nodosus*, *Hydrocharis morsus ranae*, *Nymphoides peltata*, *Stratiotes aloides*, the older data—pre-1945—indicate more locations than in the following decades (Häupler and Schönfelder 1988). This is due to infilling of former flood channels and other floodplain water bodies.

In the terrestrial part of the floodplain, regularly flooded in the past, numerous of the characteristic large river valley species such as *Viola persicifolia*, *Veronica longifolia* and *Euphorbia palustris* also turn into rare due to modifications in the hydrological regime, drainage and also land-use.

The alteration of the hydrological regime has created favourable conditions for the expansion of neophytes, for example *Impatiens parviflora* and *Galinsoga parviflora* on the Lech River, the right-bank alpine tributary of the Danube (Müller 1991a, b). *Impatiens glandulifera* and *I. parviflora*, first mentioned in 1997 on the Isar, have expanded as well in some places (Foeckler et al. 2010). The invasive Indian Balsam (*Impatiens glandulifera*) has been observed also on the source river Breg, upstream of Donaueschingen.

Apart from the consequences for habitat and species diversity the loss of floodplains is responsible as well for the loss of important ecosystem services such as the important flood regulation ecosystem service. This has led to an increased flooding risk because of loss as well of a large retention area. The pressure on the rivers and their valleys reached a degree that was not further acceptable, and a solution needed to be found (Klepser 2005).

6 Measures for Improvement: Studies, Programmes and Plans for Restoration

The need for flood protection has led to a change in thinking and a search for appropriate solutions. This was the starting point for the development of the Integrated Programme of the Danube of the Federal State Baden-Württemberg, similar to the Integrated Programme of the river Rhine (Ministerium für Umwelt Baden Württemberg 1988; Umweltministerium Baden-Württemberg 2007), combining flood protection and ecological restoration (Gewässerdirektion Donau/Bodensee 1999). The Programme for flood protection through ecological restoration on the Danube started after the decision from 28th January 1992 with a package of 169 measures (Gewässerdirektion Donau/Bodensee 1999), completed later to a total number of 223 different measures (Klepser 2005) such as protected area nomination, flood protection and restoration measures on an integrated basis. Ongoing from the integrated view of the problems on the Upper Danube in Baden-Württemberg the main goals of the programme have been from the beginning to ensure a large flood retention area for high floods and if needed, to enlarge it, to protect the near-natural floodplain area and to restore modified floodplains and not least to develop the whole Danube area on a sustainable basis (Klepser 2005). As a result of the initiated Integrated Danube Programme a large number of measures were implemented. Among the first examples one should mention restoration measures on the Upper Danube stretch at "Blochinger Sandwinkel" near the locality Blochingen, in Sigmaringen County (Klepser 2005) and in the area of Hundersingen and Binzwangen, Biberach County (Kaiser 2005). Due to the restoration of morpho-dynamic processes, conditions for the recolonisation of typical pioneer floodplain habitats and species has occurred. Erosion and deposition processes created a great number of microhabitats such as smaller and larger flood channels, gravel banks of large interstitial volume and steep banks (Klepser 2005).

Recognising the loss of floodplains and consequences for flood protection, a Bavarian Floodplain Programme (www.lfu.bayern.de/Natur/auenprogramm/index.htm, 2013) was established. The objective of this programme is the sustainable protection of the still existing intact, near natural floodplains and the development, i.e. restoration of floodplains including the restoration of natural functions of the floodplain, between others the water retention during high floods. In the same time the restoration of typical floodplain habitats is an important point of the Programme. Sustainable forestry will be also possible and is being taken into account in the programme. Since 2006 the Bavarian Floodplains Programme is a permanent task of the Bavarian State Office for Environment (LfU Landesanstalt für Umwelt) and an important platform for all those working on floodplains.

These programmes in Baden-Württemberg and Bavaria are in concordance with the FFH- and Birds Directive, constituting both the Natura 2000 network and the Water Framework Directive. But, apart from the frame programmes mentioned for the Danube in Germany, numerous other studies concerning the biodiversity and ecological importance of Danube floodplains and their tributaries have been initiated and realised (Müller 1991a, b; Stadt Augsburg 1991; Birkel and Maier 1992; Bayerisches Landesamt für Umwelt LfU 2011; Foeckler et al. 2010) and plans worked out for restoration of near-natural river landscapes on important stretches of Danube tributaries such as the alpine tributaries Lech and Isar (Bayerisches Landesamt Umwelt 2011). Partly they are implemented and partly under realisation or at a planning stage. One of the first restoration projects on the Bavarian stretch of the Danube started with the initiative of the town Ingolstadt for the Danube stretch between Bergheim and Ingolstadt, situated between two hydropower stations dams. As a first step a feasibility study were realised. On this base started a project of "dynamisation of the Danube floodplains between Neuburg and Ingolstadt" in 2001. The first flooding of the floodplain forest took place in 2011 (Fischer et al. 2012; Stammel et al. 2011).

According to a recent evaluation of the floodplains of the German stretch of the Danube and the main, the proportion between recent and former floodplains, with land use data and protected area are presented and gives a clear picture about the recent state of the Upper German Danube tributaries (Brunotte et al. 2009). It becomes very clear that, on the Danube and its main tributaries, a remarkable loss of floodplains and their site-typical habitats mentioned above has taken place, but that at the same time good potential exists for restoration.

This potential is presented in the above mentioned Integrated Danube Programme of the Federal state Land Baden-Württemberg (Gewässerdirektion Donau/Bodensee 1999; www.rp.baden-wuerttemberg.de) and the Bavarian Floodplains Programme Bayerisches Landesamt für Umwelt (2013). The restoration potential of the whole Danube River and its main tributaries has also been the subject of other studies (WWF-DCP & WWF-Auen-Institut 1999; Schwarz 2010).

7 Present State of the Habitats on the German Upper Danube

As mentioned above, large stretches along the Danube River and its tributaries have been subjected to many changes, and only a few of them have remained in a near-natural state with representative site typical habitats. The greatest changes have occurred within plant communities and habitats which developed on river stretches with natural hydro-morphodynamic, erosion and deposition processes of variously sized sediments. Newly created river banks offer colonisation possibilities for herbaceous and woody pioneer species that require such vegetation-free banks for their development. But due to the lack of morphodynamics and open river banks natural regeneration is not further possible (Markgraf 2005).

The lack of dynamic river bank i.e. their occurrence only in a few of stretches are the reason for the low representative of gallery like softwood wood and shrubby willow communities, as well as *Myricaria germanica* stands (Table 4). A recent evaluation of floodplains and their ecosystem functions mentions that the conservation status of softwood floodplain forests on the Danube between Ulm and mouth of Lech is favourable, but downstream until Passau the conservation status of the softwood fringes is unsatisfying (Scholz et al. 2012). In area with ecological restoration the redevelopment of willow bush formations has been documented after restoration works on the upper Danube in Baden-Württemberg (Klepser 2005), a fact which is confirming the restoration potential if the determining ecological conditions, the hydrological and the morphological dynamic exists and the ecosystem is functioning. The lacking dynamics is responsible too for the reduced

Table 4 Extent of Natura 2000 area in the floodplains of Upper Danube tributaries, including the rivers and the adjacent recent and former floodplain (according to data from Brunotte et al. 2009)

Tributary	Water body ha (%)	Recent floodplain ha (%)	Old floodplain ha (%)
Iller	312	888	280
Wörnitz	95	813	36
Lech	1377 (35.1)	732 (37.7)	4696 (14.8)
Wertach	–	–	–
Altmühl	236 (46.6)	364 (12.8)	48 (3.4)
Naab	472 (74.3)	334 (7)	11 (0.5)
Regen	491 (80.1)	1460 (41.7)	142 (18.4)
Isar	1131 (48.8)	4748 (68.8)	5814 (15.6)
Amper	264 (88.3)	2232 (39.4)	173 (5.1)
Vils	43 (50)	255 (12.2)	6 (0.9)
Inn	1620 (39.8)	2223 (42.4)	2700 (15.1)
Tiroler Achen	7743 (99.4)	1511 (70.5)	2879 (40.4)
Alz	151 (52.1)	660 (39.3)	217 (11)
Salzach	338 (51.9)	1358 (72.5)	324 (16.2)
Saalach	25 (13.7)	209 (48.9)	67 (6.4)

presence of annual pioneer species and their communities which normally occur on the river banks around and below the mean water level.

Due to the large area of impounded stretches on the Upper Danube the Conservation status of the hardwood floodplain forest on the Upper Danube is as well unsatisfactory, and only on a stretch upstream from the mouth of Lech, in the area of Ingolstadt, is the hardwood floodplain forest in a favourable state (Scholz et al. 2012).

8 The Natura 2000 Network on the Upper Danube

With the implementation of the Natura 2000 network and the creation of specific management plans started significant activity for all habitats of community interest inventories (Ssymank et al. 1998, LUBW 2008, Regierung von Niederbayern (2011), Fuchs et al. 2010); Schwarz et al. (2008). In the same time an evaluation of the conservation status of the habitats were realised. The map of Natura 2000 sites on the German Upper Danube stretch and its tributaries present the area of the Natura 2000 network. It shows many smaller and also some large area on the tributaries. Numerous Natura 2000 sites are on the upper part of the Danube in Baden-Württemberg, the majority of them on the left bank of the Danube River and on its mountainous tributaries (Fig. 6).

Along the Upper Danube in Germany the Natura 2000 area (including Special Area of Conservation according to the FFH Directive and Special Protected Area

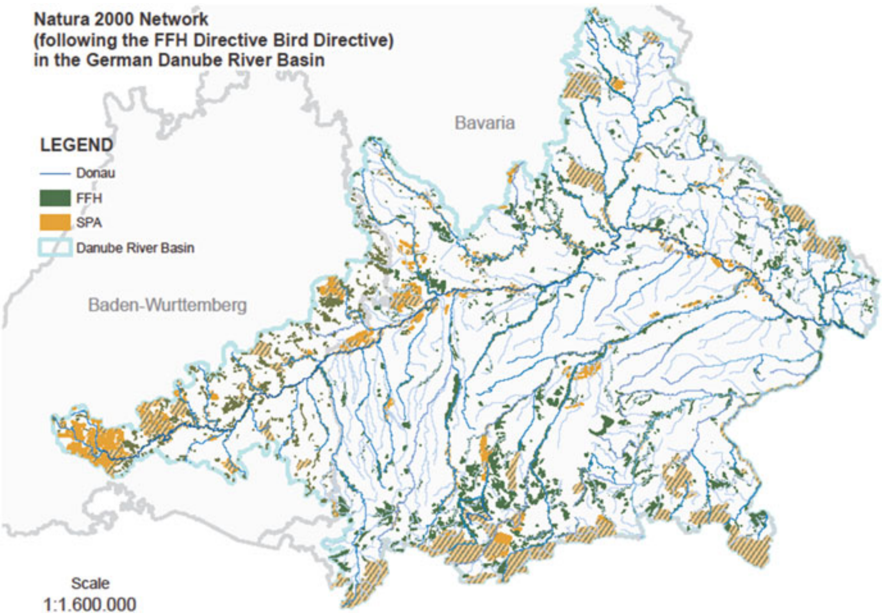

Fig. 6 Natura 2000 network on the Upper Danube in Germany (according to Brunotte et al. 2009)

according to the Birds Directive) represents the recent and former floodplain of the Danube and its tributaries in various proportions (Table 5). In addition to the Natura 2000 sites, other types of important protected area such as those following the National legislation (Naturschutzgebiete), protected landscape areas and Nature Parks exist on the Danube River and its tributaries. One of the largest protected areas is the Nature Park of the Upper Danube (Naturpark Obere Donau) in the region of "Schwäbische Alb" ["Swabian Jura"]. The Nature Park around the break through the Swabian Jura is characterized by high biodiversity (Königsdorfer 2011).

Considering the extent of the Natura 2000 area on the Danube, 16.950 ha (58.6%) are situated in the recent floodplain and 13.509 ha (17.9%) are in the former floodplain. On the tributaries the situation is identical, in general with larger area in the recent floodplain areas and smaller area in the former floodplain areas (Table 4).

Most of the habitat types of the Natura 2000 areas on the Danube are represented as linear landscape elements along the rivers and are very important for the connectivity of the network (Klepser 2005, Fig. 7).

On the uppermost stretch of the Danube softwood galleries (EU habitat type 91E0) are represented as very small fringes, the existing also small floodplain being covered by intensively used grasslands (Fig. 7). Locally on the source rivers Breg and Brigach and also downstream the confluence at Donaueschingen the willow and alder fringes are interrupted by tall herbaceous vegetation of the habitat type 6430 identified by *Filipendula ulmaria*, *Epilobium hirsutum* and other species. The gallery-like softwood forests of White Willow (*Salix alba*) and Crack Willow (*S. fragilis*) follow the whole river course, even if on the impounded stretches they are not representative and lack natural regeneration possibilities.

Analysing the habitats on the Upper Danube and their structure and composition of characteristic species, it became clearly visible that the most site-typical floodplain habitats covers small area and have a low representation. This corresponds to the EU habitat types 3220 Alpine rivers and the herbaceous vegetation along their banks, 3230 Alpine rivers and their ligneous vegetation with *Myricaria germanica*, 3240 Alpine rivers and their ligneous vegetation with *Salix eleagnos*, 3260 Water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation and 3270 Rivers with muddy banks with *Chenopodion rubri* p.p. and *Bidention* p.p. vegetation (Bayerisches Landesamt für Umwelt LfU & Bayerisches Landesamt für Wald und Forstwirtschaft LWF 2010). The two last mentioned (EU habitat type 3260, 3270) have low representation, but are present on the Danube River and its mountainous tributaries (Table 5). The habitat types 6410, 6430, 6510, 7230, 91 E0 occur also on the Danube River and all its right-bank tributaries (Table 5). The habitat type 6210 Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*) (∗important orchid sites) is also present over the whole Danube area and most of the tributaries without mountain stretches (Bayerisches Landesamt für Umwelt LfU & Bayerisches Landesamt für Wald und Forstwirtschaft LWF 2010).

The EU habitat type 6440 Alluvial meadows of river valleys of the *Cnidion dubii* species are present in the area of the mouth of the Isar River into the Danube River.

Table 5 Habitat types (HT) on the Upper Danube stretch and its alpine tributaries included in Annexe I of the EU Habitats Directive

		1	2	3	4	5	6
Nr. HT	Habitat type	Iller	Lech	Isar	Inn	Salzach	Danube
	Standing waters						
3140	Hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp.	x	x	x			x
3150	Natural eutrophic lakes with Magnopotamion or Hydrocharition—type vegetation			x, Lo	x	x	x
	Running waters						
3220	Alpine rivers and the herbaceous vegetation along their banks			x			
3230	Alpine rivers and their ligneous vegetation with *Myricaria germanica*	+	+	x	+		
3240	Alpine rivers and their ligneous vegetation with *Salix elaeagnos*	x	x	x			x
3260	Water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation	x	x	x	x	x	x
3270	Rivers with muddy banks with *Chenopodion rubri* p.p. and *Bidention* p.p. vegetation	x	x	x	x	x	x
	Habitats of the open landscape						
5130	*Juniperus communis* formations on heaths or calcareous grasslands	x	x	x			x
6210	Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*) (∗important orchid sites)		x	x	x	x	x
6410	*Molinia* meadows on calcareous, peaty or clayey-silt-laden soils (*Molinion coeruleae*)	x	x	x	x	x	x
6430	*Hydrophilous* tall herb fringe communities of plains and of the montane to alpine levels	x	x	x	x	x	x
6440	Alluvial meadows of river valleys of the *Cnidion dubii*			x, L			x
6510	Lowland hay meadows (*Alopecurus pratensis*, *Sanguisorba officinalis*)	x	x	x	x	x	x
7210	∗Calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae*	x	x	x			
7220	Petrifying springs with tufa formations (*Cratoneurion*)			x	x	x	
7230	Alkaline fens	x, L	x	x	x	x	x, U

(continued)

Table 5 (continued)

		1	2	3	4	5	6
Nr. HT	Habitat type	Iller	Lech	Isar	Inn	Salzach	Danube
	Floodplain forests						
91E0	∗Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion*, *Alnion incanae*, *Salicion albae*)	x	x	x	x	x	x
91F0	Riparian mixed forests of *Quercus robur*, *Ulmus laevis* and *Ulmus minor*, *Fraxinus excelsior* or *Fraxinus angustifolia*, along the great rivers			x, L	x, L	x, L	x

U upper part of the river, *L* lower part of the river, *o* old i.e. former floodplain

The habitat with a more Eastern European distribution is in the German Danube is on the western border of its repartition. The habitat type includes the phytocoenoses of the association Veronico longifoliae-Euphorbietum lucidae Bal.-Tul. et Knez 1973 (Oberdorfer 1983; Bayerisches Landesamt für Umwelt LfU & Bayerisches Landesamt für Wald und Forstwirtschaft LWF 2010) present at the mouth of the Isar river.

The habitat type 6410 *Molinia* meadows on calcareous, peaty or clayey-silt-laden soils (*Molinion coeruleae*) is represented in the Upper Danube area and the tributaries (Table 5), but in general its area decreased. An appropriate management is needed and also monitoring to follow the future development of the state of this habitat type.

The habitat types 3140 Hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp. and 3150 Natural eutrophic lakes with Magnopotamion or Hydrocharition-type vegetation are represented but also on a smaller scale. Habitat types 7210 ∗ Calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae* and 7220 Petrifying springs with tufa formations (*Cratoneurion*) are present at smaller frequency (Bayerisches Landesamt für Umwelt LfU & Bayerisches Landesamt für Wald und Forstwirtschaft LWF 2010).

The habitat type 91F0 Riparian mixed forests of *Quercus robur*, elms (*Ulmus laevis* and *U. minor*), and ash (*Fraxinus excelsior* or *F. angustifolia*), along the great rivers occurs on the Danube and the lower part of its tributaries the Isar, Inn and Salzach, but due to the hydrotechnical works on the Danube the flood regime is disturbed.

9 Future Perspectives

In recent years different restoration measures have been implemented on the Upper Danube river in Germany to improve the ecological situation (IDP, Klepser 2005; Kaiser 2005; Markgraf 2005; Fischer et al. 2012) of the floodplain habitats. Further

Fig. 7 The Upper Danube Valley in the area of limestone mountains of the Schwäbische Alb, with small willow bush stands and intensively used grasslands (photo: O. Rether 1998)

proposals exists (IDP, WWF-DCP & WWF-Auen-Institut 1999; Schwarz 2010) and indicate a clear option for restoration and sustainable basin-wide management and protection. The Natura 2000 network, the Water Framework Directive and also the Integrated River Basin Management Plan offer appropriate instruments to improve the ecological situation, to restore wherever possible the floodplain areas and to give more attention to the important ecosystem services of a functioning floodplain.

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www.rp.baden-wuerttemberg.de – IDP im Überblick – Integriertes Donauprogramm Regierungspräsidium Tübingen 2013

The Upper Engadine: Headwater Region of the River Inn. A Swiss Hot Spot of Plant Diversity and Premium Tourism Region

Conradin A. Burga and Elias Landolt

1 Geography

This contribution to the Danube's tributary river Inn (En in Romance, Oenus or Enus in Latin) covers its headwaters region (Fig. 1), i.e. the upper part of the Upper Engadine Valley (Samedan—St. Moritz—Bernina—Sils/Segl—Maloja, approx. 415 km^2). The area includes the villages of Samedan, Celerina, St. Moritz, Pontresina, Silvaplana, Sils/Segl and Maloja, the last since 2010 belonging to the community of Val Bregaglia. Approximately 13,000 people live there; and, of course, in the winter and summer seasons there are many tourists as well.

The Inn river has its source on the Piz Lunghin (2780 m) at c. 2590 m a.s.l.; it flows from here to the first small Lake Lunghin (2484 m). After a short distance, the young Inn reaches the first big Lake of Sils/Segl in Maloja at 1801 m. The Swiss Inn catchment is 90 km long and covers 1717 km^2. The river drains parts of Switzerland, Austria, Italy and Germany. In Passau, at the Inn's mouth, it carries for the most part of the year more water than the Danube (Inn's average discharge 732 m^3/s, peak discharge 5600 m^3/s); the Salzach River is the Inn's main tributary river. The Inn catchment contains more than 800 glaciers. Less than 20% of the total length of the Inn's main stream is free-flowing and in a near-natural state. Regarding the whole Danube river basin, the following data for the Inn catchment are given: mean catchment elevation 1260 m, catchment area 26,128 km^2 and 515 km long, average annual air temperature 4.6 °C, average water temperature 7.3 °C (1991–2005), mean annual precipitation 136.0 cm, mean annual discharge 23.1 km^3; land use (% of catchment): urban (2.9%, ca. 2.2 million people, cities of Innsbruck and Salzburg), arable (14.7%), forest (35.2%), natural grassland (13.5%), wetland (0.3%),

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Fig. 1 Overview to the Inn headwater region: Lakes of St. Moritz (foreground), Champfèr, Silvaplana and Segl/Sils (background) (Photo C.A. Burga, July 2015)

17 (of former 35) fish species (biomass c. 54 kg/ha) on small river sections; protected area: 0.9% of catchment (data after Tockner et al. 2009).

The Upper Engadine lies valley between 1700 m and 1800 m a.s.l.; it rises from east to west from Samedan to the Maloja pass, where the topography changes westwards in the direction of the Val Bregaglia. Several lakes lie between St. Moritz and Maloja, such as the Lej da S. Murezzan, Lej da Champèr, Lej da Silvaplauna and Lej da Segl.

The highest mountain peaks of the area are: Piz Bernina (4049 m, highest in the canton of the Grisons and the Eastern Alps), Piz Roseg (3937 m), Piz Palü (3900 m), Piz Corvatsch (3451 m), Piz Julier (3380 m), Piz Languard (3262 m), Piz Lagrev (3165 m), Piz la Margna (3159 m) and Piz Rosatsch (3123 m). Ca 10.2% of this area is covered by glaciers (2015). The topography was formed by erosion and accumulation, mainly during the Last Ice Age (Würmian) (Staub 1952). The Upper Engadine lake district and the mountain topography of Bernina belong to the Swiss National Inventory of Landscapes and Nature Sanctuaries (object no. 1908) since 1983 (see also Pro Natura Graubünden 2009) (Figs. 2a, b and 3).

2 Climate

Due to its Central Alpine location, the climate of the Upper Engadine has a very continental character (<1000 mm annual precipitation): low annual precipitations are recorded in Samedan (702 mm), Segl-Maria (980 mm) and on the Piz Corvatsch (850 mm). The regional climate is mainly influenced by the weather of the southern

Fig. 2 (**a**) The young Inn near its field of source of Piz Lunghin. (**b**) Detail of the Inn source (Photo C.A. Burga, July 2015)

side of the Alps (Gensler and Schüepp 1991). Due to the relatively low altitude of the Maloja Pass, moist air enters from the south-west into the valley and so produces a moister upper section. The snow cover is rather weak (average 51–113 cm in Segl-Maria and 60–124 cm in Maloja from December to March) (Gensler 1978;

Fig. 3 The Inn at Segl/Sils Baselgia (Photo C.A. Burga, July 2014)

Kirchhofer 1982–1991). The vegetation growth period is rather short; it starts late in April or May. In general, the climate is weakly cloudy and very sunny (average 1900 h sunshine per year) (Urfer et al. 1979). In winter the high valleys show very low temperatures and the Samedan-Bever basin is filled with cold air. During that period temperatures as low as below −20 °C have often been recorded: e.g. Samedan: −31.6 °C (19/20.12.2009), −36.9 °C (06.01.1985) (MeteoSchweiz 2009). The Maloja wind, blowing from South-West to North-East during the day, is a specific wind circulation type (Gensler 1978). During rainy days, typical stripes of clouds called "Maloja snakes" can be seen down the valley.

3 Geology

The main Engadine valley runs parallel to a crustal fault zone, the so-called "Engadine Line". The greater part of the Upper Engadine region geologically belongs to the Lower East Alpine nappe system, which derived from the African continental margin of the Alpine Tethys. Along Alpine tectonic convergence the nappes were thrust in a northward direction for at least 100 km over the European margin nappes. Therefore, the East Alpine nappes covered large parts of the Central and Eastern

Alps of Switzerland. Due to their high structural position in the early Alpine nappe pile only low-metamorphic overprint occurred, and they were already exposed to erosion in the Tertiary period.

The basement of the Lower East Alpine nappes is made up of ancient metamorphic schists and gneisses, which were metamorphosed prior to and during the Alpine folding; late- and post-Varican intrusive rocks (mostly granodiorites, granites and diorites) display only Alpine metamorphism (Staub 1946; Spillmann and Trommsdorff 2005, 2007). The Mesozoic sedimentary cover of the nappes is dominated by Triassic dolomites and limestones several kilometers thick. During the Tertiary Alpine folding in the Upper Engadine, huge nappe slivers were displaced 3–6 km northward over the Penninic paleogeographic units. Several sub-nappes are distinguished in the Upper Engadine nappe stack (Gnägi and Labhart 2015; Peters 2005). In the Val Forno region lies the eastern part of the late orogenic Bergell granite, which was intruded into the previous Alpine nappe stack.

4 Glacier and Vegetation History

There have been several investigations into the glacier and vegetation history of Upper Engadine of which only a few can be mentioned here. For the Tertiary and Quaternary history of the valley, see Staub (1952) and Hantke (1991, 2011). The glaciological map (Glaziologische Karte Julier-Bernina 1998) shows the actual and former glacier extensions; also included is information about snow, permafrost and rock glaciers. In the area of Maloja pass, the late- and post-glacial stages of the Forno glacier and the flora and vegetation history have been investigated [pollen analyses of peat bogs and glaciological investigations by Kleiber (1974), Heitz-Weniger et al. (1982) and Studer (2005)]. Some moraines south of Maloja caused the build-up of the existing peat bogs. Ohlendorf (1998) carried out analyses of sediment cores from all four lakes in the area. He correlated these lake sediments with late- and post-glacial glacier extensions and with paleo-summer temperatures. Peat bog profiles and lake sediments of the Lej da S. Murezzan and the Bernina pass area provided information about late- and post-glacial flora and vegetation history, as well as data concerning the first human settlers of the Neolithic and Bronze Age (Zoller et al. 1982; Punchakunnel 1983; Zoller and Brombacher 1984; Burga 1987; Burga and Perret 1998; Gobet et al. 2004).

5 Flora

The investigated region of Upper Engadine is situated between 1600 and 4000 m a.s.l. It contains 600–900 flowering plant species and ferns in an area of about 500 km^2. This is a remarkable species diversity compared to similar regions in the

Swiss Alps. Due to the central location within the Alps most species of the general flora of the silicate Central Alps are present. There are in the present high valley numerous small ecological niches of mainly continental but also oceanic type sites. Due to strong solar radiation during summer season, many plant species occur at higher altitudes. Only very few of these species (c. 100 plant species occurring above c. 3000 m a.s.l.) were able to survive the ice ages because most of the area was covered by ice. The greatest proportion of species survived the Last Ice Age in east and south Alpine and more distant refuges (Burga and Perret 1998). The mountain ranges neighbouring to the South allowed more possibility for survival, as they were not so heavily covered by ice. Species typical for calcareous regions only had chances of survival in the northern and southern ranges of the Alps. They had to recolonise the inner Alps from there over long distances and many obstacles. Most calcareous species immigrated from the North via Central Grisons. Therefore, the number of calcicolous species is relatively low compared with the whole Alps in the isolated limestone areas of Upper Engadine. So, some species of a wide Alpine range are missing in this area, e.g. *Thlaspi rotundifolium*, *Galium megalospermum*, *Pedicularis oederi* and *Dryopteris villarii* (nomenclature according to Lauber et al. 2012).

By contrast, the siliceous species could easily immigrate from all directions during the Holocene thanks to the extensive area of granitic rocks.

The studied region is located east of an ill-defined borderline between the western and the eastern Alps connecting Constance Lake and Como Lake. Various species do not cross this line from the East or from the West. This demonstrates the intermediate position that the Upper Engadine occupies between the eastern and the western middle Alps. Some examples to East Alpine plant species reaching in the Engadine region their western limit are the followings: *Saxifraga aphylla*, *Pedicularis rostrato-capitata*, *P. aspleniifolia*, *Phyteuma globulariifolia*, *Senecio incanus* ssp. *carniolicus* (Fig. 4), *Crepis kerneri*, *Hieracium hoppeanum*, *Sempervivum wulfenii* and *Stemmacantha rhapontica* s.str.; some examples of west Alpine plants reaching in the Engadine region their eastern limit are the followings: *Pinus mugo* ssp. *uncinata*, *Alchemilla pentaphyllea*, *Aquilegia alpina*, *Pedicularis helvetica*, *Gentiana purpurea*, *Achillea nana*, *Senecio incanus* ssp. *incanus* (Fig. 4), *Crepis pygmaea* and *Lilium croceum*.

Particular species characteristic for the region are missing because of the heavy glaciations during the Last Ice Ages. However, some endemics of the Southern Alps just reach the most southern part (e.g. *Phyteuma hedraianthifolium*, *Gentiana engadinensis*, *Rhinanthus antiquus* and *Ranunculus allemannii*).

The high proportion of arctic-alpine and boreal species is very special for the Swiss Alps. All these species immigrated during the Holocene in majority from the eastern Alps and survived at favourable sites (e.g. *Trientalis europaea* (Fig. 5), *Juncus arcticus* and *Linnaea borealis*). Later some members of the steppe flora reached the lower parts of the region from the South and East. Because of the regression of typical sites the steppe flora is very rare today (e.g. *Juniperus sabina*,

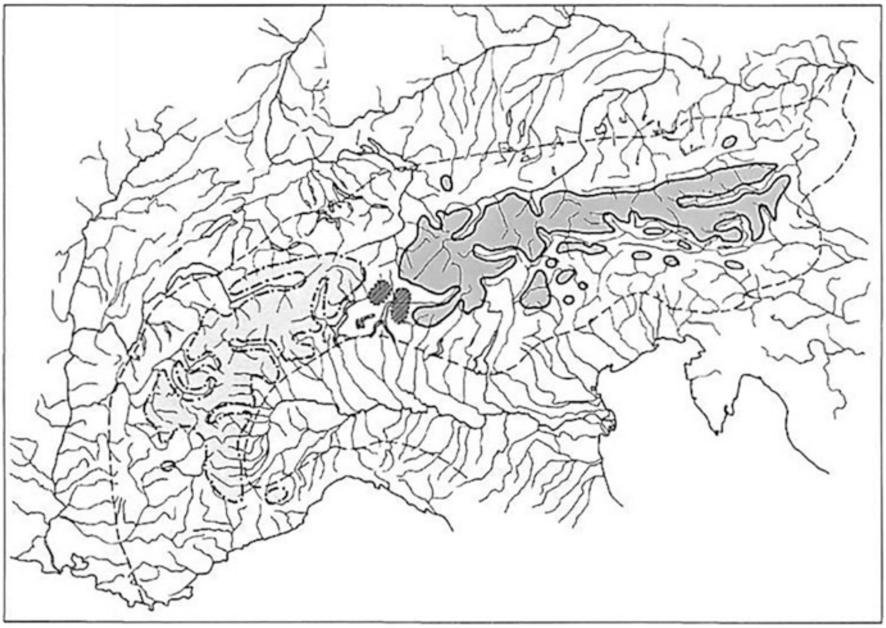

Fig. 4 Range of *Senecio incanus* ssp. *incanus* (light stippled), occurring in the Western Alps; *S. incanus* ssp. *carniolicus* (dark stippled), occurring in the Central and Eastern Alps and *S. incanus* ssp. *insubricus* (hatched), occurring in the Canton Ticino and in the Grisons (Misox Valley) (after Merxmüller from Landolt 2003)

Stipa austriaca, *Asperula cynanchica*, *Galium pumilum* and *Dracocephalum ruyschiana*). Mostly lacking in the region are Archaeophytes and Neophytes (e.g. *Senecio rupestris* and *Papaver croceum*).

Of the plant species present, 70% are not endangered (LC), 30% species are potentially endangered (EN) whereas ca. 15% of them are vulnerable (VU), critically endangered (CR) or regionally extinct (RE). But related to the Eastern Alps the proportion of vulnerable, endangered, critically endangered and regionally extinct species of the Upper Engadine is much lower: VU: 10% resp. 3%, EN: 10% resp. 1–2%, CR and RE: 10% resp. 0–1%. The Upper Engadine flora consists mainly of boreal and arctic species which are North European floristic elements (six critically endangered species are arctic plants, e.g. *Carex norvegica*, *Juncus arcticus*, *Gentiana prostrata* and *Silene suecica*). The second group consists of some steppe plants, growing at the upper limit of their potential occurrence (e.g. *Stipa austrica* and *Asperula cynanchica*). The third group is formed of a few South Alpine endemic species, which are located in some special sites. Fortunately, most plant species of the region are not endangered just as long as the influence of tourism remains controlled. However, for the preservation of the few endangered arctic-alpine and boreal species, as well as the steppe plants and endemic species, the sites of these plants have to be strongly protected (see the Red List of flowering plants and ferns of Moser et al. 2002).

Fig. 5 *Trientalis europaea*, a glacial relict, occurring only on two sites of the Upper Engadine (Photo C.A. Burga, July 2014)

6 Hot Spots of Flowering Plants Diversity

The mapped area includes a total of 210 plant relevés, containing 19 different plant communities (Burga et al. 2010) (Figs. 6 and 7: two sections of the vegetation map). The plant diversity has been calculated using the Shannon index. The highest diversity of 264 and 230 plant species (mean Shannon index 2.40 and 2.64 respectively) indicates sub-alpine (alpine) dwarf shrub heath and two grass communities (Blue Sesleria steppe and Mat-Grass pasture). By contrast, the lowest plant diversity shows the Cushion Sedge grassland with only 30 species. The average Shannon index for all the areas fluctuates between 1.17 and 2.88. There are three hot spots characterised by high plant diversity within the Upper Engadine region: (1) the area of Grevasalvas, (2) the slope north of St. Moritz-Celerina (Cristolais, Trais Fluors), Munt da S. Murezzan and Val Fex, and (3) the area of Piz Alv-Val da Fain (in the region of the Bernina pass) (Burga et al. 2007). The plant species inventory includes a total of 920 species, 119 of which belong within the Red List of the Swiss flora. Nature conservation aspects are therefore an important topic in this area (Fig. 8: plant diversity map).

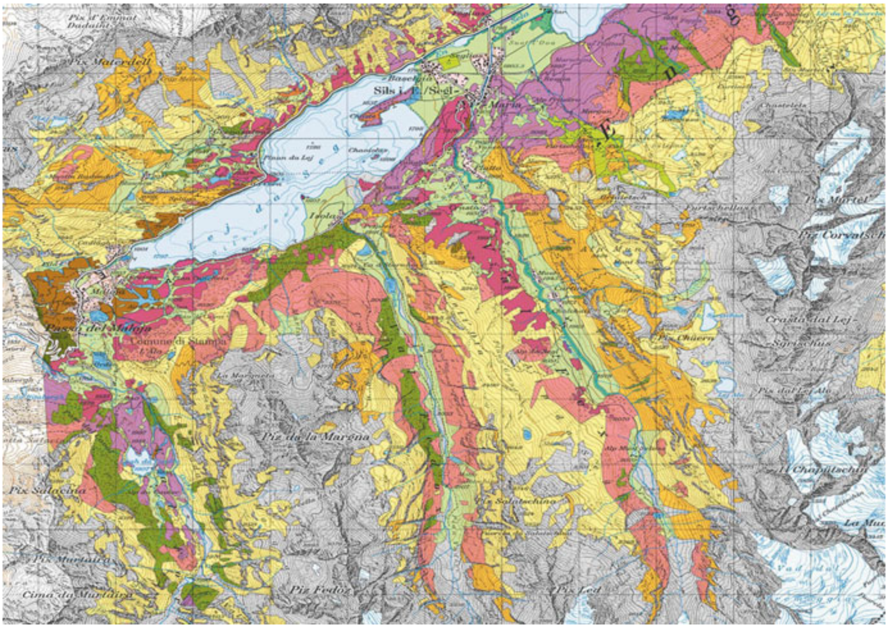

Fig. 6 Section of the vegetation map of Upper Engadine: Region of Segl/Sils-Maloja pass with the tributary valleys of Fex, Fedoz and Forno. *Legend to the vegetation units*: Blue: peat bog; brown: dwarf mountain pine forest; purple: arolla pine forest; pink: larch forest; red: dwarf shrub heath; dark green: green alder scrub; light yellow: grasslands on silicate bedrock; dark yellow: grassland on calcareous bedrock; light green: rich meadows and pastures; green: land planting; light pink: settlements (from Burga et al. 2010)

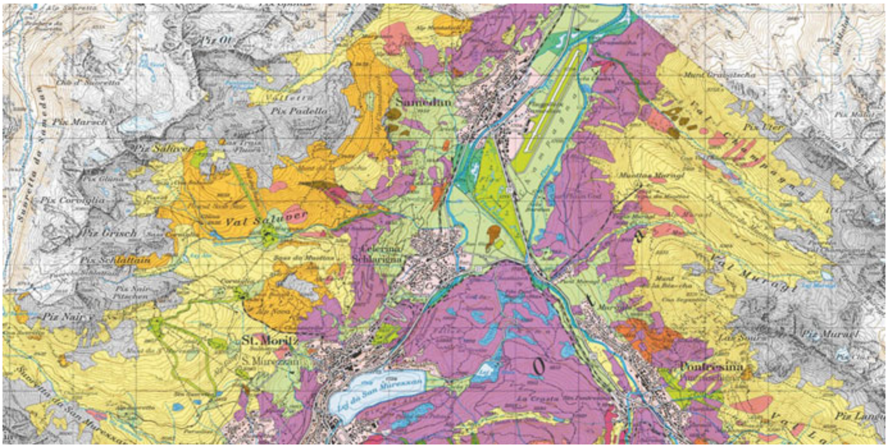

Fig. 7 Section of the vegetation map of Upper Engadine: Region of Samedan-St. Moritz-Pontresina. *Legend to the vegetation units*: See legend to Fig. 6. The map shows also ski grounds, golf course and the airport of Samedan (from Burga et al. 2010)

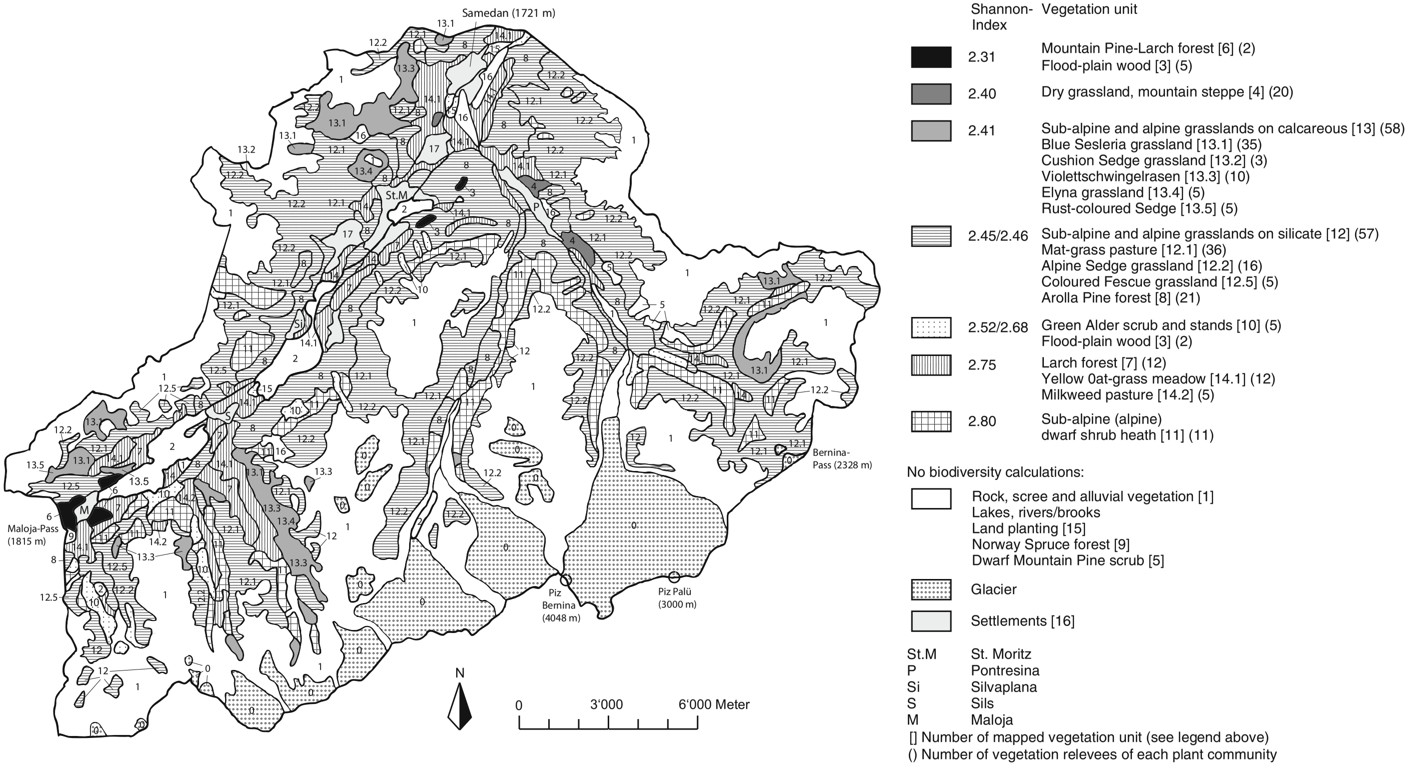

Fig. 8 Phytodiversity map of the area Samedan-St. Moritz-Maloja. The plant diversity is based on the Shannon-Index. The highest diversity shows the sub-alpine (alpine) dwarf shrub heath with a value of 2.80 (from Priewasser 2008)

7 Altitudinal Vegetation Zonation

The vegetation patterns depend on local climate and soils with granite or calcareous parent material. Basiphilous plants occur on soils of alkaline silicate rocks (gabbro, diorite), and on acidified calcareous soils acidophilous plants can occur. The bottom of the valley and some slopes can be used for agriculture (former fields used for rye, barley and potatoes). The Yellow Oat-grass meadows (*Polygono-Trisetetum flavescentis*) with a high species diversity yield a high-quality hay.

7.1 Sub-alpine (including supra-sub-alpine) belt (1600–2300 m)

The dominant forest community is larch-arolla pine coniferous forest (*Larix decidua*, *Pinus cembra*, *Larici-Pinetum cembrae*), which occurs mainly on the slopes, whereas Norway spruce (*Picea abies*) is only rarely present (area of St. Moritz-Surlej, near Segl and close to Val Bregaglia). In the supra-sub-alpine belt, located between the sub-alpine and alpine belt, arolla pine (*Pinus cembra*) dominates on the timberline (ca. 2300 m). Situated on the upper limit of this belt grows ericaceous dwarf shrubs (e.g. Alpenrose), and on former clear-cutting sectors various types of meadow have been established (*Sieversio montani-Nardetum* and *Seslerio-Caricetum sempervirentis*).

7.2 Alpine belt (2300–2900 m)

The upper limit of the alpine belt in the Upper Engadine area at c. 2700–3000 m is marked by the occurrence of closed alpine grass communities. At this altitude the average July temperature is around 5 °C. Characteristic graminoids are Evergreen Sedge (*Carex sempervirens*), Alpine Sedge (*C. curvula*) and False Sedge (*Elyna myosuroides*). This grassland is occasionally used as pasture for cattle and sheep. In snow hollows in the upper alpine belt, which have a long period of snow cover, typical dwarf willow vegetation occurs ("Schneetälchen-Vegetation", *Salicetum herbaceae*, *Arabidetum caeruleae*).

7.3 Sub-nival belt (>2900 m)

Flowering plant associations' patches mark the upper limit of this belt. Typical plant cushions and rock colonisers are Alpine Rock-jasmine (*Androsace alpina*), King-of-the-Alps (*Eritrichium nanum*), Purple Saxifrage (*Saxifraga oppositifolia*), Cyphel

(*Minuartia sedoides*) and Glacial Crowfoot (*Ranunculus glacialis*). In this belt there is very little soil. The upper limit of the sub-nival belt is marked by a snow-free period of some three months duration.

7.4 Nival Belt (>3000 m)

In this belt single flowering plants occur only occasionally in warmer niches. More than 100 flowering plants can survive at an altitude of over 3000 m; among these are plants such as Alpine Rock-jasmine and saxifrage species. Here also there can be any of more than 200 lichen species, together with several mosses and over 100 species of algae (Landolt 2003).

8 Premier Swiss Tourism Region

8.1 Population of the Upper Engadine Area (permanent residents)

Between 1980 and 2013 the human population of the upper Engadine grow from 13,757 people to 17,153, with a maximum of 17,247 in 2011 (data according to Amt für Wirtschaft und Tourismus Graubünden 2015).

8.2 Economic structure (years 2005, 2008 and 2011)

For the three employment sectors the following data of employees are given for the years 2005, 2008 and 2011: Primary employment (agriculture, forestry, fishing): 301/289/228; secondary employment (manufacturing, utilities, construction): 2764/2768/2829; tertiary employment (services, tourism): 10,484/11,229/13,689; total of employees for the years 2005, 2008 and 2011: 13,549/14,286/16,746. Between 2005 and 2010 the tertiary employment shows an increase of 1.0% (tourism) and 0.7% (catering) respectively and a decline in primary employment, mainly in agriculture. For 2005–2010 the income in tourism and catering show an increase of 1.8% and 1.3% respectively, i.e. for the year 2010 a national income of CHF 984.7 million and CHF 200.3 million respectively. The annual gross domestic product (GDP) for 2010 was CHF 1234.9 million (data according to Amt für Wirtschaft und Tourismus Graubünden 2015).

8.3 Building construction activities 2000–2013 (holiday apartments)

Between 2000 and 2013 in St. Moritz, Celerina/Schlarigna and Sils/Segl were built in total 594, 424 and 113 holiday apartments respectively. Construction boom years were 2001 (St. Moritz: 84, Celerina: 63 new apartments), 2004 (St. Moritz: 71, Celerina: 69, Sils/Segl: 28 new apartments) and 2006/07 (St. Moritz: 90, Celerina: 111 new apartments).

During the years 1970–2000 in the Upper Engadine were built in total 6059 (1970) and 15,576 (2000) permanent and holiday apartments respectively, i.e. an increase of 9517 apartments or 157%. From which the percentage of holiday apartments amounts to an increase of 6121 apartments or 246%. The biggest holiday apartment construction boom was during the period 1970–1980. Between 1970 and 2000 the proportion of holiday accommodation rose from 41.0% to 55.2% (data according to Amt für Wirtschaft und Tourismus Graubünden 2015).

8.4 Tourism (opportunities, accommodations, overnight stays)

The Engadine area provides a wide selection of tourism opportunities: During winter there are 350 km of ski slopes, 220 km of cross-country skiing and 150 km of walking trails; during summer 580 km of walking trails and 400 km of mountain bike trails.

The whole Upper Engadine region offers a wide range of a total of 344 one- to five-star hotels, 6201 bedrooms and 12,352 beds. In 2014 were recorded 465,416 arrivals and 1,506,285 overnight stays. The top destination, St. Moritz offers 35 hotels, 2981 bedrooms and 5730 beds; in 2014 there were 217,443 arrivals and 669,244 overnight stays (data according to Amt für Wirtschaft und Tourismus Graubünden 2015). During the winter season (mid-January 2016), the price of a single overnight stay including breakfast in a three- to five-star hotel in St. Moritz ranges from CHF 300 to CHF 1875 respectively (in the youth hostel, CHF 160). In the Engadine area were noted for 2005/06 and 2013/14 a total of 1,893,796 and 1,596,571 overnight stays respectively. The main tourist season is the winter, with 1,030,228 overnight stays in 2005/06 and 824,528 overnight stays in 2013/14 respectively, i.e. a marked recession (data according to Amt für Wirtschaft und Tourismus Graubünden 2015). In 2015 the Upper Engadine region celebrated 150 years of winter tourism. The recession in overnight stays during the last decade is mainly caused by the economic situation for potential tourists and by different demand during the winter and summer season. So, the Engadine region and the Canton of Grisons plan a new tourism strategy offering a wide selection of fitness and medical care opportunities for wealthy senior citizens and rehabilitation clients. For a mixture of healthy and sick clients this will include offers to holiday activities, prevention, recovery, health and medical care over the whole year.

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Vegetation and Flora Near the Danube in Austria

Erich Hübl

The river Danube runs through Austria in the main direction from West to East. The whole length of the Danube is 2850 km, in Austria about 350 km. The inclination is about 40 cm/km, the drift is about 3 km/year in Austria. The water level fluctuates up to 7 m. In Austria the amount of water flowing through the Danube is normally 1500–1900 m^3/s. At the time of low water it decreases to 600–900 m^3/s. The extremest low water was 342 m^3/s in February 1885. During the last 100 years the highest amount of water flowing through was 11,000 m^3/s in August 2002. In Austria the Danube has the characteristics of a river of high land. The velocity of flow is 1–3 m/s. The melting of snow in the mountains causes high waters from late spring till mid summer. High waters caused by high precipitations can appear all the year round.

The Danube reaches Austria near Passau (Bavaria, Germany) and leaves Austria near Bratislava in Slovakia. In Austria the Danube flows through Upper Austria, Lower Austria and Vienna (Fig. 1). There are only two free flowing sections left, 35 km in the Wachau and 47 km east of Vienna. The rest of the course of the Danube is dammed up by 11 hydropower stations, beginning in the west with Jochenstein (together with Bavaria) and ending in Vienna with Freudenau. They were built between 1956 (Jochenstein) and 1988 (Vienna, Freudenau). The two free flowing sections left, were not dammed up because of massive public protest to protect nature. In Upper Austria and in the western part of Lower Austria the Danube flows through the southern part of the Bohemian Massive built by silicate rocks. The main influx comes from the Alps in the south, beginning with the river Inn, which is flowing into the Danube near Passau, and brings more water than the Danube itself. All tributary rivers coming from the south rise in or flow through the northern Alps built mainly by limestone. Because of the higher precipitations in the Alps than in

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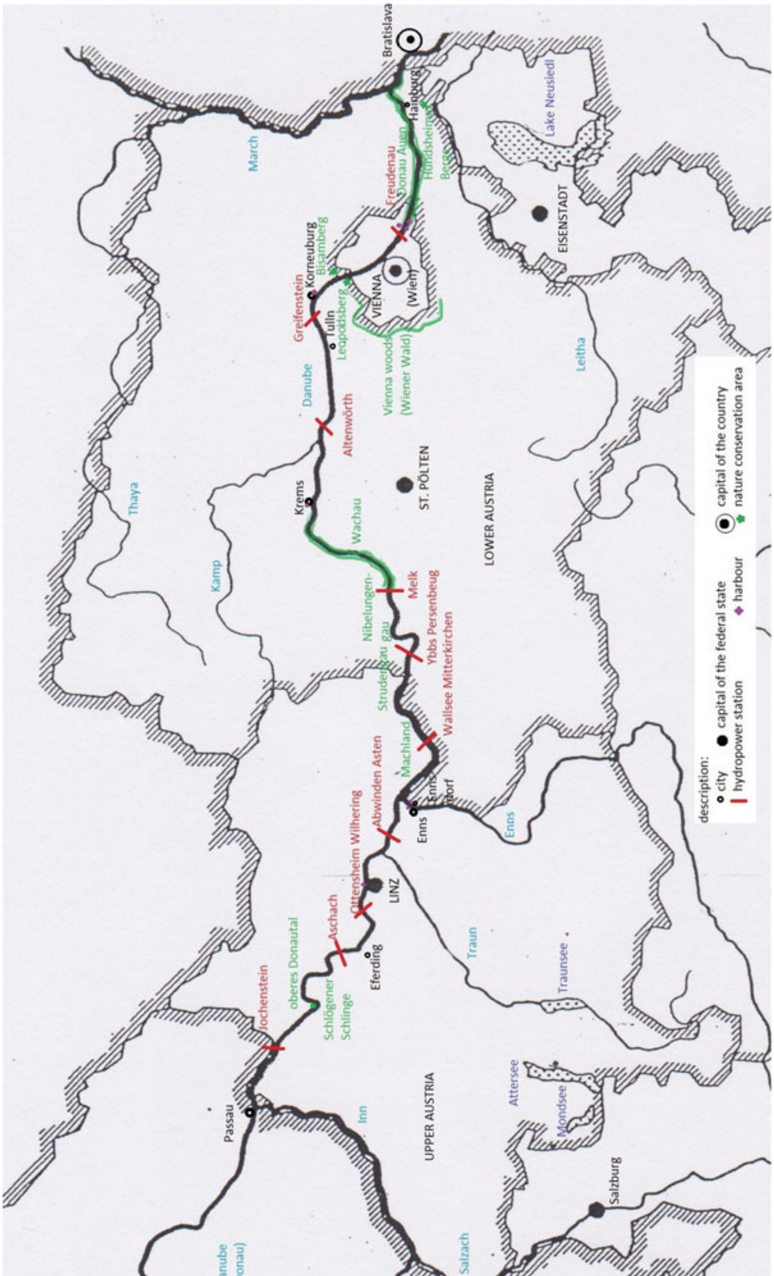

Fig. 1 Map of the Danube in Austria

the Bohemain Massive the main influx comes from the Alps. Therefore the depositions of the Danube are rich in calcium, even in the east of Lower Austria (Marchfeld).

From west to east narrow valleys are interrupted by basins with river branches: basin of Eferding (west of Linz), basin called Machland (at the border of Upper and Lower Austria). In the east of Machland the different parts of the Danube valley have different names, beginning in the west with Strudengau (the name relates to the former rapids dangerous for shipping), Nibelungengau (related to the Nibelungenlied, in which a Rüdiger of Pechelaren (now Pöchlarn) appears) and Wachau. In the Nibelungengau and the Wachau the Danube valley widens with more arable land. In the Nibelungengau traditionally fruits are grown. You find tall pear trees and apple trees for making fruit wine ("Most"). In the eastern part of the Wachau the climate becomes warm enough to grow wine and apricots (*Prunus armeniaca*). There also starts a thermophilous vegetation and flora. East of Krems the Danube leaves the Bohemian Massive and flows through the basin called Tullnerfeld. Near the northern most point of Vienna the Danube flows through the eastern most parts of the Alps called Vienna Woods (Leopoldsberg at the right bank) and Bisamberg (near the left bank). The basin of Vienna is the eastern most basin in Austria. Between the Lower Carpats near Bratislava (Slovakia) and the Hundsheimer Berge in Austria the Danube leaves Austria.

The climate changes from west to east from cool moist to warm as it is seen in the following overview (period 1971–2000). The precipitation is lowest in the Wachau (Krems).

Average temperature (°C)	Aschach	Linz	Ybbs/P.	Melk	Krems	Wien Hohe W.
January	−1.2	−0.7	−0.6	−0.8	−0.6	0.1
February	−0.4	0.7	0.5	0.0	0.8	1.6
March	4.4	5.1	4.8	4.7	4.9	5.7
April	8.1	9.3	8.6	8.6	9.3	10.0
May	13.5	14.6	14.0	13.9	14.6	15.2
June	16.1	17.3	16.7	16.9	17.6	18.2
July	18.1	19.1	18.8	18.8	19.5	20.2
August	17.7	18.7	18.5	18.5	18.9	19.8
September	13.7	14.4	14.3	14.5	14.3	15.3
October	8.9	9.4	9.0	9.0	8.9	9.9
November	3.1	3.8	3.7	3.6	3.7	4.6
December	0.1	0.6	0.8	0.6	0.7	1.5
Year	8.5	9.4	9.1	9.0	9.4	10.2

Average percipitation (l/m^2)	Aschach	Linz	Ybbs/ P.	Melk	Krems	Wien Hohe W.
January	64.7	59.7	48.8	33.6	17.3	37.2
February	45.3	48.4	38.5	29.8	21.0	39.4
March	57.4	64.2	52.5	39.2	27.4	46.1

(continued)

Average percipitation (l/m^2)	Aschach	Linz	Ybbs/ P.	Melk	Krems	Wien Hohe W.
April	58.5	63.8	60.6	43.2	37.5	51.7
May	61.2	70.9	66.0	57.4	58.2	61.8
June	92.4	91.2	86.9	73.5	80.2	70.2
July	90.5	107.0	101.3	90.1	79.8	68.2
August	81.6	83.9	70.5	66.4	62.0	57.8
September	54.2	63.2	53.0	44.0	45.5	53.5
October	48.5	52.3	46.9	36.4	28.3	40.0
November	60.5	62.1	57.5	40.7	33.6	50.0
December	71.8	65.7	62.0	40.1	24.9	44.4
Year (Σ)	787.2	832.4	744.5	594.4	515.7	620.3

Site	Aschach	Linz	Ybbs/Persenbeug	Melk	Krems	Wien Hohe Warte
Altitude (m)	282	263	231	240	207	202
Longitude	14° 1′	14° 17′	14° 4′	15° 21′	15° 37′	16° 21′
Latitude	48° 23′	48° 18′	48° 11′	48° 13′	48° 25′	48° 14′

1 Vegetation at the Danube

1.1 Softwood Flood Plain

Now we follow the description of the vegetation of the flood plain near Wallsee [Machland, Upper Austria (Wendelberger-Zelinka 1952)].

The vegetation of flood planes follows the dynamics of the river. On principal we can distinguish three models of succession:

1. The deposit of gravel and sand inside of the river bed.
2. The deposit of moist sand and mud in the area of slowly flowing river branches.
3. Paludification of stagnant old river branches.

In the first case the river throws up gravel and sand on places where the current is weaker. At first *Agrostis stolonifera* colonises the new substratum. After that woody plants follow: On dry gravel *Salix eleagnos* and *Populus nigra*, on more moist gravel *Salix purpurea*, *Salix pentandra* and *Salix triandra*. These first colonists were often destroyed by flood, but they slow down the current and promote the sedimentation, and some herbaceous plants come along, like *Artemisia vulgaris*, *Tanacetum vulgare*, *Saponaria officinalis*, *Achillea millefolium*. *Salix purpurea* becomes dominant. High waters increase deposition of sand. The first forest is formed by *Salix alba*. In the shrub layer grow *Cornus sanguinea* and *Humulus lupulus*, in the field layer *Rubus caesius*, *Scrophularia nodosa* and *Symphytum officinale*.

The second way of succession starts on sand and mud along slowly flowing river branches. First a sand-bank is only temporary not covered by water. The typical vegetation is the *Heleocharis acicularis–Limosella aquatica*–ass. The caracteristic species are *Eleocharis acicularis*, *Rorippa amphibia*, *Riccia cristallina*, *Botrychium granulatum* (alga), *Limosella aquatica*, *Rorippa sylvestris*, *Ranunculus circinatus* f. *terrestris*, *Scirpus radicans*, *Cyperus fuscus*, *Eleocharis ovata*.

Limosella aquatica is the first coloniser. The first seedlings of woody plants are from *Salix triandra*, which is very flood tolerant. The succession towards *Salicetum albae* begins with the stage of *Agrostis stolonifera* together with some hydrophylus plants like *Myosotis palustris*, *Lythrum salicaria*, *Mentha aquatica* and *Phragmites communis*.

The third way of succession develops in old river branches, cut off the main stream by constructing river beds for shipping in the nineteenth century. The paludification takes longer time than the former successions, because it is built only by accumulation of organic material by the vegetation itself. At the deepest spots grow hydrophytes: *Myriophyllum verticillatum* and *M. spicatum*, *Nuphar lutea*, *Potamogeton natans*, *P. crispus*, *P. densus*, *P. perfoliatus*, *P. pectinatus*, *Elodea canadensis* (neophyte) and *Stratiotes alioides*. In the marginal zone helophytes are dominant: *Sagittaria sagittifolia*, *Oenothera aquatica*, *Utricularia vulgaris*, *Glyceria fluitans* and *Sparganium erectum*. The border is built by stands of *Phalaris arundincea* often in mixture with *Phragmites communis*. There also grow *Typha latifolia*, *Schoenoplectus lacustris*, *Butomus umbellatus*, *Rumex hydrolapatum*, *Iris pseudacorus*. The succession leads to the *Salicetum albae* in its wet variant.

1.2 Salicetum albae

The first forest in the succession of the flood plain is the forest of *Salix alba* (*Salicetum albae*) with the following characteristic species: *Salix alba*, *Lysimachia nummularia*, *Calystegia sepium* and *Rudbeckia laciniata* (neophyte).

The S*alicetum albae* can be subdivided into a deep subass. of *Phalaris arundinacea* and a high subass. of *Cornus sanguinea*. The subass. of *Phalaris arundinacea* can be subdivided into the wet variant of *Iris pseudacorus* and the moist variant of *Myosotis palustris*. Typical species of the variant of *Iris pseudacorus* are *Stachys palustris*, *Phragmites communis*, *Lysimachia vulgaris*. Typical species of the variant of *Myosotis palustris* are: *Rumex obtusifolius*, *Polygonum hydropiper*, *Ranunculus repens*, *Agrostis stolonifera*, Filipendula ulmaria, *Salix fragilis*, *Rorippa sylvestris*.

Typical species of the subass. of *Cornus sanguinea* are *Circaea lutetiana*, *Prunus avium*, *Carduus crispus*, *Brachypodium sylvaticum*, *Glechoma hederacea*, *Sambucus nigra*, *Alnus incana*, *Fraxiunus excelsior*, *Scrophularia nodosa*, *Senecio ovatus* (*fuchsii*), *Carex acutiformis*, *Cirsium oleraceum*, *Chaerophyllum temulum*, *Euonymus europaeus*, *Paris quadrifolia*, *Impatiens parviflora* (neophyte), *Impatiens* *noli-tangere*, *Allium ursinum*. Very common in the variant of *Cornus sanguinea* is *Humulus lupulus*.

In direction to the margin of the flood plain with decreasing height of flood *Alnus incana* becomes dominant. With its nitrogen binding bacteria it raises the fertility of soil. Typical plants of *Alnetum incanae* are: *Carduus crispus*, *Circaea lutetiana*, *Cornus sanguinea*, *Sambucus nigra*, *Alnus incana*, *Prunus padus*, *Fraxinus excelsior*, *Geum urbanum*, *Glechoma hederacea*, *Galanthus nivalis*, *Lamium maculatum*, *Festuca gigantea*, *Impatiens noli-tanger*e, *Brachypodium sylvaticum*, *Paris quadrifolia*, *Euonymus europaeus*, *Lamiastrum montanum*, *Scrophularia nodosa*, *Allium ursinum*, *Quercus robur*, *Aegopodium podagraria*, *Impatiens parviflora* (neophyte), *Stachys sylvatica*, *Ulmus minor*. It has a marked aspect of flowering in spring: *Galanthus nivalis*, *Scilla bifolia*, *Gagea lutea*, *Leucojum vernum*, *Corydalis cava*, *Allium ursinum.*

In the *Alnetum incanae fraxinetosum*, *Fraxinus excelsior* becomes dominant, forming a tree layer from 20 to 25 m above the sparse stands of *Alnus incana* with 10–15 m. The dominant *Fraxinus* allows to pass much light. Therefore the shrub layer and the herb layer are good developed. Typical species are *Euonymus europaeus*, *Primula elatior*, *Platanthera bifolia*, *Quercus robur*, *Ligustrum vulgare*, *Pulmonaria officinalis*, *Symphythum tuberosum*. Very sparse grows *Populus alba* in the higher parts of the flood plain, therefore it was not possible to describe exactly a *Populetum albae*.

The description above followed Wendelberger-Zelinka "Die Vegetation der Donauauen bei Wallsee" in Machland (1952). It describes the vegetation of flood plains upstream of Vienna in the basin of Machland at the border between Upper and Lower Austria. Due to the power stations built, there are possible changes in the vegetation during the past years.

The next description follows Margl (1972), which describes the vegetation of the flood plains downstream of Vienna. The most striking distinction is the development of *Populus* stands and of a hardwood flood plain.

At the beginning of the succession on dry gravel besides *Salix eleagnos Populus nigra* is important. Important herbaceous plants are *Vicia cracca*, *Daucus carota*, *Plantago lanceolata*, *Artemisia vulgaris*, *Calamagrostis epigejos*.

Stands of *Populus alba* are well developed. There you can also find *Ulmus laevis*, *Crataegus monogyna*, *Prunus spinosa*, *Prunus padus*, *Cornus sanguinea*, *Viburnum opulus*, *Circaea lutetiana*, *Impatiens noli-tangere*, *Humulus lupulus*, *Galeopsis speciosa*, *Galeopsis tetrahit*, *Glechoma hederacea*, *Impatiens parviflora* (neophyte), *Galium aparine*, *Arctium nemorosum.*

1.3 Hardwood Flood Plain

Downstream of Vienna the hardwood forests are well developed. Species of communities in the end of succession are *Quercus robur*, *Ulmus minor*, *Corylus avellana*, *Fraxinus excelsior*, *Acer campestre*, *Vitis vinifera*, *Pyrus pyraster*, *Ligustrum vulgare*, *Viola riviniana*, *Viola reichenbachiana*, *Geum urbanum*, *Pulmonaria officinalis*, *Carex sylvatica*.

The highest part of the hardwood forest is named after *Tilia* (Linden-Au). It grows on the old embarkments, which are flooded only every 5–10 years and where the upper soil is separated from the ground water by a layer of gravel. But the thickness of the upper ground is enough for the roots of the trees.

Typical plants are *Tilia cordata*, *Populus x canescens*, *Carpinus betulus*, *Acer pseudoplatanus*, *Malus sylvestris*, *Prunus avium*, *Frangula alnus*, *Rhamnus cathartica*, *Rosa canina*, *Cornus mas*, *Hedera helix*, *Viburnum lantana*, *Viola mirabilis*, *Viola suavis*, *Heracleum sphondylium*, *Polygonatum latifolium*, *Dactylis polygama*, *Listera ovata*, *Platanthera bifolia*. Common parasitic epiphytes are *Viscum album* and *Loranthus europaeus* (on *Quercus*). Exotic trees introduced by men are *Juglans nigra*, *Fraxinus pennsylvanica*, *Robinia pseudacacia*, *Populus x canadensis* s.l. Neophytes on the bank of Danube are *Asclepias syriacus*, *Hemerocallis fulva*, *Amorpha fruticosa*, *Acer negundo*.

1.4 Try Spots ("Heißländen")

Even in the flood plain very dry spots exist called "Heißländen". The underground is composed of gravel overlied by thin layers of sand or mud. They are developed by extremely high floods, in which gravel was deposited as high as that the following floods could reach them seldomly. Trees grow only solitary in between some shrubs and prevailing grasses. There you find *Populus nigra*, *Salix eleagnos*, *Betula pendula*, *Quercus robur*, *Tilia cordata*. After Wendelberger-Zelinka (1952) the following shrubs are typical near Wallsee: *Crataegus monogyna*, *Cornus mas*, *Rhamnus cathartica*, *Cornus sanguinea*, *Ligustrum vulgare*, *Euonymus europaeus*, *Viburnum lantana*, *Pyrus pyraster*, *Lonicera xylosteum*, *Rosa canina*, *Clematis vitalba*, in the east of Vienna also *Berberis vulgaris* and the tree *Quercus cerris*.

The most important herbaceous plants are *Dactylis glomerata*, *Poa angustifolia*, *Asparagus officinalis*, *Achillea collina*, *Galium verum*, *Securigera* (*Coronilla*) *varia*, *Vicia tetrasperma*, *Euphorbia cyparissias*, *Elymus hispidus*, *Plantago lanceolata*, *Eryngium campestre*, *Hypericum perforatum*, *Salvia pratensis*, *Allium scorodoprasum*, *Knautia arvensis*.

In the Lobau, in the basin of Vienna, on thin layers of sand there are settlements of *Hippophae rhamnoides* between dry meadows. The dry meadows have two different formations (Sauberer 1942), one on pure gravel, the other on a thin layer of sand. The most important species on gravel are *Bothriochloa ischaemum*, *Cerastium pumilum*, *Teucrium botrys*, *Apera interrupta*, *Veronica dillenii*, *Sedum sexangulare*, *Petrorhagia saxifraga*, *Potentilla arenaria*, *Arenaria serpylifolia*, *Saxifraga tridatylites*, *Sanguisorba minor*, *Myosotis ramosissima*, *Melica ciliata*, *Euphorbia cyperissias*, *Helianthemum ovatum*, *Erophila verna*, *Hypericum perforatum*, *Teucrium chamaedry*s, *Veronica arvensis*. Mosses: *Tortella inclinat*a, *Syntrichia* *ruralis*, *Rhacomitrium canescens*, *Abietinella abietina*. Lichens: *Cladonia pyxidata*, *Placodium lentigerum*, *Toninia coeruleo-nigricans*.

The most important species on sand are *Stipa pennata* agg., *Orchis morio*, *Orchis ustulata*, *Orchis coreophora*, *Orchis militaris*, *Dactylorhiza incarnata*, *Muscari racemosum*, *Centaurium minus*, *Oxalis stricta* (neophyte), *Scabiosa columbaria*, *Asperula cynanchica*, *Alyssum alyssoides*, *Vincetoxicum hirundinaria*, *Digitaria ischaemum*, *Cynoglossum officinale*, *Dianthus carthusianorum* s.l., *Aristolochia clematitis*, *Salsola kali*, *Orobanche lutea*, *Dorycnium germanicum*, *Asparagus officinalis*, *Platanthera bifolia*, *Knautia arvensis*, *Astragalus onobrychis*, *Euphorbia virgata*, *Euphorbia segueriana*, *Tragopogon orientalis*, *Myosotis arvensis*, *Festuca rupicola* and the funghi *Geopyxis cupularis* and *Morchella esculenta*.

1.5 Ecology of the Flood Plain

The vegetation of the flood plain is primarily characterized by adaption to flooding. The influence is first of all mechanically by destruction of leaves and bark and covering by sediments. The willows growing near brooks and rivers have generally flexible brunches and narrow leaves. The branches of the willows *Hippophae rhamnoide*s and *Populus nigra* will take roots if they are covered by sand or mud. During longer lasting flooding *Salix alba* can drive roots into the water. *Populus alba* can develop root shoots after destruction of its trunk. *Cornus sanguinea* is spreading by runners.

In spite of the devastation by flooding the flood plain forest is the most luxuriant indigenous plant community. This depends on enough water during vegetation period and on the intake of new soil and new organic material by flooding. It is a habitat which is fertilized by the nature itself. This allows a rapid growth. Therefore the floodplane forest is the native place of our quickest growing trees and of many ruderal plants.

Also the seed dispersal of the trees is according to the habitat. *Salix* and *Populus* have airworthy seeds. They have only a short time of viability and need moist sand or mud. Most of the other trees also develop airworthy seeds or fruits. Only *Quercus robur*, which is growing on the highest parts of the flood plain has fruits which are spread by animals (squirrel and jay).

Among the shrubs only the distinctive pioneers have airworthy seeds (*Salix* and *Myricaria germanica*). Most of the shrubs have fruits spread by animals. The fruits of *Hippophae rhamnoides* are floatable.

1.6 The Occurrence of Mountain Plants

The connection between the flora of flood plains and the mountain flora is closest in gravel vegetation. Typical gravel plants are *Myricaria germanica* and *Hippophae* *rhamnoides*. Both became rare because of adaptions for shipping. Related to the whole distribution they are continantal plants. The genus *Hippophae* and the genus *Myricaria* reach their highest variety in the mountains of Asia. Both are widely distributed on gravel of rivers. *Hippophae rhamnoides* also grows on the shores of the North Sea and East Sea. In the nineteenth century *Myricaria germanic*a spread till the eastern border of the basin of Vienna. *Hippophae rhamnoides* was spread only till the beginning of the basin of Vienna. *Salix eleagnos* is spread till Slovakia and Hungary. *Selaginella helvetica* has its main area in the mountains at rough meadows on limestone. In the flood plain it grows on sand covering gravel with sparse vegetation. At the Danube it reaches its most eastern distribution in Slovakia. *Selaginella helvetica* is spread from the mountains of central Europe to south east as far as Caucasus. *Alnus incana* grows with decreasing vitality as far as Hungary. Its main area is Scandinavia and north eastern Europe. It also grows in the mountains of middle and south east Europe. Along the rivers it advances into the plains. In the mountains it is not bonded to rivers and colonizes also open grounds. As a shallow rooted plant it is sensitive to parching. Therefore it disappears along with the decreasing number of high waters in summer. *Aconitum napellus*, a plant of subalpine tall herbaceous vegetation, grows quite luxuriant in the flood plains of Upper Austria. Down the river it retracts more and more into the shadow of woods. The last populations are in Tullnerfeld in the west of Vienna. *Astrantia major* also grows as far as the Tullnerfeld. It has a similar main distribution like *Aconitum napellus*. *Silene dioica*, also a mountain plant, with an entire suboceanic distribution, occurs as far as Stockerau upstream of Vienna in the Tullnerfeld. Near Stockerau also ends the distribution of *Primula elatior*. *Cirsium oleraceum*, with mainly European and Saramatic distribution, is a plant of moist fertile meadows in regions with higher precipitation. Downstream of Vienna in the so called Pannonian climate it becomes a typical plant of the flood plain, which needs the shadow of trees. With decreasing occurrence it reaches the national border to Slovakia near Wolfsthal. At the border to Slovakia also ends the occurrence of *Impatients noli-tangere*. In the Pannonian climate it is connected to shadow too. As an annual plant its frequency depends on the meteorological conditions of the specific year. *Salvia glutinosa*, a plant of forests in European and Asiatic mountain ranges, grows in the upper part of the softwood flood plain and in the hardwood flood plain in the whole Pannonian part of Lower Austria. *Carex alba*, a species of drier soil, but of atmospheric humidity, grows mainly in mountain forests of *Fagus sylvatica*. It grows in the highest parts of the flood plain and is sensitive to extraordinary high flooding.

Acer pseudoplatanus is a tree of humid mountain forests in middle and south Europe. It is also found in the hardwood forests of the flood plain, but it is very sensitive to high flooding and depends on supply of fruits from the mountain area. *Carpinus betulus*, with the main area in hills, avoids the dry Pannonian plain and grows in the highest parts of the flood plain.

2 The Occurrence of Thermophilous Plants

2.1 Thermophilous Plants with a Wider Distribution

Populus nigra and *Populus alba* dominate increasing downstream in the higher parts of the softwood area. Sometimes they are pushed back by early cuttings in favour of *Alnus incana*.

Ulmus laevis, a tree with continental distribution, advances widest of all hardwood trees into the softwood flood plain and grows nearly exclusively in the flood plain. *Ulmus minor* is the most common *Ulmus* species, also in the hardwood of the flood plain. It prefers warm and fertile places outside of the flood plain, sometimes also such strongly influenced by men.

Acer campestre common also outside of the flood plain and there mostly growing as a shrub grows in the flood plain up to a tree. Downstream it becomes more frequent as far as Hungary.

*Ligustrum vulgar*e is a thermophilous shrub, common in shrub societies, and grows also regularly in the hardwood part of the flood plain.

2.2 Thermophilous Plants Growing Mainly Downstream of Vienna

First *Cornus mas* grows sparsely in the flood plain of Tullnerfeld upstream of Vienna and becomes common in the Wiener Becken. Outside of the flood plain it often grows together with *Quercus pubescens.*

Lithospermum purpurocaeruleum is restricted to the highest parts in the flood plain. Out of the flood plain it also grows together with *Quercus pubescens*.

Polygonatum latifolium appears first in the flood plain in the basin of Vienna. Out of the flood plain it also grows in thermophilous oak-woods.

Vitis sylvestris subsp. *sylvestris* grows from the Lobau near Vienna downstream. It was first cultivated in middle Europe before the Roman period.

In Lower Austria *Loranthus europaeus* is a plant mostly of the eastern (Pannonian) part and after Fischer et al. (2008) increasing. This seems to be true also for the Danube. After Halácsy (1896) Hollenburg (near Krems) was its western most locality at the Danube. Schweighofer (2001) writes in his “Flora des Bezirkes Melk”: “In the valley of Danube always more advancing”.

At the Danube near Vienna the great variety of different species is caused by the fact that plants of cooler climate meet plants of warmer climate, for example *Polygonatum multiflorum* and *P. latifoliu*m and *Anemone nemorosa* and *A. ranunculoides* (Schratt-Ehrendorfer 2011).

2.3 Mainly in the Flood Plain of March (Morava) Growing Plants

Along the March runs the border between Austria and Slovakia. In contrast to the Danube the March is a slowly flowing river in the plain before it flows into the Danube. It deposits mainly sand and mud. Compared to the Danube it has a proportional wider area of hardwood forests. A typical tree is *Fraxinus angustifolia* (*oxycarpa*), which also grows near the Danube, but there it rarely develops pure stands and it is often hybridized with *Fraxinus excelsior*.

In former times *Leucojum aestivum* was also growing at the Danube, but it seems to be died out there.

At the March *Galium rubioides* grows in moist meadows. At the Austrian Danube it only grows at the border to Slovakia.

Clematis integrifolia grows in meadows in the flood plain of the March, at the Danube only near Vienna.

The following hydrophtes and helophtes occur only at the March and not at the Danube in Austria: *Trapa natans*, *Nymphoides peltata*, *Urtica kioviensis*, *Lycopus exaltatus*.

3 Vegetation of Steep Slopes Above the Danube

Now there is a short description about the vegetation at the Danube, but outside of the flood plains.

3.1 Example of the Vegetation of Tributary Rivers Flowing into the Danube

The rivers of the Bohemian Massive often form gorges before they flow into the Danube. After Dunzendorfer (1992) in the raven forests *Fraxinus excelsior*, *Ulmus glabra*, *Acer pseudoplatanus*, *Abies alba* and uphill *Carpinus betulus*, *Tilia cordata* and also *Acer platanoides* are growing in the tree layer. The most common shrub is *Corylus avellana*. Above them *Fagus sylvatica* becomes dominant. Only on talus grow *Pinus sylvestris* and *Sorbus aucuparia*. In the gorges typical herbs are *Matteucia struthiopteris*, *Corydalis cava*, *Galeobdolon montanum* (*Lamistrum galeobdolon*), *Anemone nemorosa*, *Ranunculus lanuginosus*, *Caltha palustris*, *Brachypodium sylvaticum*, *Aruncus dioicus*, *Knautia maxima* (*dipscifolia*), *Thalictrum aquilegifolium*, *Geum rivale*, *Geranium sylvaticum*.

3.2 Examples of the Vegetation at Slopes Near the Danube

Mayer (1969) described the vegetation in the extremely narrow valley of the Danube 5 km in the east of Grein in Strudengau (Upper Austria). There is a reservation (Naturwaldreservat Freyensteiner Donauwald "Schwarze Wänd"). The reservation adjoins directly to the Danube. The geological subsoil is granite (Weinsberger Granit). The reservation is about 20 ha large. Mayer distinguished ten types of forests, beginning in the highest parts:

(a) *Vaccinio—Pinetum luzuletosum*
(b) *Luzulo—Abietetum myrtilletosum*
(c) *Taxo—Fagetum*
(d) *Luzulo—Abieti Fagetum dryopteridetosum*
(e) *Dentario bulbiferae—Fagetum*
(f) *Dentario bulbiferae—Fagetum typicum*
(g) *Aceri—Tilietum polypodietosum*
(h) *Ulmo—Aceretum impatientetosum*
(i) *Aceri—Fraxinetum petasitetosum*
(j) *Fraxino—Alnetum glutinosae caricetosum remotae*

The name giving plants of the forest types are: *Vaccinium myrtillus*, *Pinus sylvestris*, *Luzula luzuloides* (*albida*), *Abies alba*, *Fagus sylvatica*, *Dryopteris dilatata*, *Cardamine* (*Dentaria*) *bulbifera*, *Acer pseudoplatanus*, *Ulmus glabra*, *Impatiens noli-tangere*, *Fraxinus excelsior*, *Petasites albus*, *Alnus glutinosa*, *Carex remota*.

Hübl and Holzner (1977) describe the thermophilous vegetation of the Wachau. Mostly at spots where marble is in the ground *Quercus pubescens* grows in small stands. *Prunus fruticosa* formed thin belts of edges of scrubs. *Festucetum pallentis* is a typical turf on siliceous rocks. There you find *Festuca pallens*, *Jovibarba hirta*, *Alyssum saxatile*, *Allium montanum*, *Seseli osseum*. In this community *Onosma helvetica* subsp. *austriaca* grows very rarely, endemic in the Wachau and now threatened by extinction.

The north eastern part of the Leopoldsberg slopes steeply to the Danube. At the opposite side of the river the western part of the Bisamberg slopes deeply to the Danube valley. Both mountains belong to the so called "Flyschzone", built by sandstone and marl, the northern most zone of the Eastern Alps. At the Leopoldsberg in Vienna (Zukrigl 2005) the north east slope nearly reaches the Danube. Its typical vegetation is a forest dominated by *Tilia platyphyllos* with *Fraxinus excelsior* and *Acer platanoides* and fewer *Fagus sylvatic*a and *Ulmus glabra*, sometimes also *Acer campestre*, *Sorbus torminalis*, *Carpinus betulus*, rarely *Quercus pubescens* and *Pyrus pyraster*. Shrubs are *Cornus mas*, *Daphne laureola* and *Staphylea pinnata*. Constant herbs are *Hepatica nobilis*, *Arabis turrita*, *Viola odorata* and suavis, *Melica uniflora*, *Galium odoratum*, *Glechoma hirsuta*. Also nitrophilous plants are common: *Alliaria petiolata*, *Galium aparine*, *Lamium maculatum*, *Sisymbrium strictissimum*, *Chaerophyllum temulum*, *Lapsana communis*, *Elymus caninus*. The

Bisamberg (Hübl and Maier 2013) has a thermophilous vegetation on its slope to the valley of Danube. The scrub developed to a shrub forest of *Quercus pubescens*, *Crataegus monogyna*, *Cornus sanguinea*, *Cornus mas*, *Virburnum lantana*, *Ligustrum vulgare*, *Amelanchier ovalis*, *Euonymus europaeus*, *Euonymus verrucosu*s. At the margins of the scrub grow *Prunus fruticosa* and *Rosa spinosissima*.

Between the scrub are spots of dry meadows with a flora rich in species: *Carex humilis*, *Pulsatilla grandis*, *Anthericum ramosum*, *Stipa pennata* agg., *Odontites luteus*, *Scorzonera austriaca*, *Iris pumila*, *Allium flavum*, *Potentilla incan*a (*arenaria*), *Globularia bisnagarica* (*punctata*), *Linum flavum*, *Polygala major*. Particularities of rare plants: *Artemisia pancicii*, *Vinca herbacea*, *Himantoglossum adriaticum* (*hircinum* s. l.), *Crepis pannonica*. *Crepis pannonica* is threatened to die out.

A rich thermophilous vegetation and flora growing on limestone is also developed at the Hundsheimer Berge (Hainburger Berge). Englisch and Jakubowsky (2000, 2001) give an overview about the turf vegetation. In Austria thermophilous plants with restricted occurrence are: *Ranunculus illyricus*, *Astragalus austriacus*, *Astragalus exscapus*, *Astragalus vesicariu*s subsp. *vesicarius*, *Oxytropis pilosa*, *Helictotrichon desertorum* (in Austria only at Hundsheimer Berge).

4 Plants in the Harbours of the Danube

In 2013 Vladimir Jehlík published "Die Vegetation und Flora der Flusshäfen Mitteleuropas". In this book he describes the vegetation and the flora of Elbe with Moldau and Danube from the southern border of Hungary (harbour Mohács number 39 to number 62 Regensburg) in Bavaria (Germany). In Austria are the following harbours (number 50–58):

50 Vienna—Lobau, Ölhafen; left bank
51 Vienna—Albern, Getreidehafen; right bank
52 Vienna—Freudenau, Handelshafen; right bank
53 Korneuburg, former shipyard; left bank
54 Krems, Getreide- und Industriehafen; left bank
55–56 Enns–Ennsdorf: 2 harbours at the bank of the river Enns, near the mouth into the Danube
55 Ennsdorf, harbour at the right bank of the Enns; Hafenbecken Ost
56 Enns, harbour at the left bank of the Enns; Hafenbecken West
57 Linz, Tankhafen; left bank
58 Linz, Handelshafen; right bank

Jehlík found 19 plant communities:

1. *Poëtum annuae*, Linz
2. *Polygono arenastri—Lepidietum ruderalis*, Vienna—Freudenau, river port

3. *Tanaceto—Arrhenatheretum rumicetosum thyrsiflori*, Vienna—Lobau, Linz river port
4. *Petrorhagio saxifragae—Sedetum sexangularis*, Linz harbour
5. *Saxifrago tridactylitis—Poëtum compressae*, Linz river port
6. *Capsello—Descurainietum sophiae*, Krems grain port
7. *Hordeetum murini*, Vienna—Albern, grain port, Vienna—Freudenau river port
8. *Chenopodietum stricti*, Krems grain port
9. *Bromo tectorum—Sisymbrietum orientalis*, Vienna—Lobau tank port
10. *Carduo acanthoidis—Onopordetum acanthiii*, Vienna—Lobau tank port
11. *Echio—Meliotetum*, Vienna—Lobau tank harbour, Vienna—Freudenau river port, Korneuburg former shipbuilding yard, Enns industrial port
12. *Bunias orientalis* community, Vienna—Albern grain port
13. *Cuscuto europaeae—Convolvuletum sepium*, Vienna—Lobau tank harbour
14. *Lepidio drabae—Agropyretum repentis*, Vienna—Albern grain port
15. *Elytrigia repens* subsp. *repens* society, Vienna—Lobau tank harbour, Linz tank harbour
16. *Conyzo canadensis—Cynodontetum dactylis*, Vienna—Albern grain port, Vienna—Freudenau river port, rail, Linz tank port and trade port
17. *Plantagini majoris—Poëtum compressae*, Enns industrial port
18. *Convolvulo arvensis—Caricetum hirtae*, Linz river port
19. *Clematis vitalba* community, Vienna—Albern grain port

Jehlík states 1255 taxa for the two river systems. About 600 of these grow at the Austrian Danube. The following table contains plants (in alphabetical order) which occur in Austria and in at least 50% of all harbours in middle Europe.

Name of the plant	Attribute	% of the occurrence in middle European harbours	Harbours in Austria (number 50–58)
Acer negundo	inv., neoph. NA	77.4	50–56, 58
Alliaria petiolata	indig., apoph.	69.4	50–54, 56–58
Amaranthus albus	inv., neoph. A.	53.2	51–54, 56–58
Amaranthus powellii	inv., neoph. A.	85.5	51–58
Amaranthus retroflexus	inv., neoph. NA	96.8	51–56, 58
Ambrosia artemisiifoia	inv., neoph. NA	62.9	51–56, 58
Anthriscus sylvestris	indig., apoph.	69.4	51, 52, 54, 56–58
Apera spica venti	inv., archeoph.	72.6	51–56, 58
Arabidopsis thaliana	indig.	74.2	50, 52–58
Arctium minus	archeoph.	53.2	50–58
Armoracia rusticana	archeoph.	51.6	50, 52, 55–58
Arrhenatherum elatius	inv., archeoph.	95.2	50–58
Atriplex oblongifolia	inv., archeoph.	56.5	50–52, 54, 55
Atriplex patula	archeoph.	85.5	50–58

(continued)

Name of the plant	Attribute	% of the occurrence in middle European harbours	Harbours in Austria (number 50–58)
Atriplex prostrata	indig.	67.7	55
Atriplex sagittata	inv., archeoph.	71.0	50, 52–54
Avena fatua	inv., archeoph.	66.1	51, 52, 54–56, 58
Ballota nigra subsp. *nigra*	inv., archeoph.	88.7	50–54, 57, 58
Barbarea vulgaris	indig., apoph.	54.8	50–58
Betula pendula	indig., apoph.	71.0	51–53, 55
Bidens frondosa	inv., neoph. NA	91.9	50, 52–54, 56–58
Brassica napus subsp. *napus*	cult.	88.7	51, 52, 54–58
Bromus hordeaceus	archeoph.	95.2	50–58
Bromus sterilis	archeoph.	90.3	50–58
Bromus tectorum	archeoph.	75.8	50–54, 56–58
Calystegia sepium	indig., apoph.	85.5	53–58
Capsella bursa-pastoris	neoph.	100	50–58
Cardaria draba	inv., archeoph. Euras	66.1	50–54, 57, 58
Carduus acanthoides	archeoph.	64.5	50–54, 58
Carduus crispus	Archeoph. or indig.	59.7	51, 53–56
Carex hirta	apoph.	82.5	50–58
Centaurea stoebe	apoph.	56.5	50–54, 56–58
Cerastium holosteoides	apoph.	85.5	50–58
Chaerophyllum bulbosum	apoph.	50.0	51, 52
Chenopodium botrys	inv., archeoph.	66.1	50, 52–58
Chenopodium pedunculare	inv., archeoph.	71.0	51, 53–56, 58
Chenopodium strictum	inv. neoph. Asia	93.5	50–56, 58
Chenopodium suecicum	neoph. NE Eur.?	67.7	51, 54, 55, 58
Cirsium arvense	archeoph.	100	50–58
Cirsium vulgare	archeoph.	69.4	51–58
Clematis vitalba	apoph.	64.5	50–58
Convolvulus arvensis	archeoph.	95.2	50–54, 56–58
Crepis biennis	archeoph.	69.4	50–56, 58
Dactylis glomerata	indig.	98.4	50–58
Datura stramonium	neoph. NA	56.5	51, 54–56, 58
Daucus carota	archeoph.	88.7	50–58
Descurainia sophia	archeoph.	82.3	50–58
Digitaria sanguinalis	archeoph.	67.7	51–54, 57, 58
Diplotaxis tenuifolia	archeoph.	50.0	50–54, 56–58
Echinochloa crus-galli	inv., archeoph.	92.0	51–56, 58
Elytrigia repens	indig., apoph.	100	50–58

(continued)

Name of the plant	Attribute	% of the occurrence in middle European harbours	Harbours in Austria (number 50–58)
Epilobium angustifolium	indig.	66.1	52, 55, 56, 58
Epilobium ciliatum	inv. neoph. NA	64.5	52, 54–58
Equisetum arvense	indig., apoph.	74.2	50, 51, 53–58
Eragrostis minor	archeoph.	67.7	50–58
Erodium cicutarium	archeoph.	66.1	50–54, 56–58
Euphorbia cyparissias	indig., apoph.	50.0	50–58
Fallopia convolvulus	archeoph.	85.3	50–58
Fallopia dumetorum	indig., apoph.	87.1	50–54, 56–58
Festuca brevipila	apoph.	56.5	51, 54–58
Festuca rubra	indig., apoph.	90.3	50–58
Fraxinus excelsior	indig., apoph.	61.3	51, 53, 55, 56, 58
Galinsoga ciliata	inv. neoph. A	64.5	52, 55, 56, 58
Galium aparine	indig., apoph.	96.8	50–58
Geranium pusillum	archeoph.	69.4	50–52, 54–58
Geranium robertianum	indig., apoph.	62.9	51–58
Glechoma hederacea	indig., apoph.	66.1	50–55, 57, 58
Helianthus annuus var. *macrocarpus*	cult. NA	71.0	50–56, 58
Heracleum sphondylium s.l.	indig., apoph.	71.0	50, 51, 53, 55–58
Hordeum distichon	cult. SW Asia	54.8	51, 54–56, 58
Hordeum murinum	archeoph.	74.2	50–54, 57, 58
Humulus lupulus	indig. cult.	83.9	50–58
Hypericum perforatum	indig., apoph.	88.7	51–58
Impatiens parviflora	inv. neoph. Asia	74.2	50–58
Kochia scoparia subsp. *scoparia*	inv. neoph. Euras.	59.7	50–53, 56
Lactuca serriola	archeoph.	96.8	50–58
Lamium album	archeoph.	62.9	57
Lamium purpureum	archeoph.	74.2	50–58
Lapsana comunis	archeoph.	72.6	50–54, 56–58
Lathyrus tuberosus	archeoph.	58.1	50–52, 54, 55, 57
Lepidium ruderale	archeoph.	72.6	50–52, 54, 56–58
Linaria vulgaris	archeoph.	91.9	50–54, 56–58
Lolium perenne	indig., apoph.	98.4	50–58
Lotus corniculatus	indig.	87.1	50–58
Lycopus europaeus	indig., apoph.	69.4	53, 54, 56–58
Malus domestica	archeoph., cult.	74.2	50–53, 55–58
Malva neglecta	archeoph. Asia	56.5	51–54
Matricaria discoidea	neoph. Asia	82.3	50, 54–58
Matricaria recutita	archeoph.	66.1	51, 54–58
Medicago lupulina	archeoph.	90.5	50–58

(continued)

Name of the plant	Attribute	% of the occurrence in middle European harbours	Harbours in Austria (number 50–58)
Medicago sativa	neoph. Asia, cult.	62.9	50–52, 54–58
Melilotus albus	archeoph.	88.7	50, 52–58
Meliotus officinalis	archeoph.	83.9	50–56, 58
Microrrhinum minus	archeoph. S Eur.	50.0	51–58
Myosoton aquaticum	indig., apoph.	62.9	50, 53–56
Oenothera biennis	indig., apoph.	82.3	50–58
Onopordum acanthium	archeoph.	53.2	50–52, 54
Papaver rhoeas	archeoph.	85.5	50–58
Pastinaca sativa	archeoph. Asia	54.8	50–54, 56–58
Persicaria amphibia	indig., apoph.	59.7	51, 58
Persicaria lapathifolia	indig., apoph.	90.3	50, 53–58
Persicaria maculosa	indig., apoph.	80.6	50, 52–58
Persicaria mitis	indig., apoph.	74.2	50–57
Phalaris arundinacea (incl. var. picta)	indig.	85.5	50, 52, 54–57
Phleum pratense	indig., apoph.	59.7	50–52, 54–58
Pimpinella saxifraga	indig., apoph.	50.0	50, 52, 56, 58
Plantago lanceolata	indig., apoph.	96.8	50–58
Plantago major	archeoph.	96.8	50–58
Poa angustifolia	indig., apoph.	87.1	50–54, 57, 58
Poa annua	indig.	98.4	50–58
Poa compressa	indig., apoph.	98.4	50–58
Poa palustris	mostly apoph.	95.2	50–58
Poa pratensis	indig., apoph.	98.4	50–58
Poa trivialis	indig., apoph.	77.4	52–58
Polygonum arenastrum	probalby archeoph.	100	50–58
Populus cf. × *canadensis* (=P. × euroamericana)	inv. neoph.	80.6	50–58
Populus tremula	indig., apoph.	51.6	52, 55, 56, 58
Potentilla anserina	indig., apoph.	50.0	50, 53, 56–58
Potentilla argentea	indig., apoph.	79.0	50–52, 56–58
Potentilla reptans	indig., apoph.	87.1	50–58
Potentilla supina	indig., apoph.	62.9	50, 52–54, 56–58
Ranunculus repens	indig., apoph.	85.5	50–58
Reseda lutea	archeoph., Med.	74.2	50–58
Robinia pseudacacia	inv. neoph. NA	67.7	50–54, 56
Rorippa palustris	indig., apoph.	53.2	54–58
Rorippa sylvestris	indig., apoph.	77.4	50, 52–54, 56–58
Rubus caesius	indig.	98.4	50–58

(continued)

Name of the plant	Attribute	% of the occurrence in middle European harbours	Harbours in Austria (number 50–58)
Rumex crispus	indig., apoph.	96.8	50–58
Rumex obtusifolius s.l.	indig., apoph.	83.9	50–58
Rumex thyrsiflorus	inv., archeoph.	72.6	50–52, 54, 58
Salix alba	indig.	75.8	50–58
Salix caprea	indig.	71.0	50–56, 58
Sambucus nigra	indig., apoph.	91.9	50–58
Saponaria officinalis	archeoph., ornam.	71.0	50–58
Scrophularia nodosa	indig., apoph.	66.1	52–58
Secale cereale	archeoph., cult.	62.9	51, 52, 54–56, 58
Securigera varia	indig., apoph.	59.7	50–53, 56–58
Sedum acre	apoph.	71.0	50–54, 57, 58
Senecio viscosus	archeoph.	83.9	51–58
Senecio vulgaris	archeoph.	80.6	50–52, 54, 56–58
Setaria pumila	archeoph.	61.3	53–56, 58
Setaria viridis subsp. *viridis* var. *viridis*	archeoph.	79.0	51–54, 56–58
Setaria viridis subsp. *viridis* var. *weinmanni*	archeoph.	64.5	50–54, 56, 58
Silene latifolia	archeoph.	96.8	50–58
Silene vulgaris	indig., apoph.	71.0	50–58
Sinapis arvensis	archeoph.	72.6	50–52, 54–58
Sisymbrium altissimum	neoph.	61.2	50–52, 54, 55, 57, 58
Sisymbrium loeselii	inv., archeoph.	91.9	50–54, 56, 58
Sisymbrium officinale	archeoph.	71.0	55–58
Solanum decipiens	neoph.	75.8	52–55, 57, 58
Solanum dulcamara	indig., apoph.	71.0	50, 53, 54, 56, 57
Solanum lycopersicum	neoph., cult. A.	53.2	52, 55, 57
Solanum nigrum	archeoph.	54.8	50–52, 55, 58
Solidago canadensis	inv. neoph. NA	83.9	51–58
Sonchus oleraceus	archeoph.	96.8	50–58
Stellaria media	indig.	95.2	50–58
Symphytum officinale	indig., apoph.	61.3	50, 51, 53–58
Tanacetum vulgare	archeoph.	91.9	50–58
Taraxacum sect. *Ruderalia*	indig.	100	50–58
Thlaspi arvense	archeoph.	67.7	52, 54–56, 58
Tragopogon dubius	archeoph.	53.2	50–54, 56, 58
Trifolium campestre	indig., apoph.	58.1	50–58
Trifolium pratense	indig., cult.	77.4	50–58
Trifolium repens	indig., apoph.	95.2	50–58

(continued)

Name of the plant	Attribute	% of the occurrence in middle European harbours	Harbours in Austria (number 50–58)
Tripleurospermum inodorum	inv., archeoph.	100	50–58
Triticum aestivum	archeoph., cult.	74.2	51, 52, 54–56, 58
Tussilago farfara	indig., apoph.	91.9	50, 52–58
Ulmus sp.	mostly apoph.	54.8	50–53, 55, 56, 58
Urtica dioica	indig., apoph.	93.5	50–58
Valerianella locusta	indig., apoph.	53.2	50, 51, 53, 54, 56–58
Verbascum phlomoides	indig., apoph.	69.4	50–56, 58
Veronica arvensis	archeoph.	75.8	50–58
Veronica persica	neoph. Central Asia	62.9	50–58
Veronica sublobata	indig., apoph.	61.3	50–58
Vicia angustifolia L. agg. (incl. *V. sativa* L.)	archeoph.	67.7	50–58
Vicia cracca	indig., apoph.	69.4	50–58
Viola arvensis	inv., archeoph.	85.5	50–58
Mosses			
Brachythecium rutabulum		71	50–58
Bryum argenteum		95.2	50–58
Ceratodon purpureus		98.4	50–58
Funaria hygrometrica		74.2	50, 51, 54–58

A America, *apoph.* apophyte, *archeoph.* archeophyte, *cult.* cultivated, *E* easters, *Euras.* Eurasia, *Eur.* Europe, *indig.* indigenous, *invas.* invasive, *Med.* Mediterranean, *NA* Northern America, *NE* North East, *neoph.* neophyte, *ornam.* ornamental plant, *S* Southern, *SW* South West

Atriplex prostrata and *Lamium album* occur only in one harbour each. *Atriplex prostrata* is generally rare in Austria (Fischer et al. 2008). *Lamium album* grows mainly in more cooler habitats and is rare in the valley of Danube.

5 Plants of the River Valleys (*Stromtalpflanzen*)

The most frequent plants you can find in the table above: *Acer negundo*, *Ambrosia atemisiifolia*, *Amoracia rusticana*, *Bidens frondosa*, *Carduus crispus*, *Chaerophyllum bulbosum*, *Clematis vitalba*, *Fallopia dumetorum*, *Rumex thyrsiflorus*. Plants, which are not so common, you find in the following table (Jehlík 2013).

Name of the plant	Attribute	% of occurrence in middle European harbours	Harbours in Austria (50–58)
Ailanthus altissima	inv., neoph. E Asia	48.4	50–54
Allium schoenoprasum	indig., apoph.	27.4	58
Allium scorodoprasum	indig.	25.8	50–52, 57, 58
Angelica archangelica subsp. *archangelica*	indig., apoph.	45.2	54, 58
Aristolochia clematitis	indig.	22.6	50, 52
Aster simplex	inv., neoph. NA	14.5	55, 56
Buddleja davidii	inv., neoph. China	14.5	51, 52, 55–58
Carduus personata	indig., apoph.	3.2	56
Cuscuta europaea	parasite, apoph.	25.8	51, 54
Elymus caninus	apoph.	21.0	52, 53, 56
Epilobium dodonaei	eur., neoph.	6.5	50, 52
Erysimum durum	indig., apoph.	27.4	53, 56
Helianthus tuberosus	inv., neoph. NA	22.6	54
Impatiens glandulifera	inv., neoph. A	32.3	54
Lithospermum officinale	indig., apoph.	4.8	50, 54, 56
Parthenocissus inserta	inv., neoph.	37.1	50–53, 58
Reynutria japonica var. *japonica*	inv., neoph. E A	38.7	54
Solidago gigantea	inv., neoph. NA	48.4	50–56, 58
Thalictrum flavum	indig., apoph.	17.7	54, 56–58
Ulmus laevis	indig., apoph.	17.7	53
Verbascum blattaria	indig., apoph.	14.5	58

6 Table of the Nature Conservation Areas at the Danube in Austria

Federal state	Conservation area	Status	Additional protection
Upper Austria	Oberes Donau- and Aschachtal	European protection area	Bird protection area
	Rannatal	Federal protection area	
	Kleines Klößlbachtal	Federal protection area	
	Schloss Neuhaus	Federal protection area	
	Pesenbachtal	Federal protection area	
	Urfahrwänd	Federal protection area	
	Traun—Donauauen	Federal protection area	Bird protection area
	Machland Nord	Natura 2000 area	
Lower Austria	Machland Süd	European protection area	Bird protection area
	Wachau—Jauerling	European protection area	Bird protection area
	Tullnerfelder Donau—Auen	European protection area	Bird protection area
	Stockerauer Au	Federal protection area	
	Wiener Wald	European protection area	Bird protection area
	Bisamberg	European protection area	
Vienna	Wiener Wald	European protection area	
	Bisamberg	European protection area	
	Lobau—Schüttelau—Schönauer Hafen	Federal protection area	
	Donau Auen	European protection area, Natura 2000 area, national park	Bird protection area
Lower Austria	Lobau—Schüttelau—Schönauer Hafen	Federal protection area	
	Donau Auen	European protection area, Natura 2000 area, national park	Bird protection area
	Untere Marchauen	Federal protection area	
	Hundsheimer Berge	European protection area, Natura 2000 area	

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Italy in the Danube Geography: Territory, Landscape, Environment, Vegetation, Fauna, Culture, Human Management and Outlooks for the Future

Kevin Cianfaglione and Franco Pedrotti

1 The Danube and Italy

The Danube is one of the most important waterways in Europe, connecting several countries and cultures. Danube River is strictly linked with Italy for historical and geographical reasons. In fact, four of the waterways that flow into the Danube have their source in Italian localities. These valleys are situated in Lombardia Region (Valtellina, more precisely, in the Valle di Livigno), Trentino-Alto Adige Region (Val Pusteria, more precisely, in the Valle della Drava; and Val Venosta), and the Friuli-Venezia Giulia Region (Tarvisiano, more precisely, in the Val Canale). Consequently, the waters of these four valleys flow not into the Mediterranean but into the Black Sea. In all, it is estimated that almost 565 km^2 of Italy lies within the hydrographic (catchment) basin of the Danube, corresponding to 0.15% of the total Danube basin and 0.2% of Italian national territory.

Today, these four valleys remain among the few residual elements of Italian cultural heritage beyond the watershed ridgeline of the Alps, still contained within the Italian national borders (Fig. 1).

In areas inhabited for centuries, in addition to biological and geographic factors, it is important to evaluate ethnology, historical and cultural features in order to analyse the landscape, the biodiversity dynamics, and to understand the value (heritage) of environmental goods. Despite the many positive, loyal, covenant and cooperative

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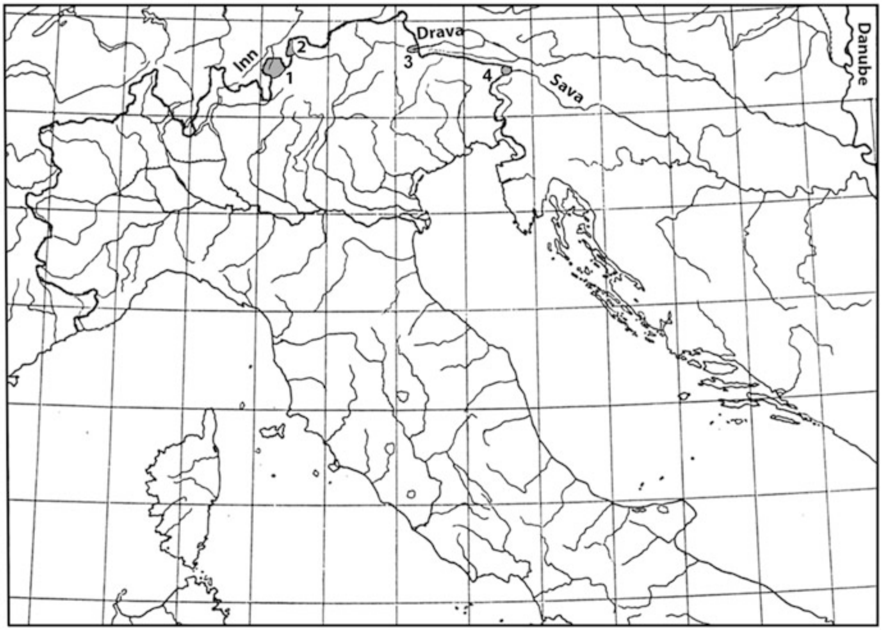

Fig. 1 Valleys from Italian Danube: (1) Livignasco (Inn River sub-basin); (2) Incuneata dei tre confini (Inn River sub-basin); (3) Valle della Drava (Drava River sub-basin); (4) Tarvisiano (Sava River sub-basin)

acts, sometimes the adverse events (or perceived somehow as negative) can be a key to trying to understand the issue of cooperation and "ethnic" conflicts, especially those related to border's peoples related environmental conditions, perception, management, needing and the possible different points of view about.

The four Italian Danubian valleys have some different geographical and botanical characteristics. In the highest levels of the study area, as in the rest of the Italian Alps, frequently we have a toponomy distinction between "Ghiacciaio" (the classic glacier) and "Vedretta" (small glaciers formed in less extensive basins or on steep slopes); for simplicity, in this work we shall not focus on this difference, considering both as glaciers.

In our study area, from West to East we have (Fig. 1):

- Raetian sector, Inn river basin, with two sub-sectors (Livignasco and Incuneata dei tre confini)
- Upper Drava valley, from the Drava river basin
- Tarvisiano, Drava river basin (Val Canale, through Slizza and then, Gail rivers) and partially Sava river basin (Upper Valromana)

Valle di Livigno, is the most continental and the most glacial valley, as demonstrated by the strong presence of Arolla or Swiss pine (*Pinus cembra*) and larch (*Larix decidua*) in extended climax-like forests. Next, the Alta Val Venosta, close to the previous valley, with similar environmental conditions and always in Raetian (Central) alpine sector. Then, we have the upper Drava valley, from the Sella di Dobbiaco. This valley is still of the continental type, but manifesting a lower degree of continentality, due to moist air currents from the lower part of the Valley, as seen by the almost absence of Swiss pine (*Pinus cembra*) and by the presence of silver fir (*Abies alba*) and Norway spruce (*Picea abies*) in some climax-like forests; with some nuclei of *Pinus cembra* and *Larix decidua* in the high part of the lateral valley "Valle di Sesto", which is less influenced by these moist currents. Finally, the Val Canale, with oceanic characteristics as demonstrated by the widespread presence of beech (*Fagus sylvatica*) and silver fir (*Abies alba*) large forests. Each of these valleys can be respectively characterized by a flag species such: the Raetian Pine (*Pinus* × *rhaetica*), the Dolomite Houseleek (*Sempervivum dolomiticum*), and the Black Pine (*Pinus nigra* subsp. *nigra* var. *nigra*).

Raetian or Engadine pine (*Pinus* × *rhaetica*), believed to be a hybrid between *P. mugo* and *P. sylvetris*, is still a debated taxon, with many synonyms (see Pignatti 1982; Christensen 1987; Conti et al. 2005). In any case, this tree characterizes the Livigno area, and surroundings. Dolomite Houseleek (*Sempervivum dolomiticum*), endemic to the Dolomites, is the species that most represents the Mountains of the Valle della Drava and the nearby Cadore (Veneto Region). Black pine (*Pinus nigra* subsp. *nigra* var. *nigra*), with a distribution limited to the Eastern Alps, is the emblematic species of the Slizza Basin, where it is indigenous. It was sometimes used in the past for reforestation purposes, against hydro-geological problems, also in other National areas.

2 Raetian Sector

This study area sector falls into two Italian regions, by two sub-sectors: Livignasco (Lombardia Region) and "Incuneata dei tre confini" (Trentino-Alto Adige Region). They corresponds to two close valleys (one per region) both belonging to the Inn River ideographic basin.

2.1 Livignasco or the Valle di Livigno (Lombardia)

The Valley of Livigno belongs to the Danube basin inasmuch as it holds the Acqua Granda torrent, also sometimes called Spöll. In truth, the Spöll begins after the Lago di Livigno, in Swiss territory. Acqua Granda-Spöll is a secondary tributary of the Danube, through the Inn River (in Romansch En; in German Inn; in Italian Eno). All derived from the Latin *Aenus*). The main spring is considered to be the Inn one, giving the name to the river; but the Acqua Granda springs system seem to be more distant from the other (Fig. 2).

Fig. 2 Livigno Valley, with Passo della Forcola Mts. in background; in foreground the village positioned on the valley terrace (photo: Kevin Cianfaglione, June 2011)

2.1.1 Geographical and Administrative Information

The valley of Livigno is geographically part of the Raetic Alps (Central Alps). Administratively the Livigno valley belongs to two municipalities, Livigno and in part Valdidentro, always in the province of Sondrio, Lombardia Region. The largest inhabited area is Livigno (1816 m. a.s.l.) which lines the valley bottom, with a number of hamlets positioned on terraces, hillsides and slopes, such as Trepalle (2250 m, the highest permanently inhabited site of the Alps), Santa Maria, and Florino. Temporary summer residences comprise chalets (known locally as Bait, Baita, Casina or Maso) and farmhouses (locally known as Maso or Malga), distributed both on the slopes and in the valley bottom, and shepherd's huts, such as the Malga Alpisella. The buildings are part masonry and part wood, in a sort of "Blockbau" style, with interlocking beams (Fig. 3). Casel, Cassina, Casina, Capanna, Baracca, Baitèl and Crot, they could also indicate old traditional type of binder-free constructions from the Tholos type, typically used as temporary "settlements" or temporary productive places. Their constructive characteristics are very widespread throughout Italy, Mediterranean basin and others parts of Europe.

The Valle di Livigno is delimited on the orographic left slope by Punta la Stretta (3104 m), Monte Cotschen (3104 m), Pizzo di Cassana (3070 m), Piz dall'Acqua (3126 m) and on the right slope by Punta Paradisino (3302 m), Punta Zembrasca (3089 m), Punta Filone (3133 m), Monte Foscagno (3058 m), Monte Rocca (2810 m), Pizzo del Ferro (3054 m), Pizzo Aguzzo (2572 m) and Cima del Serraglio

Fig. 3 Ancient farm unit, with the barn in the foreground, followed by the house; typical construction made up between stones (masonry) and wood, in a sort of “Blockbau” style (photo: Kevin Cianfaglione, June 2011)

(2685 m). In this study area sector, there are several glaciers (Ghiacciai and Vedrette), including the Glacier cirque “Circo glaciale di Val Nera” and the Glacier “Ghiacciaio delle Mine”.

The main alpine lakes are the Lago del Filone, the Lago del Ghiacciaio delle Mine, some of the Laghi di Foscagno, the Lago dei Dossi and the Lac Salin.

The Valle di Livigno has many ramifications and is crossed by the main torrent called the Acqua Granda as well as numerous secondary torrents that come from the numerous lateral valleys.

The main valleys have many lateral valleys. Starting from Val Nera, the largest valleys are on the orographic left: Valle del Saliente and Val Viera. On the right: Val delle Mine and Val Nera, the Vallaccia (with Valle di Foscagno and Valle della Foppa), Valle Alpisella and, finally, the Valle del Gallo (with Valle Bruna, Valle dell’Orsa, Valle della Tagliata and Valle Chaschabolla).

The Acqua Granda originates from two torrents: Torrente Tresenda (from the Ghiacciaio delle Mine, through Val delle Mine) and the Torrente Nera (from Forcola di Livigno, Vedrette del Paradiso and Val Nera, through the Val Nera) to then form the Lago del Gallo lake. From this lake, also called “Lago di Livigno”, it flows the Spöll River, from this point correctly named as such. This sub-artificial basin receives the waters of five affluent torrents: the main one is the Acqua Granda; to the right, Canale Torto (that originates from the Vallaccia torrent, the Foscagno torrent, and the Alpisella lake torrent); Acqua del Gallo (in the Swiss section also called “Aua da Val Mora”), with the Bruna torrent and the Ova da Chaschabella. To

Fig. 4 Lago del Gallo, Livigno, with its dam and the Valle del Gallo, where grow *Pinus mugo* subsp. *uncinata* and *Pinus* × *raethica*, also known as *P. sylvestris* subsp. *engadinensis* (photo: Kevin Cianfaglione, June 2011)

the left of the Acqua Granda, the Lago di Livigno is fed by the Saliente torrent (from Pizzo Saliente through Valle Saliente) which also collects sulphurous waters, and the Viera torrent (through Valle Rossa and Val del Cantone). The "Lago di Livigno" or "Lago del Gallo" lake, today is sub-artificial because is a hydro-power dam, derived from an extension and modification of a pre-existing small natural lake. Reservoir capacity is more or less of 164,000,000 m^3 (Fig. 4).

The valley of Livigno, from the Passo della Forcola to just below the town of Livigno, is formed of 'crystalline rocks', in prevalence quartziferous phyllites, gneiss, and mica-schists. The morphology of the valley is the typical U-shaped glacial valley; in the high part of the mountains glacial cirques are frequent, while in the valley bottom there are abundant morainic and fluvial deposits, interrupted by a series of alluvial cones and fans that descend from both slopes of the valley (see also Pozzi 1974; Saibene 1974). The lower part of the Valle di Livigno with all its lateral valleys, including the Valle del Gallo, is formed almost exclusively by stratified crystalline dolomitic rocks with intercalations of black lastriform limestones; in the Valle del Canale Torto are outcrops of grey limestones of the Liassic period, and on the Punta Saliente crystalline dolomitic rocks of the Noric period. It is a very narrow gorge, steep and precipitous between the two slopes. Consequently, there are two quite distinct areas, one with an acidic substratum in the high part of the valley and one with a basic substratum in the lower part of the valley, which produce very different soils, ranker and podzol in the first case, rendzina and dark calcareous soil in the second. These two lithological and pedological facies are in consequence responsible for the development of the two different mega-geoseries of vegetation.

According to Gafta (1994), the climate of the Valle di Livigno is Continental-Alpine, which is divided into polar, subpolar, and cold boreal climates, according to the variation of altitude; the Gams index of hygric continentality ranges is between 60° and 75°. The average annual precipitation is 675 mm in Livigno and 657 in the zone of Trepalle, markedly less compared to the surrounding areas, where it rises to 800–900 mm (Ceriani and Carelli 2000). The average annual temperature of Livigno is 2.5 °C.

2.1.2 Altitudinal Belts

The study zone comprises the following altitudinal levels: the nival, alpine, subalpine, and upper montane belts (Pirola et al. 2000).

The nival belt, between 2850 and 3800 m, is characterized by perennial snow creating a "snow desert", with few species of phanerogams and populations of lichens and bryophytes, the so-called Alpine Tundra. The vegetation of the alpine belt, located between 2400 and 2850 m, is formed of primary grasslands. The subalpine belt, between 2200 and 2400 m, hosts subalpine shrub woods, while the upper montane belt, between 1500 and 2200 m, is characterized by forests of larch (*Larix decidua*) and Swiss pine (*Pinus cembra*). In addition, the sporadic presence can be noted of birch (*Betula pendula*) and European mountain ash (*Sorbus aucuparia*) accompanied in the lower part of the valley by aspen (*Populus tremula*).

The vegetation varies greatly according to the two types of substratum described above: on the crystalline substrata the primary grasslands are formed of *Primulo-Caricetum curvulae* and *Festucetum halleri* and shrub woods of *Rhododendretum ferruginei*; the forests are formed by *Larici-Pinetum cembrae*; on the calcareous substrata the primary grasslands are represented by *Caricetum firmae* and by *Seslerio-Caricetum sempervirentis*, the shrub woods by *Erico carneae-Pinetum prostratae*, *Rhododendro hirsuti-Pinetum prostratae* and *Erico-Pinetum uncinatae*, while the forest is represented by a few nuclei of *Carici humilis-Pinetum engadinensis*.

2.1.3 The Vegetation Landscape

In the high Valle di Livigno (of "crystalline" rock substratum), the vegetation landscape is characterized at high altitudes by primary pastures with the two associations *Primulo-Caricetum curvulae* and *Festucetum halleri*. In the alpine belt there are frequent cryonival phenomena with the formation of polygonal soils and grassy cushions (Pirola 1959, 1963, 1974; Rossi et al. 1998).

In the band of the *Primulo-Caricetum curvulae,* small nival valleys are frequent, where the snow remains longer than in the surrounding zones; here the vegetative period is reduced to only 1 (or 2) months. In these small nival valleys, grows the alpine Tundra vegetation (see also Theurillat et al. 1995; Caccianiga and Andreis 2004), in some communities and with a prevalence of Cryptogams; the most significant species is *Polytrichum norvegicum.* In these nival valleys of silicatic substrate, we can find also a community characterized by *Salix herbacea.*

Below the primary pastures are *Rhododendretum ferruginei* and *Larici-Pinetum cembrae*. However, it should be pointed out that, in the lower part, farmers have substituted the Swiss pine woods with an artificial formation, so-called "larch pastures", above all on the alluvial fans. The larch pastures are formations with an arboreal determinate layer of larch (*Larix decidua*) and a grassy layer of undergrowth, while the typical species of the *Vaccinio-Piceetea* class are lacking. In the valley bottom or in the lower parts of the slopes, farmers have instead obtained vast areas of mowable meadows (*Trisetetum flavescentis*), indispensible for the production of hay for the winter months. In the spring, the meadows of the *Trisetetum flavescentis* association have beautiful wildflowers such as globe flower (*Trollius europaeus*) and bistort (*Polygonum bistorta*). In the more depressed parts of the valley bottom, with standing water and layers of peat, the mowable meadows are substituted by *Caricetum fuscae* vegetation.

In some points on the slopes there are some strips of xeric meadowlands with *Festuca ovina*, *Oxytropis campestris*, *Potentilla verna*, *Plantago serpentina*, *Astragalus leontinus*, *Sempervivum arachnoideum*, *Carex verna* and other species (according to Pirola 1965); this vegetation is conditioned by Livigno's meagre rainfall and its geomorphology, since these are slopes with an eastern or western exposure.

The riparian vegetation (in the upper Acqua Granda torrent) on the pebbly gravel beds is formed by two associations, *Epilobietum fleischeri* and *Salici-Myricarietum* in the lower fluvial terraces, of which the main species are *Epilobium fleischeri*, *Rumex scutatus*, *Linaria alpina*, *Arabis alpina*, *Myricaria germanica* and *Salix purpurea.* On the somewhat higher fluvial terraces there are some bushes of *Salix purpurea*, which is sporadic and has a low degree of cover, so that the strip observed cannot be attributed to a given association; in addition, there are rare small trees of *Larix decidua* and *Pinus cembra*.

The Acqua Granda torrent, from Livigno village to the bottom valley, was channeled, and afterwards restored with naturalistic engineering works on the banks and by plantings of various willow species, among them *Salix purpurea* (s.l.). On the edges of the inhabited area of Livigno, along the torrent, two tracks (one for cycling and one for running) have been built, and a few trees planted, including *Picea abies.*

The synanthropic vegetation here is composed of *Rumicetum alpini*, which is widely found around the houses and chalets and in the "*grassi*" (fertilized meadows with stable manure and usually present around the shepherd's huts). Sometimes these "*grassi*" are also place names, as: Grasso di Pra de Grata, Grasso del Corno, Grasso del Larice, Grasso del Gallo, Grasso dell'Orsa, Baitel del Grasso degli Agnelli, etc.

In the calcareous sector (the lower Valle di Livigno and Valle del Gallo) the primary meadows are represented by the *Caricetum firmae* and *Seslerio-Caricetum sempervirentis* associations.

In the subalpine belt, in the lower Valle di Livigno and Valle del Gallo, there is also Uncinate Pine (*Pinus uncinata* = *P. mugo* subsp. *uncinata*), in pure populations or mixed with Swiss Mountain Pine (*Pinus mugo* subsp. *mugo*), larch (*Larix decidua*), Swiss stone Pine (*Pinus cembra*), and Raethian Pine (*Pinus* × *rhaetica*). This pine forms the *Erico-Pinetum uncinatae* association, distributed in the western Alps (Ozenda and Borel 2006), which, however, also pushes into the Central Alps, as in the Spöll Valley. In the same places, Engadine pine forms the *Carici humilis-Pinetum engadinensis* association (Braun-Blanquet 1946; Reinalter 2003).

2.1.4 Thematic Maps of the Area

Many thematic maps have been prepared on the Livigno Valley, depicting its geology, geomorphology, climate and vegetation, as follows:

Ceriani M, Carelli M (eds.)—*Carta delle precipitazioni medie annue del territorio alpino lombardo* [Map of the Average Annual Precipitation of the Alpine Territory of Lombardia], 1: 250,000 (in: Ceriani and Carelli 2000)

Credaro V, Pirola A—*Carta della vegetazione attuale della Provincia di Sondrio* [Map of the actual Vegetation of the Province of Sondrio], 1: 100,000 (in: Credaro and Pirola 1975)

Gafta D, 1994—*Macroclimate types map of the Stelvio National Park*, 1: 500,000 (in Gafta 1994)

Martinelli M, Gafta D, Patella Scola A, Pedrotti F—*Carta delle unità ambientali del Parco Nazionale dello Stelvio* [Map of the Environmental Units of the Stelvio National Park], 1: 50,000 (in Pedrotti et al. 1997)

Pedrotti F, Orsomando E, Cortini Pedrotti C, 1974—*Carta della vegetazione del Parco nazionale dello Stelvio (e notizia esplicativa*) [Vegetation map of the Stelvio National Park (and explanation note)]. Amm.ne Parco Naz. Stelvio: 1–86 (in Pedrotti et al. 1974)

Pirola A, 1965—*Carta della vegetazione del Piano di Livigno, zona di S. Maria (prov. di Sondrio)* [Map of the Vegetation of the Livigno Plain, S. Maria Zone (Province of Sondrio)], 1: 2000 (in Pirola 1965)

Pirola A, Cagnolaro L, 1974—*Carta della vegetazione con annotazioni per la grossa fauna del Parco Naturale Regionale delle alte Valli dell'Adda e dello Spöll* [Map of the Vegetation with Notes about the big Fauna of the Upper Adda and Spöll Valleys Regional Nature Park], 1: 50,000 (in Agnelli 1974)

Pozzi R, Gelati R, Saibene C, 1974—*Carta geologica con annotazioni di geomorfologia* [Geological Map with Geomorphology Notes], 1: 50,000 (in: Agnelli 1974)

Verde S, Assini S, Andreis C, 2010—*Carta delle serie di vegetazione della Regione Lombardia* [Map of the Vegetation Series of the Lombardia Region], 1: 500,000 (in Blasi 2010)

2.1.5 Important Fauna Aspects

The Valle di Livigno hosts all the Alpine species of large fauna, and in particular Red Deer (*Cervus elaphus*), Alpine ibex (*Capra ibex*), Chamois (*Rupicapra rupicapra*), Marmot (*Marmota marmota*), Snow-Grousesnow-grouse (*Lagopus mutus*), Nutcracker (*Nucifraga caryocatactes*) and Golden Eagle (*Aquila chrysaetos*). Bearded vulture (*Gypaetus barbatus*) began nesting around Livigno in 1999, arriving from nearby Swiss territory. The Bear was considered almost extinct or extinct in central Alps (see Castelli 1935). Sporadically this study zone can be visited by brown bear (*Ursus arctos*), which arrives from the groups of the Adamello-Brenta mountains (Trentino-Alto Adige Region), largely repopulated from Slovenia; and pushing as far also in Swiss, Austrian and German territories. In 2008, a Brown bear arrived in Switzerland, notwithstanding the desires of Swiss naturalists and protectionists, someone did not welcome its presence, shooting it after a few weeks near Thusis (Pedrotti 2008). Similarly also was in Austria and Germany where bears were killed or where the arrival of a specimen caused strong controversy. Controversies for the presence of some bears have also take place in Trentino-Alto Adige region, with some Bear deaths; reported by the press.

Here there are still extended relatively undisturbed wild areas, suitable for Lynx (*Lynx lynx*), which has been observed numerous times in recent years. Occurrences of this species, probably derive from individuals reintroduced into the Swiss National Park in the Engadine. In the early years of the twentieth century, Red Deer (*Cervus elaphus*) were extinct in the Italian Central Alps, and only a few individuals survived in the Engadine. With the establishment of the Swiss National Park in 1914, the Deer found protection and have been able to re-populate Italian territory as well (Castelli 1941).

2.1.6 Protected Areas, History of the Territory and Anthropogenic Impact

The lower part of the Valle di Livigno and the Valle del Gallo were first proposed by the Lombardia Region for the establishment of a Regional Natural Park; later, in 1977, this territory was included in the Stelvio National Park, already in existence since 1935. In this way, two important protected areas were 'unified': the Stelvio National Park in Italy, and the Engadine National Park in Switzerland. These two National Parks, together form the most extensive protected area in Europe, facilitating the exchange of fauna in this important sector of the Central Alps. Thus the request for the establishment of a protected area in Livigno, expressed in 1910, was finally realized, and today it functions as a cushion zone between the two great parks of Engadine and Stelvio (Pedrotti 2005). In this area of research, there are also areas protected by local regulations.

In the years between 1965 and 1970, pursuant to international agreements, the Swiss electrical company (Ouvras Electricas d'Engiadina, Zernez) in according to the Italian electrical company (Azienda Elettrica Milanese) built a dam (Diga del Punt dal Gall) and a related artificial reservoir, known as the Lago di Livigno or Lago del Gallo, for hydro-electric energy. The dam is half in Italy and half in Switzerland, while the artificial reservoir is almost completely in Italy. The construction of the dam and formation of the reservoir caused a huge alteration of the landscape.

In addition, in December 2010, under the pressure of Bolzano and Trento provincial administrations, the Italian government decided to dismember the Stelvio National Park, for political reasons of an entirely local nature Italian environmentalist associations and various politicians have thus mobilized in unison to avoid this grave precedent, which could have repercussions in other parts of Italy under pressure from blatant political opportunism with myopic and intolerant parochialism. The dissolution of the Stelvio National Park and its demotion into three local protected areas: two provincial parks about Trentino Alto Adige Region (Bolzano and Trento Provinces) and one regional park in Lombardia Region, is extremely worrisome. This could further facilitate "Local appetites", urbanization, economic speculation and hunting activities, which could be carried out up to the high altitudes, according to the local regulations of the two provinces of the Trentino Alto Adige region, with special status of administration autonomy.

In 1914 the Italian army built and opened a motor-road connecting Bormio and Livigno; but the community of Livigno still remained completely isolated in the winter, from the first snow of autumn, up to snowmelt in the spring; until the winter of 1952/53, when the programmed winter opening of the Foscagno pass started. In 1960 the touristic phenomena began. In 1965–1970, after the construction of the "Lago di Livigno" artificial reservoir, the ancient trail of the Valle del Gallo was closed. In that case, another approach was made by the opening the tunnel "Galleria Munt la Schera", "Galleria la Drossa" or "Galleria Livigno"; built for service access to the "Diga ponte del Gallo" or "Diga del punt dal Gall" (the Lago di Livigno dam bridge), accessible by travelling on the dam and paying a toll to the Swiss authority. This narrow Tunnel thoroughfare, is one-lane with alternating traffic.

In recent decades, the original urban structure, with aligned built-up areas in the valley bottom, scattered and formed of few houses, has been transformed greatly into a large conurbation; with the construction of new buildings and touristic activities that, have compromised the landscape and the nature of some areas. In fact, over 30–40 years, the Livigasco has tripled its population. A demographic development generated by the economy of the tourism, of the commercial trade and by the building speculation, has eroded in some ways the soul and the traditional landscape features of the area, which is known as "il Piccolo Tibet" alias the Little Tibet, for its extraordinary peculiarities.

2.2 *Incuneata dei tre confini (Trentino Alto Adige Region)*

This area is sited in Province of Bolzano. It corresponds to the wedge given by the tripoint border between Italy, Austria and Switzerland, in Alta Val Venosta, partially involving the municipalities of Curon Venosta and Malles Venosta.

In this area there are numerous streams that go towards the Inn determining an hydrographic complex of Torrents, Burns and Springs, sometimes without name. Four distinct local sub-zones can be distinguished by the following geographical features: (1) Passo Resia, with the Rio Valmiur-Stiller which continues towards the Austria; (2) Monte Dosso di Dentro, with the Assa Torrent, towards the Switzerland; (3) Palù del Passo di Slingia, with the Ulina Torrent, towards Switzerland; (4) Sesvenna Mts. group, with the Clemgia Torrent, towards the Switzerland.

The first sub-zone is characterized by the torrent “Rio Valmiur” or “Torrente Stiller”, which born in Italy, following the confluence of several Springs, Burns and Torrents (Rio Lieger, Rio Brend, Rio dei Prati Povolo, Rio di Cufra, plus several nameless streams) to then move to Austria through Passo Resia, flowing into the Inn. Among the national most important contributions to this torrent, to the left orographic side we can mention the waters of the Italian side of Mount Piz Lat (2808 m asl) including the waters that flow into Austria, in the Grünsee Lake-Rauchtal torrent system (The Alto Lagoverde-Vallefumo); and the Torrente Gufra (Rio Confine) torrent which in the upper part flows in Italy, while in its lower part it flows along the border to its confluence in Austria. To the orographic right is the Rio di Plamort torrent, also known as “Torrente Kompatsch” which born in Italy, in the “Gola delle Capre”, between “Monte di Mezzo” Mt. (2750 m asl) and “Monte Cima Castello” Mt. (2920 m asl) that enter the “Rio Valmiur-Stiller” Torrent in Austria. The same is for Palù Pian dei Morti waters, that enter the “Rio Plamort” torrent in the Austrian territory.

Going a little further south, the second sub-zone corresponds approximately to “Monte Dosso di Dentro” (2768 m asl), mostly via “Forcola di mezzo” and “Forcola di dentro—Fuorcla Lunga”, through several small torrents of high altitude without name, which are collected in Swiss territory in the Assa Torrent (via “Val d’Assa” Valley) to the Inn, in Switzerland.

The third sub-zone, is still slightly more to the south, and it corresponds to the Ulina Torrent that born in Italy collecting the waters of the “Palù del Passo di Slingia” Pass, plus several mountain streams, via the Slingia Pass, leading to the Inn in Swiss territory.

The fourth sub-zone corresponds to other small secondary streams that originate in Italy, mostly on the mountains of the Sesvenna Group: i.e. Piz Sesvenna (3205 m asl) and Monte Punta di Rasass (Piz Rasass 2941 m asl), up to the “Passo Cruschetta” Pass (2296 m asl) feeding the Clemgia Torrent, a tributary of the Inn, in Switzerland.

Regarding the protected areas, in this zone there are some protected biotopes, including the “Palù del Passo di Slingia” Pass known as “Biotopo Ulina” and the “Biotopo Palù Pian dei Morti”.

3 Valle Della Drava (Trentino-Alto Adige)

The Upper Valle della Drava is broadly crossed by the Drava River and its tributaries such as "Rio Sesto" and many secondary streams or springs, then flowing directly into the Danube.

3.1 Geographical and Administrative Information

The Valle della Drava is situated in the Alpi Pusteresi, from the Sella di Dobbiaco (1256 m) and then descending eastwards to Prato alla Drava, between impressive mountain groups, and onwards to Austria. The Drava begins in the Sella di Dobbiaco, at the feet of Cima Nove (2581 m), in the group of the Rocca dei Baranci, on the Dolomiti di Sesto, in the so-called "Foresta delle Canne" (Fig. 5). It is a vast system of valley bottom springs and alpine streams, in particular on the right slope, while the input from the left slope is much less (it is more impermeable). The Drava in San Candido is mostly formed by the Rio Klapf, Rio Kaser, and Rio Sesto confluence. The furthest large source is that of Rio Sesto, which, however, is considered a tributary (Fig. 6). This Rio descends from the Passo di Monte Croce Comelico (at the border with the Veneto Region), forming the Valle di Sesto; with laterals Rio Landro and Rio Fiscalino Torrents (from the Val Fiscalina) and the

Fig. 5 The "official" Drava source equipped as touristic space (photo: Kevin Cianfaglione, June 2011)

Fig. 6 Dolomites of Sesto, the Cima Nove mountain, where the Drava is considered to rise. In general, the vegetation here is the *Adenostylo-Piceetum*, with hay-meadows in the bottom valley (photo: Kevin Cianfaglione, June 2011)

Torrente San Candido or “Campo di Dentro” (from the Valle Campo di Dentro Valley) (Fig. 7). Small lakes “Laghetti del Piano” lie on the high part of the left branch of the Val Fiscalina. In the San Candido village, the small Drava rivulet receives as tributary the Rio Sesto, much richer in water. The “Baranci” toponym is the plural of *Pinus mugo*; this term derives from the Ladin “*baranti*” (from ancient Rhaetic derivation). The Rio Sesto once flowed into the Rienza River and its waters reached the Adriatic Sea through the Isarco River and then the Adige. At the end of the glacial period (11,000 years ago) a “capture” phenomenon occurred in which landslides and detritus from the Corno di Fana (2563 m) blocked and changed the course of the torrent, thus becoming a tributary of the Drava and flowing this time into the Black Sea. The watershed which was once situated between San Candido and Versciaco thus shifted to the Sella di Dobbiaco. After the urbanised area of Sesto, a small dam was built, forming the actual small artificial lake: Lago di Sesto Pusteria. These waters flow into a water channel that supplies a hydro-electric station at Versciaco (Fig. 8).

After the “Rio Sesto” Torrent, on the orographic left, there is the “Rio del Monte della Chiesa” Torrent which also takes the waters of the “Rio di Selva”, passing inside the village of “Prato alla Drava” to the Drava River. Further downstream, on the orographic right side, is the “Rio Kartzeler” Torrent, which born in Italy to join the Drava in the Austrian territory, just after the boundary.

The orographic left slope culminates with the Corno di Fana (2563 m) and the Cornetto di Confine (2545 m) and is furrowed by some secondary gorges. The

Fig. 7 The Valle di Sesto is the main lateral valley of the Drava Valley; slopes with spruce forests (*Luzulo nemorosae-Piceetum*). Foot and slopes are converted into Larch meadows; part of the slopes, valley bottom and alluvial fans are transformed in secondary meadows with ancient old woody barns. Along the Rio di Sesto, some disturbed fragments of riparian vegetation remain (photo: Kevin Cianfaglione, June 2011)

orographic right slope in turn is deeply divided in two by the Valle di Sesto, which descends from the Passo Monte Croce Comelico; thus it comprises the subgroup of the Dolomiti di Sesto with the Cime di Lavaredo (2998 m), Cima Undici (3092 m), Cima Dodici (3094 m), Cima Tre Scarperi (3152 m), Croda dei Baranci (2994 m), Croda Rossa (2939 m) rising over the Passo Monte Croce Comelico and then the group of Monte Arnese (2551 m) – Monte La Mutta (2591 m); these mountains are cut by some minor valleys, namely the Valle Campo di Dentro, Valle Sassovecchio and the famous Val Fiscalina. This valley is famous for his nature and its high level of Wilderness, but in recent decades some works for leveling or hydraulic and tourism reasons have created a big impact, especially in its bottom part. The same is true of the nearby Valle Campo di Dentro. The upper Drava Valley is formed by crystalline and sedimentary rocks. Crystalline rocks constitutes the left side valley, and the right part of the Velle di Sesto. They are represented by orthogensis, quartziferous phyllades and in part also sandstones, tuffs, and breccias of the Permian period. There are very extensive morainic deposits of the Pleistocene and alluvial deposits in the valley bottom. The sedimentary rocks are mainly represented by dolomitic carbonate rocks which build the entire group of the Dolomiti di Sesto.

On the morning of 12 October 2007, a collapsing landslide of “Cima Una” of the Dolomiti di Sesto occurred; from the left side of the peak (from the side of the mountain facing the Val Fiscalina) a rocky spur estimated to be between 60,000 and

Fig. 8 In the background: Sesto's Dolomites with Fiscalina and Campo di Dentro valleys; with large coniferous woodlands (*Larici-Piceetum* and *Luzulo nemorosae-Piceetum*), the village of Sesto with large meadows, larch meadows and scattered ancient woody barns (photo: Kevin Cianfaglione, June 2011)

150,000 m^3 broke off and slid to the valley, but fortunately in its fall did not damage anything or anybody. It raised an enormous dust cloudy visible from far away, which descended on the villages of Moso (San Giuseppe) and Sesto. A few blocks reached the trails and the stream below. But this is the sort of natural phenomenon that over thousands of years has moulded the typical charming look of the Dolomites.

The climate of the high Valle della Drava is continental-alpine, with a gradient from the lines of the crest to the valley bottom; the average annual precipitation ranges between 852 mm (Dobbiaco) and 890 mm (Sesto); the index of hygric continentality for the same stations is 55.7° and 55.8° respectively. The Phytoclimatic Map of the Trentino-Alto Adige Region by Gafta and Pedrotti (1996) indicates for the Valle della Drava the following climate types: cryo-orotemperate humid, orotemperate humid inner-alpic, upper supratemperate humid inner-alpic, and lower supratemperate humid inner alpic.

The high Valle della Drava belongs to the San Candido, Sesto and Dobbiaco municipalities, the last one only partially; all being included to the Bolzano Province, in the Trentino-Alto Adige Region (also known as: Trentino-South Tyrol). Around the settlements can be numerous isolated farmsteads that may be quite distant from each other. These farmsteads normally consist of two buildings: the family home and a Fienile—a much larger structure for hay storage (a type of barn). Throughout the zone, the ancient tradition of "Maso Chiuso" [closed farmstead] is still in effect, in which the elder son inherits all the property, while the other children receive the "Quota legittima" [legitimate share], normally as liquidity.

3.2 The Vegetation Landscape

The study area can be classified into few altitudinal belts: alpine, subalpine, upper montane and lower montane. The altitudinal sequence is different in the two sectors, with crystalline and sedimentary rocks. In the crystalline sector, the alpine belt is formed of the *Caricetum curvulae* and *Festucetum halleri* associations, and the subalpine one by *Rhododendretum ferruginei* shrublands. In the upper part of montane belt, the forest of spruce corresponds to the *Larici-Piceetum*, in the lower part to the *Luzulo nemorosae-Piceetum*; in the montane spruce forest, on the orographic right side, between Versciaco and Prato alla Drava, there are some nuclei of European silver fir (*Abies alba*) on siliceous substratum, of the *Luzulo niveae-Abietetum albae* association. In the lower montane belt there are also nuclei of acidophilous woods of Scots pine (*Pinus sylvestris*) belonging to the *Vaccinio vitis-idaeae-Pinetum sylvestris* association. The forests are often interrupted by vast clearings with isolated farmsteads or groups of farmsteads and mowable meadows (*Melandrio-Arrhenatheretum*); on the right slopes of the Valle della Drava in the area of the meadows there are often hedges of hazel and aspen (*Corylo-Populetum tremulae*) and spontaneous groups of *Sambucus racemosa* near the houses and the chalets; frequent groups and isolated trees of ash (*Fraxinus excelsior*) appear to indicate the remains of a vegetation that was once more widespread and then limited by man. Near houses often there are the traditional cultivated shrubs of *Syringa vulgaris* and sometimes *Philadelphus* sp.pl., etc. In addition, on the lower part of the slopes and on the alluvial cone, the forests of spruce have been transformed by the farmers into "pascoli a larice" [larch pastures] entirely similar to those noted for Livigno.

On a steep slope with an incline of 30° in San Candido, Braun-Blanquet (1961) reported a small strip of xeric grasslands (Trockenrasen), "Prati aridi" in Italian that represents an impoverished facies of the *Potentillo-Festucetum sulcatae* association.

In the calcareous sector, the alpine belt includes the vegetation of the primary basophilous meadows with the *Caricetum firmae* and *Seslerio-Caricetum sempervirentis* associations. In a very few stations in the alpine belt it is possible to find *Sempervivum dolomiticum*, a rare endemic species with a distribution limited to a few dolomitic groups, discovered and described in 1854 by Francesco Facchini, a physician and botanist from Valle di Fassa (Trento), a scholar of the flora of the Dolomites. In the subalpine belt there are two main associations of Swiss mountain pine (*Pinus mugo*) developed on screes and in rocky sites, *Erico carneae-Pinetum prostratae* and *Rododendro hirsuti-Pinetum prostratae*; in sites of lower incline on acidified soils, the associations evolve towards a third association of Swiss mountain pine, namely *Sorbo chamaemespili-Pinetum mugo*. The Swiss pine woods frequently descend to the valley bottom in the gorges and on the alluvial cones. The upper montane belt is formed of forests of spruce of carbonate substrata, *Adenostylo glabrae-Piceetum*, which forms a continuous and homogenous strip. The bottom of the Drava valley landscape is still characterized by mowable meadows with association which can be seen on the slopes and with riparian vegetation. The Drava River is today totally channelized but a few limited fragments of natural vegetation still remain, especially among the tributaries, such as: grey alder (*Alnetum incanae*) and willow woods (e.g. *Salicetum albae*); other willow formations, such as *Salix purpurea* are sporadic. Some nuclei of *Fraxinus excelsior* are also present.

3.3 Thematic Maps

A list of the thematic maps for the high Drava Valley follow:

Gafta D., *Phytoclimatic map of Trentino-Alto Adige*—1: 250,000 (in Gafta and Pedrotti 1996)

Gafta D., Pedrotti F—*Geosynphytosociological map of the Trentino-Alto Adige Region*, 1: 250,000 (in Pedrotti and Gafta 2003)

Pedrotti F—*Carta delle serie di vegetazione—del Trentino-Alto Adige [Map of the Vegetation Series of Trentino-Alto Adige]*, 1: 500,000 (in Pedrotti 2010)

Pedrotti F., Gafta D., Minghetti P—*Map of natural potential vegetation of the Trentino-Alto Adige Region*, 1: 750,000 (in Gafta and Pedrotti 1996)

Peer T—*Carta della vegetazione naturale attuale dell'Alto Adige [Map of the Current Natural Vegetation of Alto Adige]*, 1: 200,000 (in Peer 1995)

Schiechtl HM, Stern R—*Karte der aktuellen Vegetation, Blatt 11, Brixen-Pustertal, [Map of Actual Vegetation, Sheet 11, Bressanone-Val Pusteria]* 1: 100,000 (in Schiechtl and Stern 1976)

3.4 Important Fauna Aspects

In the upper Drava a number of fish and other species are present (according to Kottelat and Freyhof 2007), but because of pollution, adjustments, canalization and artificial barriers, many fish species such as the spined loach (*Cobitis elongatoides*), stone loach (*Barbatula barbatula*), bullhead (*Cottus gobio*), common minnow (*Phoxinus phoxinus*), European bitterling (*Rhodeus sericeus*), grayling (*Thymallus thymallus*) and northern pike (*Esox lucius*) have disappeared or become rare. Is also conceivable that Danube salmon (*Hucho hucho hucho*) was almost occasionally present in the past up to our study area (see Holćik et al. 1988) towards the river's sources for reproduction. Before the river regulation works, marshes reclamation and deforestations, the landscapes of the Drava afforded very good biotopes for White-Clawed Crayfish (*Austropotamobius pallipes*), today present only as rare residual populations. Other notable species of alpine fauna here are the Golden Eagle (*Aquila* *chrysaetos*), Black Woodpecker (*Dryocopus martius*), Raven (*Corvus corax*), Wood Grouse (*Tetrao urogallus*), Rock Ptarmigan (*Lagopus mutus*), Black Grouse (*Tetrao tetrix*) and White-Winged Snowfinch (*Montifringilla nivalis*).

3.5 Protected Areas, History of the Territory, and Anthropic Impact

This study site belongs to the Bolzano province, Trentino-Alto Adige region. In the Dolomitic sector, in 1981, the Parco Naturale delle Dolomiti di Sesto [Nature Reserve of the Dolomites of Sesto] was established; in 2010 the name was changed to the Parco Naturale delle Tre Cime [Nature Reserve of the Tre Cime], because the "Tre Cime di Lavaredo" are the most famous Peaks between the Dolomites Mts, also known beyond the national borders. This is a provincial park (belonging to the Province of Bolzano) where a general protection at the landscape level is active, according to local regulations, as with other protected areas of the Province.

The entire bed of the Rio Fiscalino has been completely altered because of hydraulic works over the course of the years, which provoke grave environmental and aesthetic impact. In addition, severe impact has arisen as a result of a hotel group and tourism infrastructure in continual expansion in the mid Valle Fiscalina. In 2009 UNESCO included some sections of the Dolomites, such as the "Dolomiti di Sesto", in the *World Heritage List*—which further link these Italian Danubian sources with the mouth of the Danube, already included in the same UNESCO list. For the Dolomiti di Sesto area, this is a further acknowledgment and an important opportunity for maintaining this valuable patrimony and to improve better respect for the environment (Fig. 9). There is a long bicycle path (366 km) along the Drava River from Dobbiaco to Maribor, passing between Italy, Austria and Slovenia for city-bikes and mountain-bikes.

Regrettably, in recent years, the regional area, while being green, has been more and more urbanized, disturbed, logged/deforested, polluted also by strong intensive agronomic practices, and had rare animals (protected by State Laws) killed, driven out or threatened by local administrations choices. Often the region area is famous for good practice, but on the other hand also because of some really bad management reported by press, creating many controversies at local and national level, until having international implications. This study area is one of the richest in wild corners of the Region. Although green, clean, tidy and beautiful, it is actually very impacted by human pressure (anthropized). Surfaces, local policies, needings and lifestyle are still not enough suitable for the most rare and endangered wild species; with high probability of conflicts with human activities.

Fig. 9 Drava Valley near the Italian-Austrian border, indicated by a bilingual chart on a bridge. Landscape elements are: forests, meadows, old houses and the woody crucifix. Siepi (hedges) or chiuse (walls) delimit some properties. The ancient military structures are almost imperceptible, masked and characterizing the landscape originality. The scenario is green, although the human impact carried out during centuries have been significant in the territory, resulting in extinction of species; terraces; deforestation, favouring secondary grasslands; buildings, reclamations, canalizations and the removal of riparian vegetation. The big stones (bottom foreground) are the recent artificial embankment with which the Drava river was channelled in this sector (photo: Kevin Cianfaglione, June 2011)

4 The Tarvisano or the Valle della Slizza (Friuli-Venezia Giulia)

In the Tarvisio area, the Val Canale belongs to the Danube watershed due to the Slizza River, which runs through, is a tributary of the Gail (Zeglia in Italian), which in turn flows into the Drava.

4.1 Geographic and Administrative Information

The "Valle della Slizza" is delimited by calcareous mountain systems that culminate in several peaks, such as Ponza Grande (2274 m), Monte Mangart (2677 m), Monte Canin (2587 m), Jôf di Montasio (2754 m), Jôf Fuart (1874 m), Capin di Ponente (1736 m), Monte Forno (1508 m) and Monte Cergnala (2344 m). Monte Forno (1508 m) is the meeting point of the three borders, between Italy, Austria and

Slovenia. These mountains are formed of sedimentary rocks, including dolomitic rocks, Dachstein limestone, white oolitic limestones, light brown limestones and limestone-dolomitic rocks (often flinty), the weakly marly grey limestones with lens-shaped pieces of flint. On the orographic right there are Werfenian formations with sandstones, siltites, calcarenites, and marls of various colours. In the valley bottom, Würmian and post-Würmian moraines and supraglacial moraines, screes and cemented detritus are frequent.

The Slizza River begins at the Sella Nevea (1190 m) as the "Rio del Lago" torrent; after having crossed the valley of the same name and having entered the "Lago del Predil", it continues through the Val Canale.

After taking the waters of Rio Solitario and the Rio Freddo, it is called Slizza, and then meets the "Canale Bartolo" stream (in which flows the Rio Lussari, descending a canyon with a very remarkable inclination); after, in the village of Coccau, it meets the Rio Fusine (originated from the Rio Bianco and the Rio Vaisonz; the latter in turn originates from the waters of the Fusine in the Valromana lakes valley and its lateral parallel valley); subsequently, further downstream, the Slizza also meets the torrent "Canale dei Carrì". One should also mention the remarkable contribution by numerous other smaller streams around the area. In fact, into the Slizza (l.s.) flow a relatively small rivers and torrents, mainly along its left side. The right side is much steeper and drains less important waterways. Farther down the valley, the Slizza is increasingly embedded in the Coccau gorge, where it passes the Austrian border, becoming the Gailitz river, flowing into the Gail river, thence into the Drava.

The main lateral valleys of this study area are the "Valle del Rio Freddo", and the "Valle dei Laghi di Fusine".

The basin of the Slizza River is affected by several perennial springs the waters of which are often captured to be utilized. Among them is the spring located at the south of the "Acciaierie Weissenfels" (the steelworks of Fusine), feeding the Fusine aqueduct. Other interesting springs are the submerged springs of the "Lago Superiore" of Fusine in Valromana, where the waters of the Rio Vaisoz infiltrate and re-emerge as bubbling springs (Fig. 10).

In the Slizza basin are three lakes: the "Lago del Predil" (surface of 0.61 km^2 and 962 m. a.s.l.; less known as "Lago di Rabil") and the lakes of Fusine in Valromana ("Lago Superiore" and "Lago Inferiore"—respectively with a surface of 0.13 and 0.11 km^2; and 929 and 924 m. a.s.l.), all these lakes was created by a frontal moraine barrage. Near the "Lago inferiore" there are also two other small lakes, "Laghi Piccoli". The Lago Superiore feeds the Lago Inferiore by underground waters and it feeds consequently the effluent of both lakes: the "Rio del Lago" river (Fig. 11). On the orographic right of the Slizza River, the "Rio Chiusa" Torrent born in Italy, flowing almost all in the national territory, to flow shortly after the Austrian border in the Slizza-Gailitz River.

The Fusine in Valromana lakes, of glacial origin, are situated in a limestone amphitheatre created by the ridge of the "Picco di Mezzodì" peak of the "Monte Mangart" mountain. This lake system is considered among the finest examples of alpine lakes. The valley, which runs parallel to the border between Italy and

Fig. 10 Lakes of Fusine Valromana (Lago Inferiore) on Slizza Valley; slopes with vegetation of *Adenostylo glabrae-Abietetum* association (photo, from: Regione Friuli-Venezia Giulia, 1972)

Slovenia, has been a protected area since 1971, under the name of "Parco Naturale dei Laghi di Fusine" [Fusine Lakes Natural Park].

In the Upper Valromana, at the border between Italy, Austria and Slovenia, from the "triple point border" (Italian tripoint sector) on "Monte Forno" Mt. (1508 m asl), from the "Monte Coppa" Mt. (1496 m asl) and downstream of the "Rifugio senza frontiere" Refuge, the waters are collected in the "Valle dei Caduti per la Patria", flowing in Slovenia, through the Sopraracchia or Sopraradice Torrent, a tributary of the Trebiza Stream, together with the drainage waters of the "Colle Scenschi di Sotto" Mt. (1139 m asl) slope. The waters reach the valley floor near the Slovenian village of Rateče (Racchia or Radice in Italian), at the watershed saddle between

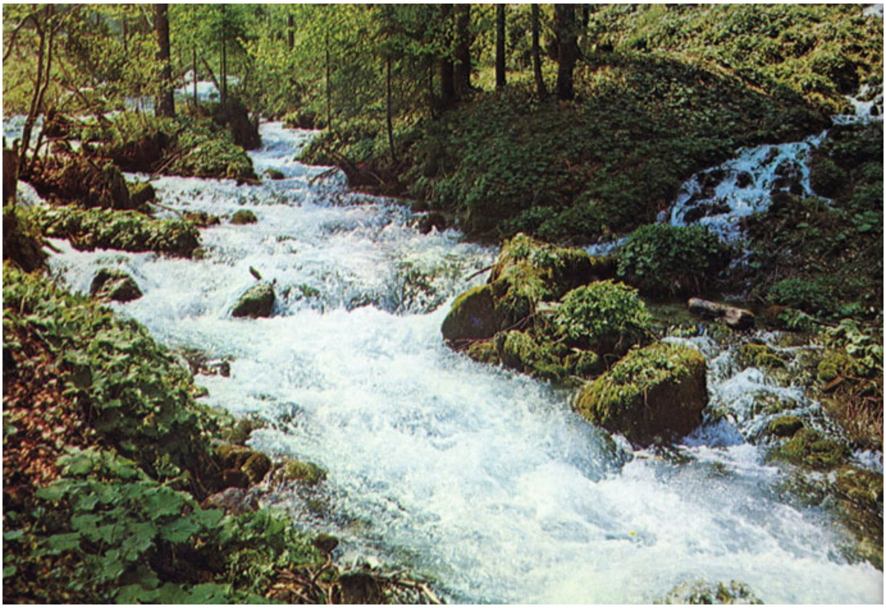

Fig. 11 The river Rio del Lago, the only outgoing river from Fusine Valromana lakes; the vegetation of the edges is composed of bryophytes and tall herbs. Alongside beautiful, and naturally free-flowing streams, surrounded by aquatic vegetation, are fully channelized and walled streams (photo, from: Regione Friuli-Venezia Giulia, 1972)

Sava and Slizza Rivers. Here, the waters falls in the Sava watershed (by drainage phenomenon) and in the Slizza watershed (by partial capture phenomenon). Normally, these waters filter through the ground, to the close Zelenci marshy area, considered the permanent source of the Sava River. During the rainfall season the valley floor is occupied by the Ledine Intermittent Lake. When large quantity of water fall in the Lake, it spills over the Sava watershed to the Slizza, passing in Italy through the "Valico di Fusine in Valromana" pass.

In the basin of the Fusine lakes there is an inversion of the vegetation belts because of the stagnation of cold air at the bottom, such that descending from the highest elevations toward the valley bottom one passes from beech groves to spruce forests.

In terms of climate, there is very high precipitation, reaching values of 1600–1800 mm per year; the rainiest months are June and November, with an equinoctial type rain distribution. At the Tarvisio station the average annual precipitation is around 1500 mm and the average annual temperature is 7.5°. The climate is of a rainy, oceanic type, and causes a notable lowering of altimetric limits of the various forest formations, in contrast to what happens in the zones of Livigno and the high Drava, where the continental climate contributes to raising the vegetation limits. The Tarvisiano land is in Udine Province, in Friuli-Venezia Giulia Region. The studied region has also a very beautiful trail, obtained on an old railway line from the nineteenth century that connected Tarvisio and Ljubljana. This scenic trail, through a forest of spruce and Scots pine, leads rapidly to the war memorial of the Austrians who died during the Napoleonic campaigns in Valcanale, then on the "Orrido dello Slizza" (the Slizza Crag).

4.2 The Vegetation Landscape

Many local species are endemic in the Julian Alps, like *Alyssum wulfenianum*, *Cerastium subtriflorum*, *Thlaspi caepefolium*, *Campanula zoysii*, *Saxifraga tenella*, *Pedicularis julica*, *Gentiana orbicularis*, etc.

The vegetation landscape of the Valle della Slizza is characterized by primary and secondary grasslands, subalpine shrub woods and forests (see also Poldini and Vidali 2010).

The primary grasslands develop on calcareous areas, and there are two associations, vicariants of analogous associations of the Central Alps, *Ranuncolo hybridi-Caricetum sempervirentis*, *Carici ornithopodae-Seslerietum* and *Gentiano terglouensis-Caricetum firmae*. In the alpine belt, on the rocky faces one finds *Potentilletum nitidae*, *Caricetum mucronatae* and *Potentillo clusianae-Campanuletum zoysii*, while the snowy small valleys host *Arabidetum coeruleae* and *Salicetum retusae-reticulatae*.

Many associations are present among the secondary grasslands, such as *Bupleuro-Brometum condensati* and *Laserpitio sileri-Festucetum alpestris*; *Gladiolo-Molinietum arundinaceae* is very widespread. Among subalpine shrub woods, the Swiss mountain pine woods are extensive (*Rhododendro hirsuti – Pinetum prostratae* and *Sorbo chamaemespili-Pinetum mugo*), and at the lower altitudes are substituted by another association, *Amelanchiero ovalis-Pinetum mugo*, which is a de-alpinized pinewood. The *Rhododendretum ferruginei* association is more localized, limited to a very few sites with acidic soil. The most common tree species in the lower parts are *Abies alba*, *Picea abies* and *Fagus sylvatica*. Higher up, *Larix decidua* and *Pinus mugo* become significant.

The most widespread spruce forests are those on calcareous substrata, with the *Adenostylo glabrae-Piceetum* association developed between 1400 and 1700 m; the two associations, *Larici-Piceetum* (1300–1800 m) and *Luzulo nemorosae-Piceetum* (below 1400 m) are limited to sites with acidic soils. The most widespread forest vegetation in the Valle della Slizza is beech woods and fir woods. The latter belong to the *Cardamino pentaphylli-Abietetum* and the *Adenostylo glabrae-Abietetum*, while the beech woods belong to of a number of associations. *Anemono trifoliae-Fagetum* prefers brown calcareous soils and podzol; *Polysticho lonchitis-Fagetum* develops on calcium-rich and dolomitic substrata; *Luzulo nemorosae-Fagetum* develops on silica substrata below 1400 m. The Pine forests of *Pinus nigra* are very common in the Tarvisiano hilly belt zone, at altitudes below 1400 m, from which a strip pushes toward the Slizza basin; belonging mainly to the *Fraxino orni-Pinetum nigrae*, with a remarkable presence of *Erica carnea* with other species such as *Amelanchier ovalis*, *Vaccinum vitis-idea* and sometimes *Pinus sylvestris* (according to Poldini 1969; Poldini and Vidali 1999).

The riparian vegetation is made up of the following associations: *Salicetum incano-purpureae*, *Hippophao-Salicetum incanae*, *Salici-Myricarietum* and *Alnetum incanae*. Some nuclei of *Fraxinus excelsior* are present. The mowable grasslands belong to two associations, *Centaureo carniolicae-Arrhenatheretum elatioris* in the valley bottom, and at higher altitudes *Centaureo transalpinae-Trisetetum flavescentis*.

4.3 Thematic Maps of the Area

Poldini L, Vidali M—*Carta delle serie di vegetazione della Regione Friuli-Venezia Giulia [Map of the Vegetation Series of the Friuli-Venezia Giulia Region]*, 1: 500,000 (in Poldini and Vidali 2010).

4.4 Important Fauna Aspects

After the original fauna of the lakes was completely destroyed in not so recent times (Ghirardelli 1972), the lakes were subsequently repopulated with brown trout (*Salmo fario*) and Arctic char (*Salvelinus alpinus*), using stock from the former Yugoslavia. In the Rio del Lago, white-clawed crayfish (*Astacus fluviatilis*) has been reported. Three species of large herbivores are common: Red Deer (*Cervus elaphus*), Chamois (*Rupicapra rupicapra*) and Roe Deer (*Capreolus capreolus*). The great extension of forests and areas above tree-line, both relatively undisturbed from several decades, is favourable for the four grouse species of the Alps, which are all present: wood grouse (*Tetrao urogallus*), black grouse (*Lyrurus tetrix*), hazel grouse or hazel hen (*Tetrastes bonasia*) and rock ptarmigan (*Lagopus mutus*). Brown bear (*Ursus arctos*) had disappeared, but spontaneously returned with individuals from nearby Slovenia, where they are common (Ariis 1987; Adamic 1987). In 1989 lynx (*Lynx lynx*) also appeared in the area, with individuals from Slovenia.

4.5 Protected Areas, History of the Territory and Land Uses

The study area is part of the Fusine Regional Nature Reserve (Fusine Laghi), which includes the lakes of Fusine in Valromana and the surrounding large forests, partially including the famous Foresta Demaniale di Tarvisio: the largest state-owned forest in Italy.

The Nature Reserve of the Fusine laghi is a protected area established in 1971 by the Friuli-Venezia Giulia Region; it is adjacent to the Monte Tricorno (Triglav

Mt. National Park, in Slovenia). At the foot of these mountains are the sources of the Sava, which is also a tributary of the Danube; where there are still Italian traces, however, outside the Country. Also in this case, as in the Livigno area, there have been some positive cross-border interactions between protected areas. In fact, in this Slovenian park, the alpine ibex (*Capra ibex*) was introduced in 1964 with individuals from the Gran Paradiso National Park, through the initiative of Renzo Videsott, at that time director of the Gran Paradiso National Park and Ivan Fabjan, director of the Triglav National Park (Pedrotti 2007): actually it results a substantial colony of this species. A few decades later other ibexes were subsequently re-introduced in Friuli-Venezia Giulia and others Italian regions. Conceivably, the current presence of animals once thought disappeared in this study area, is due also to the cross-border relationship (see also WWF 1990; Molinari 1991). Examples are the brown bear (*Ursus arctos*) and the lynx (*Lynx lynx*). About the Bear, it was developed an international EU program of 6 years between Italy and Slovenia. About the lynx another international project was carried out and two lynxes were reintroduced to reinvigorate the diversity of the Italian population of the Area, normally related only with the Slovenian one. They come from the Jura Mountains, in Switzerland; they were a gift of the Federal Office for the Environment of the Swiss Confederation and were released in the Forest of Tarvisio (in 2014). Unfortunately, a specimen disappeared a few months after the liberation, in Austrian territory, considered maybe victim of poaching. In any case, all this testifies to the necessity and to the fruitfulness of trans-boundary policies and interaction between States, institutions and protected areas.

Of Roman origin, it seems that the town of Tarvisio arose in a location inhabited previously by a Celtic population, the Taurisci, from whom the name Tarvisio derives. In the Napoleonic era, this area and nearby Malborghetto-Valbruna were the scenes of repeated battles between French and Austrian troops. It became part of the Kingdom of Italy in 1919, after the victory of the First World War. The majority of the population is Italian, but Slavic and Germanic minorities exists. As in the Italian Drava Basin here too some cultures cohabit after centuries: Tarvisiano is a special example of tetra-lingual territory in which, in addition to Italian, Slovenian, German and Furlan (Friulian) are also spoken. It is an example of peaceful spirit transculturalism, with ethic mixed or neutral realities and with cultural gradient variations and dialects. Here no laws force one or more special linguistic groups in order to advantage/disadvantage anyone; any spirit of oppression or obtuse legal xenophobic exclusion towards the other. Right now it can be considered one of the best examples of multiculturalism in Europe.

5 General Discussion

In general, in Italy the condition of the rivers is not good, and worsens from the mountain sections to the bottom valleys, because of canalization, destruction of vegetation, and pollution. Notoriously It is a very big national environmental problem, regarding all the Italian territory, as seen in some reports,[1,2] from where we understand how Italian rivers and lakes are artificialized, and how half of the Italian lakes and rivers water are polluted by pesticides. The accused are: the local and national agriculture Policies and the amount of chemicals used. Furthermore, we learned how the Regional Administrations and their local agencies for environmental protection do not help to shed light on the status of their rivers, as in many cases they do not communicate to Ispra any data, or they do it only partially.

The general environmental quality status of the rivers and others waterbodies is not just a national but a European cross-border problem. It is a serious problem not only for the bottom valleys of the great rivers, but also for the mountain streams, as shown by the WWF report in collaboration with the University of Vienna[3] on river systems in the Alps. 90% of Alpine rivers underwent change to their natural course or was blocked by dams; generally they are not enough healthy to provide sufficient water and to be able to cope with climate change.

The vegetation elimination and so called "cleaning" of waterbodies is a worrying phenomenon that is constantly increasing throughout the Italian national territory thanks to local, national and European policies (Searchinger et al. 2018) that encourage the production of energy from wood biomasses and the biomass power plant business, and because the insufficiency of controls.[4,5]

In our study, we observed the study area environmental conditions considering the actual and the potential vegetation distances. In addition we used the Index of Fluvial Functionality (IFF) created in the early 1990s and then modified and adapted to the Italian situation, becoming the RCE-II (Riparian Channel Environmental Inventory), focusing on the functionality of watercourses and their characteristics (Siligardi et al. 2000). In all the sections of the whole study area (Valle di Livigno, Valle della Drava, and Valle dello Slizza), the IFF values varies from level I/II (=green class), which is judged as good; to level IV (=orange class), judged as poor. The differences are attributable to the heterogeneity of the anthropogenic impact effects on watercourses. In the study area, the main river problem is not the pollution, but normally the main problem are canalizations, elimination of natural vegetation,

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[1]"*Fiumi e Legalità—Monitoraggio sull'illegalità e sullo stato di salute dei fiumi italiani*" 2007 by CFS—Corpo Forestale dello Stato and Legambiente ["Rivers and Legality—Monitoring the illegality and the health of the Italian rivers" 2007].

[2]"*Rapporto nazionale pesticidi nelle acque: dati 2009-2010. Edizione 2013*" by ISPRA—Istituto Superiore per la Protezione e la Ricerca Ambientale ["National Report pesticides in water: data from 2009 to 2010. 2013 edition"].

[3]WWF report in collaboration with the University of Vienna, entitled: "*Save the Alpine Rivers*—2014".

[4]"*Fiumi distrutti. Impatti sull'ambiente e la biodiversità causati dalla distruzione della vegetazione lungo i corsi d'acqua della Toscana*" Legambiente [Destroyed rivers. Impacts on the environment and biodiversity caused by the destruction of vegetation along the waterways of Toscana] by Lipu Toscana. September 2018.

[5]"*Fiumi in fumo: tagli selvaggi e danni agli ecosistemi in Emilia-Romagna*" [Rivers in smoke: wild cuts and damage to ecosystems in Emilia-Romagna] by Lipu-BirdLife Italia. May 2017.

reclamation and urbanisation. Often, even the smaller torrents and rivulets can be concreted, deviated, channeled, with the removal of vegetation, reclamation, deforestation and overbuilding. Between the four valleys in our study area, the most noticeable in this respect are the basins falling in the Trentino-Alto Adige and Friuli-Venezia Giulia regions. On the other hand, the naturality and the functionality of the upper Aqua Granda torrent of Livigno is better than might appear by this assessment; because upper part of this stream is naturally without a dense, true riparian vegetation (only few *Pinus mugo*, *Myricaria germanica*, *Alnus viridis* and *Epilobium fleischeri* formation fragments are remarkable) because it is near or above the forest-line limit. About the "Incuneata dei tre confini" waters net, the state of the streams is similar to the Livignasco. Generally the situation is good, but a differentiation between high altitude streams (glacier and nival waters) sited over the treeline limit and those below the treeline is necessary.

The upper streams, those above the treeline are in more natural conditions, they run mostly on low cover vegetation, in fluvio-glacial deposits; sometimes among primary peat bogs as is the case of Ulina Torrent. Under the treeline these streams sometimes flow into deforested areas, as is the example of the "Rio Valmiur-Stiller" torrent network, in which the potential vegetation is rarefied, relict and disturbed, generally replaced from meadow communities. Furthermore, its hydrographic network is also channeled in some points. Often the landscape could appear nice, wild or green even if largely modified by man and impacted by soil uses.

The actual National (and sometimes also European) trends about environment issues, assignment of the public property to privates; about bio-fuels (Biomass) and forests; about land use (i.e.: agriculture, hunting, urbanization, hydro-geologic risk, etc.) point in an opposite direction: too focused on utilitaristic purposes, business, oligarchic private local interests and unable to look at the most wide-ranging features/policies. The issues about the bear management and nature conservation in the Trentino-Alto Adige Region, the willingness to dismantle and downgrade the historic Stelvio National Park; the elimination from some regions (and then, in some ways elsewhere to the whole Italy) of the Corpo Forestale dello Stato "Italian State Forestry Police"; the disgregation of the historical Italian system of protected areas; together with others national historic and noble institutions, does unfortunately point in the opposite direction. The issues about species conservation, the willingness to dismantle and downgrade National Parks and other national historic and noble institutions, does unfortunately point in the opposite direction, denying civil rights and the role of this institution to build up constructive ideological principles, at the basis of cooperation and brotherhood. Nature has no borders, like Human common sense.

In general, the devolution policies carried out till now in Italy can unfortunately end up to create management difficulties, especially about environment management; till to favour destabilizing groups, bad business affair, mafia, corruption and inequality of rights; and they can be useful to local xenophobic groups, or by who seek for privileges making politic blackmails. Recent European, National and local policies have produced deleterious effects on the community and the conservation of Nature. Europe of the Regions is also likely to be a big problem if not accompanied by a serious sedimentation and layerization pathway of these important values. Risking otherwise to unnecessarily dismember the European society, accentuating the problems of instability, corruption and bad governance, proposing also the same problems already given by the nationalization of cultures in a local scale (Regions or Provinces) by standardizing dialects in new local languages imposed and artificial, erasing normal local realities and variability. In such ways, it can be very interesting to use biotopes, biodiversity and military traces of the past to promote a Memorial Heritage Complex: an intercultural historical-environmental eco-museum characterised by transboundary friendship trails. Nature conservation, species reintroduction, rewilding and Protected Areas showed to be a good and successful experience of cooperation and coexistence, working together to make a better World. Apparently, when they need, even those who take advantages by devolution, they ask for a wider environmental territorial governance. All this led us to understand how the future will not be of multiculturalism, as the lazy co-existence of different universes closed to the other ones; but it will be the transculturalism, as the individual intermingle of cultures. This clearly does not imply necessarily a betrayal of the nation, and not even the loss of the local pride; but just a correct layering of these values from the local, to national, to European, to the global scale. All this linking Nature and Culture; so the transcultural and the transboundary vision of the Nature management are both a new horizon of the human identity. Nature conservation, history and the cultural heritage are strategic issues for life quality and can be the platform where develop this features.

6 Final Conclusions

The general trends of the rivers examined here mirror for the most part the tendencies seen in the national watercourses; in fact, mountain sections or those of secondary valleys unaffected by anthropogenic disturbance are often of excellent quality, while in those more toward the valley bottom the situation worsens, close to or inside urban areas.

Although these areas studied are still very beautiful and green, with remaining attractive wild corners, in general human impact has been significant, resulting in species extinctions or reduction in their genetic variation, and with loss or damage to habitats; although frequently the landscape continues to be perceived as pleasant. Theses territories are too much anthropized, especially in the bottom valleys, also if some not urbanized areas are still remarkable.

Much remains to be done for a concrete development of cultural resources, landscape, history and nature of the area, achieving an honest, durable and sustainable development respectful of the environment, health and social rights—abandoning the senseless, harmful and opportunistic logic, both in national and especially in local policies.

Abandoned the imperialist rhetoric and the aggressive vision, the scars left by wars can be re-evaluated in paths of peace; transforming what in the past was a frontier, in paths between nations and sutures among nations and cultures. Closing down the dark sides of the past, without further speculation; without revitalizing mistakes and mischief of the past which are also the result of pasted attitudes and ideologies.

Social rights, management of environment and natural resources must look to local policies, but also needs national and international policies; where local communities can oversee the activities of the States, while at the same time the States should check the local activities, and the international community can control both the situations.

About this, given the positive experience of exchanges and inter-relations between cross-border protected areas, it should be important to expand the interactions between adjacent protected areas (in national and in international cases) providing broadened and far-sighted policies. This, to extend in the environmental field the founding spirit of the European Community, with the communion of spaces; with the cooperation of people, associations and structures: with a shared sense of solidarity and participation.

The relations between trans-boundary protected areas have impacted very positively with respect to the society, territory, landscape and biodiversity. They have impacted positively also on the process of brotherhood, respect and multiculturalism. Therefore, the economic interests of stakeholders and lobbies in one hand; and in other hand the chauvinistic and xenophobic struggles of local political groups that claim the abolition of protected areas, national parks and other important institutions could easily ends to promoting closure or deviations. This should be analyzed, to be fought, together with the study of the actual generalized erosion (for several reasons and from several fronts) of protected areas management, environmental policies and environmentalist societies.

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Forest Vegetation Along the Mura River in Slovenia

Andraž Čarni and Nina Juvan Mastnak

1 Introduction

The Mura River is a daughter of the mountains. Its source is in the Low Tauern in the South-eastern Alps at an altitude of 1898 m. In its upper sector, the Mura River is a typical alpine lotic system but when it enters the national territory of Slovenia it has already lost this character and become a calm and slow river, thus a typical lowland river with several meanders. During heavy rains and snow-melt periods in the Alps, however, it becomes quite different: it can flood the region along its course and cause considerable damage. People have long feared it: and several ameliorations have been carried out since the nineteenth century and embankments built along its course. In its lower reaches, it forms the river border between Croatia and Hungary and converges with the Drava at Legrad, at an altitude of 130 m.

The Mura River basin covers 14,304 km^2, which comprises 1.8% of the Danube basin. The Slovenian part of the basin is only 13%. The average incline of the river is 0.21%, whereas in Slovenia it is only 0.1%. The Slovenian part of the river is 96 km long and the altitude of the river bed ranges from 235 to 150 m a.s.l (Globevnik 2009; Globevnik and Mikoš 2009) (Fig. 1).

The River Mura is a typical river with an ice-snow regime, where the maximum volume of flow is at the beginning of summer. The discharge regime of the river is a

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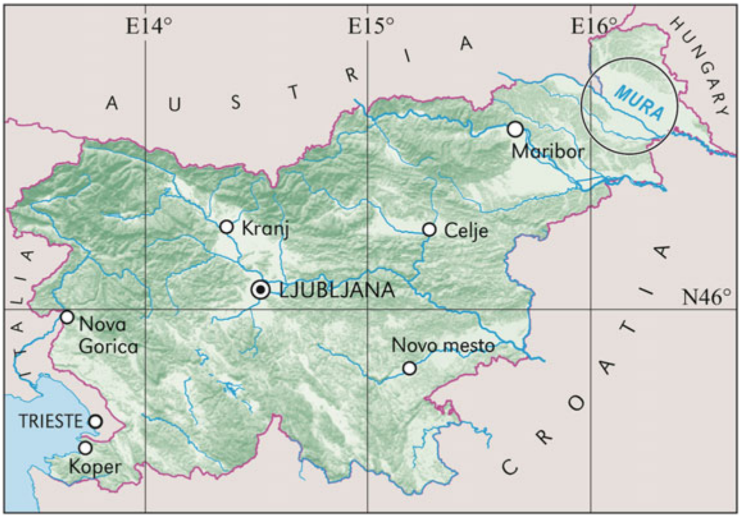

Fig. 1 The course of the River Mura in Slovenia

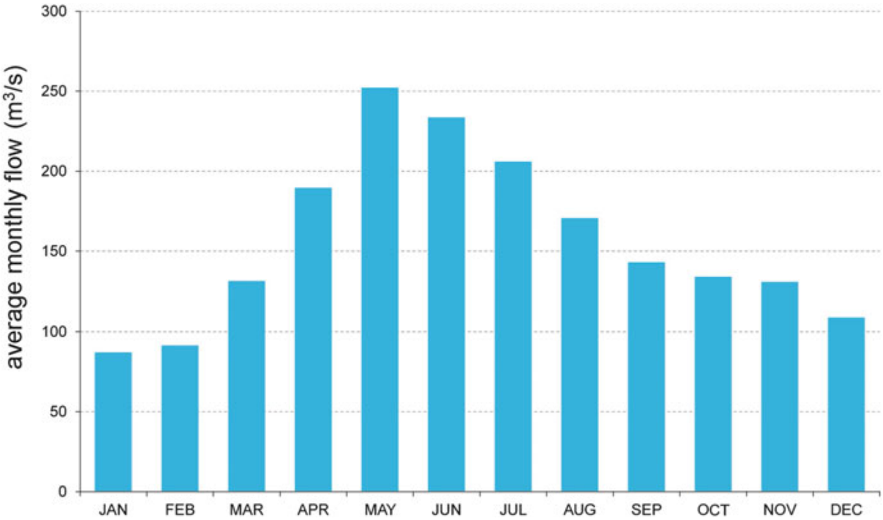

Fig. 2 The water regime of the River Mura for the period 1961–2000 (Source: Slovenian Environment Agency)

transitional nival regime, after Ilešič (1948), and an alpine snow regime, after Hrvatin (1998). This specific regime is characteristic for that rivers that have their catchments in the high mountains areas, where a high mountain climate prevails. The single discharge maximum occurs in May and June. Above-average quantities of water occur between April and August, average in September and below average in the period from October to March (Hrvatin 1998) (Fig. 2).

The Mura River can be treated as a stranded meandering river. This type of river has many streams in the riverbed itself. The main flow is in the main river bed, with the building up of new riverbeds and redirecting of the river into new river beds, the old bed becomes a backwater, called a sleeve. Such direction changings of the river are caused during extreme discharge by erosion. The stream in a straight direction is not stable in principle and so erosion cause the river to bend. The meanders are beds made by the Mura River. They become increasingly larger, until finally the river breaks through, causing the meander to become a sleeve. With deposition at the entrance and later at the exit, the sleeve loses contact with the rest of the river and becomes an oxbow. Material is gradually deposited in the oxbow, it is finally filled, and we cannot detect that there was once a watercourse there. This means that all shapes are changing from one to another in a dynamic way, so all stages are represented in the landscape. This favours high biodiversity and many different biotas (Balažic 2006; Hribar 2012).

The relatively narrow belt along the river is modified by an embankment, which prevents minor flooding causing major damage. Since these surfaces are not suitable for agriculture, but are quite fertile because of organic material brought by floods, they are covered by forests. A 2–3 km-wide belt of forest along the river can thus be found. During major floods, the Mura River overflows the embankments and also floods fields and settlements. The biggest floods were in 1925 and 1970. In November 1925, the water was 2 m high even in Murska Sobota, the regional capital (Komac et al. 2008).

The River Mura was also the border between the Austrian and Hungarian parts of the Austro-Hungarian dual monarchy. Since the flow has changed over the course of history, the first political problems concerning the course of the Mura River were reported in the sixteenth century. Tomaž Széchy, feudal lord in Lendava and Murska Sobota, protected his property along the river by ordering two river sleeves on the Prekmurje side (left bank of the river) to be filled and the main stream of the river changed to the other side. The river began to erode on the right bank and took the best fields, even approaching the houses on the other side, this caused the Styrian authorities to react and negotiate with the Hungarians (Zelko 1984). How the natural flow has changed in time can be seen from the Josephine military map dated 1763–1787 (Fig. 3). The river course is divided into the main course and backwaters. At that time, the main course contained only 40% of the whole stream, whereas 60% of the flow went through backwaters. Nowadays, almost 95% of the water flows through the main stream (Kikec 2007).

At the end of eighteenth century the Mura River was a characteristic sediment-carrying river, with many meanders. In the nineteenth century, the first amelioration works began in order to reduce the area of riverine and moorland forests and to gain more agricultural land and, at the same time, to reduce the risk of floods. Such activities were initiated in the River Mura area border with Croatia only at the beginning of the twentieth century and so this part is the most natural part of the river (Globevnik 2009).

Fig. 3 Course of the Mura River in the eighteenth century (Source: Josephine military map)

This river has also been modified due to hydro-electric power plants in the Austrian upper part. At the beginning of the twentieth century, due to a lack of electricity, people quickly realized that it would be possible to obtain energy from hydro-electric power plants on the Mura River. So the first power plants appeared at Niklasdorf in the year 1895, Lebring in 1902 and Bruck an der Mur in 1903. Altogether, 34 power stations have been built, of which only one is in Slovenia (Ceršak) (Kovačič et al. 2004).

In addition to initiatives to build hydropower plants, there have been several initiatives to protect the Mura River. In the framework of the project BioMura, two sleeves were reconstructed and reconnected (www.biomura.si, accessed 10.5.2014). This area belongs to the Natura 2000 network.

In the last century, hydraulic engineering measures (building embankments, closing the sleeves and building canals) altered the river, which is entirely canalised on the border with Austria and partly in the Slovenian course; the most natural is in the lower part, in the zone bordering Croatia.

2 The Area

The studied region contains Ravensko and Dolinsko areas (belonging to the Prekmurje region) on the left bank of the River Mura and Mursko polje on the right bank. The bedrock consists of Pleistocene and Holocene sediments that form alluvial terraces. There are two Pleistocene accumulation terraces: one is 20–30 m thick, and one of only 6–9 m above the Holocene level. The older, which is situated at an altitude of about 250 m, is on the edge of the alluvial plain. This terrace is composed of gravel, primarily quartz pebbles. The gravel is mixed with loams, which form a 6 m-deep cover. The younger terrace is covered by a 2–3 m deep layer of loam. The Holocene sediments are formed by the depositions of brooks and streams and are the youngest alluvia in the region (Gregorič 1984).

3 Bedrock and Soils

Automorphic soils are formed under the influence of meteoric water that drains through the soil profile into the subsoil. This category includes eutric and dystric ranker, eutric and dystric brown soils. These are both agricultural and forest soils.

Hydromorphic soils include continuous or periodic wet floors, which have been developed under the influence of soil, surface water and flood water. Hydromorphic soils are represented by riverine soils, gleysols and planosols. Riverine soils are young, poorly developed soils, which have emerged in recent river sediments. These types are of low agricultural value. Gleysols appear under the influence of ground and surface water. Wet meadows and alder forests appear on these soils. Planosol as poor agricultural land, appears during the process of formation of gley soils but the process is not very expressed (Stepančič 1984).

The region has a continental climate. Climatic data for Murska Sobota show that the average annual temperature is 9.2 °C; the coldest month is January, with an average temperature of −2.3 °C, the warmest is July, with 19.2 °C; the annual precipitation is 814 mm, with a peak in June (Fig. 4a, b) (Slovenian Environment Agency, www.arso.gov.si, accessed 1.6.2015).

4 Fauna

The area along the River Mura had not been studied in detail until the second half of the twentieth century. The Mura River, with its dynamics, floods, moors, sleeves and oxbows, offers a space for many species. Ameliorations have reduced their living conditions and so these species are to a large extent Endangered and belong to

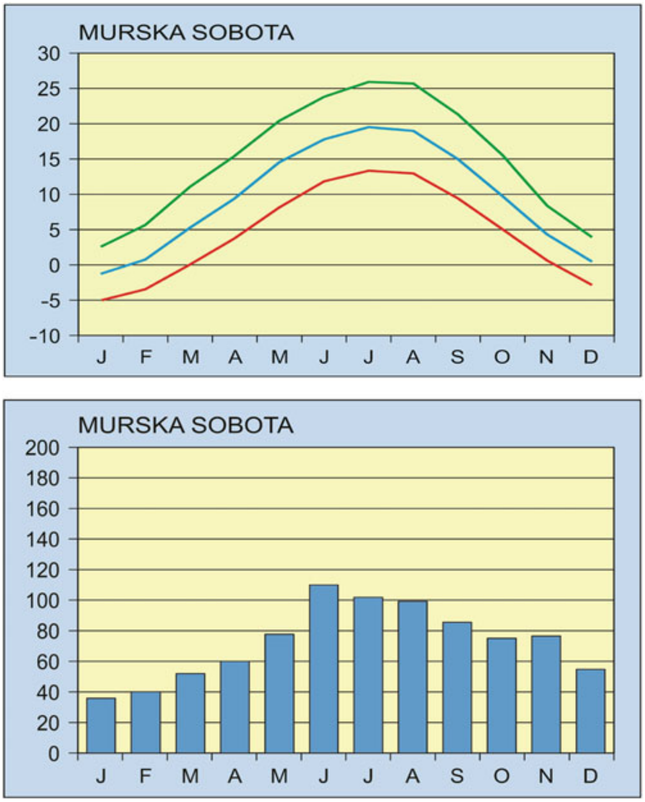

Fig. 4 (**a**) Climatic conditions in the region for the period 1971–2000; monthly temperatures—red line minimum, blue line average, green line maximum. (**b**) Climatic conditions in the region for the period 1971–2000; Right: average monthly precipitations (Source: Slovenian Environment Agency)

different Red Lists. Thirty species of Odonata exist in these habitats, including both *Leucorrhina caudalis* and *L. pectoralis*, which are rare and endangered (Bedjanič 2002). Plecoptera are very sensitive to low oxygen contents and pollutants, so they can serve as good bio-indicators. Several endangered species appear in the region sporadically, such as *Isoperla tripartita*, *Xanthoperla apicalis*, *Nemoura dubitans*, *Brachypetra braunei* and *Dinocras cephalotes* (Sivec 2002). Orthoptera are not characteristic species of wet habitats but *Ruspolia nitida* can be found there, as well as species from the genera *Conocephalus* and *Tetrix* (Gomboc 2002b). Coleoptera species are also abundant in the researched area; there are a total of 1300 species. Many are Central European species that have reached their southern border of distribution here. The most endangered species appear on gravel along the river, in oxbows (*Hydrous piceus*) and in old oak forests (*Cerambyx cerdo*, *Megopis* *scabricornis*, *Rhagium sycophanta*). These two habitats have become rare in recent years (Drovenik and Vrezec 2002). Several Lepidoptera species are present in wet environments, including species of which the caterpillar lives in water (*Elophila nymphaeata*). In alder forests, several species of moth (e.g. *Catocer fraxini*) can be found. Among butterflies (Rhopalocera), the best known species are *Lycaena dispar* and *Maculinea nausithos* (Gomboc 2002a).

The Mura River is the habitat of many fish. In the upper course, where the Mura River forms the border with Austria and the river banks are completely regulated, fishes appear that are found in faster-running rivers. Downstream appear fish species characteristic for slow running and stagnant waters, which are more and more abundant over the course of the river. Fish of stagnant water are found in sleeves. Because of regulation and pollution in the 1990s, when the Mura River was classified in the third and fourth quality class, many fish, such as *Hucho hucho*, *Rutilus pigus*, *Thymallus thymallus*, *Zingel streber*, *Barbus barbus* and others, became extinct. However, in the last decade of the twentieth century, when the Mura River became second quality class, has seen greater diversity of fish. Probably the most interesting species in the area is *Umbra krameri*, which was first found in Slovenia in 1980 and lives only in oxbows that are far from settlements and agricultural land (Povž 2002). Amphibia find many habitats in the flooded area, such as in the oxbows, sleeves, puddles, flooded meadows and forests, which are important for their development. Many important Amphibia can be found in these sites, of which the most important are *Pelobates fuscus*, *Bombina bombina*, and *Rana arvalis* (Poboljšaj 2002). Among reptiles the most frequent are *Natrix tesellata* and *Emys orbicularis* (Tome 2002). There are 110 species of breeding birds in the area, but many more migrate or overwinter (Gregori 2002). Small mammals (e.g., *Apodemus agarius*) are quite common in the region, as well as larger mammals such as wild swine (*Sus scropha*), red deer (*Cervus elaphus*), beaver (*Castor castor*) and otter (*Lutra lutra*) (Kryštufek 2002, www.biomura.si).

5 Endangered Flora

About 600 plant taxa thrive in the area of the Mura River, of which 500 are indigenous and the rest are not native. The 35 or so endangered species include *Bidens cernua*, *Ballota nigra*, *Lemna gibba*, *Salvinia natans*, *Stratiotes aloides*, *Wolffia arrhiza*, *Cicuta virrosa*, *Sagillatia sagittifolia* and *Thelipteris palustris*. All these species are on various Red Lists; the water fern *Salvinia natans* is even among strictly protected species according to the Bern Convention (Babij 2002, 2003; Babij et al. 2002; Bakan 2006; Babij and Seliškar 2010).

6 Invasive Species

The Mura River is a vector for the spread of various alien plants, many of which are invasive species that have changed the landscape in the last century. They include *Acer negundo*, *Impatiens glandulifera*, *Juglans nigra*, *Phytolacca americana*, *Robinia pseudacacia*, *Reynoutria japonica* and *Solidago gigantea* (Čarni 2002).

7 Overview of Non-forest Vegetation

The vegetation of the region is not well elaborated. This overview is based on manuscripts by Čarni (1998) and Seliškar (1998), as well as Seliškar (2002a, b).

The majority of non-forest areas have been transformed to fields, a minor part being cultivated meadows. The extensive grasslands that thrived along the Mura River were subject to afforestation or have been planted with tree species. The amelioration of the Mura River and its tributaries has induced flooded and humid grasslands to become relatively rare. Aquatic vegetation is developed along Mura oxbows, abandoned gravel pits, ponds, brooks and water-filled ditches. The natural vegetation is better preserved in the lower course of the Mura River, after Radenci, especially in the part of the Mura that is the border with Croatia. Because of hydropower plants, natural deposition of gravel on the river bank is rare, although some fragments can be found in the lower course.

The *Rumex palustris-Cyperus glomeratus* community (*Bidentetea*) appears on initial sites on non-settled gravel deposits along the Mura River and in gravel pits. *Eleusinetum indicae* Slavnić 1951 (*Eragrostietalia*, *Stellarietea mediae*) can be found on thermophilic sites on gravel in late summer. The floating liverwort community *Riccietum fluitantis* Slavnić 1956 (*Lemnetalia*, *Lemnetea*) can be found in the shade of other higher plants in mesotrophic and oligotrophic stagnant water; *Lemno-Spirodeletum polyrhizzae* Koch 1954, which can be found in moderately eutrophic water, and *Lemnetum trisulcae* Hartog 1963, which can be found in more eutrophic water, are from the same group. In fairly eutrophic stagnant and partly shaded water, the *Hydrocharitetum morus-ranae* van Langendoeck 1935 (*Hydrocharietalia*, *Lemnetea*) association prospers, with the following characteristic species: *Hydrocharis morsus-ranae*, *Stratiotes alloidis*, and *Spirodella polyrrhiza*; within this association is the sub-association *Salvinietosum natantis*, with ecological variant *Wolffia arrhiza*, which can be found in sunnier sites. From the same group, *Ceratophyllum demersi* Hild 1956 can also be found in eutrophic, stagnant waters that are warmer during the summer. *Lemno-Utricularietum vulgaris* Soó 1947 thrives in mesotrophic to fairly eutrophic stagnant waters, similarly warmer during summer.

Polygono avicularis-Plantaginetum intermediae Seliškar 1995 (*Cypeteralia fusci*, *Isoeto-Nanojuncetea*) is characteristic of banks and the bottom of ponds, where the soil is clay, compacted with much detritus; it can also appear in damp fields. *Anthriscetum sylvestris* Hadač 1978 (*Lamio albi-Chenopodietalia*, *Galio-Urticetea*) appears as a fringe community along paths. The same group includes

Urtico-Cruciatetum laevipedis Dierchke 1974, which appears by damp cultivated grasslands; *Chaerophylletum bulbosi* Tüxen 1937, which is found on nutrient-rich sites along brooks, channels and rivers; *Phalarido-Petasiteum hybridi* Schwickerath 1933, which appears on more eutrophic sites and *Chaerophyllo hirsuti-Petasitetum officinalis* Kaiser 1926 (*Convolvuletalia sepium*, *Galio-Urticeatea*), which occurs on less eutrophic and more natural sites. *Filagini arvensis-Vulpietum myuros* Oberdorfer 1938 (*Corynephoretalia*, *Koelerio-Corynephoretea*) appears on acidic sites on open, often degraded sites, such as vineyards or deposits of gravel and sand. *Hottonietum palustris* R. Tx. 1937 (*Potamogetonetalia*, *Potamogetonetea*) appears in shallow, slowly running or stagnant water. The water can dry up during the summer. These stands are often shaded by surrounding shrubs and trees.

Phragmitetum vulgaris Soó 1927 (*Phragmitetalia*, *Phragmiti-Magnocaricetea*) appears in slowly running waters, channels and similar sites. The water is meso-eutrophic and can even dry up during summer. Some other communities from the same group can also be found, such as *Thyphetum latifoliae* Lang 1973, appearing in shallow waters of gravel pits, channels, ponds and oxbows. The water is eutrophic with an accumulation of detritus at the bottom. *Thyphetum angustifoliae* Pignatti 1953 appears in medium deep stagnant eutrophic or mesotrophic waters. This community can be found primarily in oxbows. *Acoretum calami* Schultz 1941 is a neophytic community that appears in some warmer parts of Europe. It grows along some slowly running or stagnant waters and survives in this way for short dry periods. *Leersietum oryzoidis* Eggler 1933 appears on the banks of ponds, in flooded gravel pits, on the muddy bottom of channels and similar habitats. The water table fluctuates and the community can dry up during the summer. *Sparganietum erecti* Roll 1938 appears in shallow, slow-running water, rich in nutrients, in which the upper layer is composed of detritus and the lower is more organic. *Butometum umbellati* Philippi 1973 appears in shallow stagnant eutrophic water with a large fluctuation of the water table. *Caricetum elatae* Koch 1926 (*Magnocaricetalia*, *Phragmitetea*) finds optimal conditions in stagnant waters up to 0.5 m deep. It thrives on mesotrophic rather eutrophic sites with a fluctuating water table that often dries up. *Caricetum gracilis* Almquist 1929 appears in the littoral part of eutrophic stagnant waters and on flooded areas along the river or in small depressions with top soil. The community does not succeed survive extended stagnant water at the beginning of the vegetation period, nor accidentally dry periods during summer. *Phalaridetum arundinaceae* Libbert 1931 well survives changes in humidity of the site—from flooded during spring to drying up during summer. *Glycerietum fluitantis* Eggler 1931 (*Nasturtio-Glycerietalia*, *Phragmiti-Magnocaricetea*) appears in stagnant or slowly running water 10–30 cm deep. From the same group, *Glycerietum maximae* Hueck 1931 occurs in deeper water (up to 0.5 m) and survives extended periods of flooding. *Scirpetum radicantis* Nowinski 1930 (*Oenanthetalia aquaticae*, *Phragmiti-Magnocaricetea*) is characteristic of sandy or clay sites rich in organic detritus in mesotrophic water in the littoral belt of gravel pits, ponds and shallow oxbows. This community appears in sites that are dry during the summer, when *Scirpus radicans* begins to develop. *Bromo-Plantaginetum mediae* Horvat 1930 (*Brometalia*, *Festuco-Brometea*) appears on higher sites on gravel, which enables the development of dry grasslands. *Ranunculo bulbosi-Arrhenatheretum*

Ellmauer 1993 (*Arrhenatheretalia*, *Molinio-Arrhenatheretea*) belongs to the group of cultivated grasslands that form the majority (except arable fields) of the non-forest vegetation of the region. *Ranunculo bulbosi-Arrhenatheretum* appears on the driest stands covered by cultivated grasslands. *Pastinaco-Arrhenatheretum* Passarge 1964, one of the widest spread communities of cultivated meadows, is relatively rare in the region. After the abandonment of regular cutting and fertilizing, this community can convert to the *Dactylis glomerata-Festuca pratensis* community. The dampest cultivated meadows can be classified within *Ranunculo repentis-Alopecuretum pratensis* Ellmauer 1993, which can appear on damp, occasionally flooded sites or sites with a high groundwater table. The sites are considered rich in nutrients transported by floods or brought by fertilisation. *Bromo racemosi-Cynosuretum cristati* Horvatić 1930 can exist in similar ecological conditions on gleysol. *Lolietum perennis* Gams 1927 develops on grazed, trampled and ruderal surfaces that are characterised by grassland species resistant to trampling. Shrub communities (*Rhamno-Prunetea*) possess a more or less nitrophilous character. They are dominated by *Cornus sanguinea*, *Sambucus nigra* or *Robinia pseudacacia*. Fragmentarily in less eutrophic stands, *Corylus avellana* communities also appear.

8 Forest Vegetation

8.1 General Overview

Forests along the Mura River can be divided into three ecological groups. The first comprises forests that appear on the alluvial plain above the level of flooding. The second group is formed by riverine forests that appear on river banks, and the last group consists of forests that thrive on moorland at some distance from the main course of the river (Čarni et al. 2008) (Figs. 5 and 6).

8.1.1 Forests on the Alluvial Plain

The alluvial terrace is in principal covered by agricultural surfaces, with fragmentary forest areas. The commonest are mesophilous and acidophilous oak hornbeam forests that thrive on the flat. In the hilly region of Goričko in the north and Slovenske Gorice in the south can be found forests dominated by beech (Marinček and Čarni 2002; Marinšek et al. 2013). In the Mura River direction, where the influence of flooding can be found, hornbeam first disappears and forests are dominated in principal by pedunculate oak (*Quercus robor*) (Vukelić and Baričević 2004).

8.1.2 Riverine forests

Riverine forests develop on sites that are subject to periodic flooding. The existing floods transport deposits of sludge and this causes the soil here to be not *well*

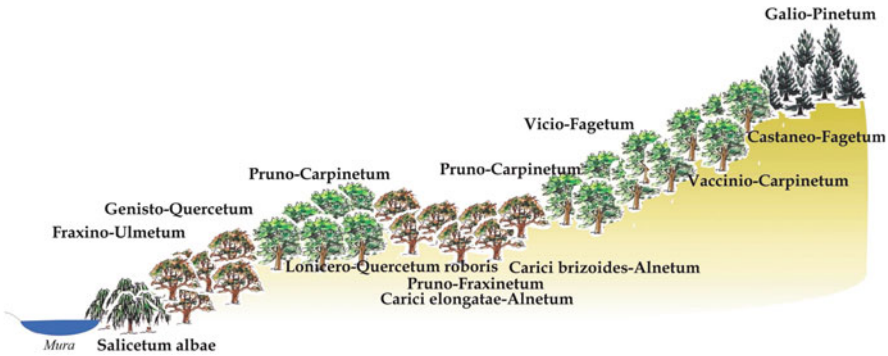

Fig. 5 Scheme of forests in the area of the Mura River (after Benedik in Čarni et al. 2008). The forest classified as *Genisto-Quercetum* in the scheme belong to the association *Fraxino-Ulmetum quercetosum roboris* according to new findings of Košir and associates (2013). Pine forests (*Galio rotundifolii-Pinetum sylvestris*) appearing on the top of hills are not elaborated in this presentation (Zupančič and Čarni 1988).

developed but rich in nutrients. During the summer, these sites become dry and well aerated. The summer dryness distinguishes them from moorland forests, which are under water practically the whole year and will be elaborated further. Riverine forests are fairly diverse and offer living space to many plants and animals. These surfaces were already ameliorated during the eighteenth century. Since these activities were initiated in the border area with Croatia only in the last century, these forests are best preserved. As well as hydro-technical work, the people also felled the forests and planted other tree species. This has changed the composition of forests and makes it difficult to investigate and understand their structure (Wraber 1959).

Riverine forests can be divided into soft- and hardwood forests. Softwood forests are formed of different species of willow and poplar (*Salix alba*, *S. fragilis*, *Populus* × *canadensis*, *P. nigra*). Hardwood forests are built up by elm (*Ulmus laevis*, *U. minor*), ash (*Fraxinus excelsior*, *F. angustifolia*) and pedunculate oak (*Quercus robur*). Softwood species forests appear close to the river course, whereas hardwood forests thrive at distance from the river course, on less flooded and better drained sectors.

The following zonation can be found on the banks of the River Mura. Immediately above the level of the river is a scrub community dominated by *Salix triandra*. It builds a mantle of willow forest dominated by *Salix alba*. Above the water occur forests dominated by elm and ash (*Fraxinus angustifolia* and *Ulmus laevis*); higher, on the border of the alluvial terrace, elm and ash forests with oak appear.

This zonation of forests along the Mura River has recently been studied by Košir and associates (Košir et al. 2013). In describing riverbank forests, they found that zonation on the river bank is more influenced by the nearest water current than the main course of the Mura River. The zonation on river banks is influenced by moisture and also by the availability of nutrients. However, the proportion of

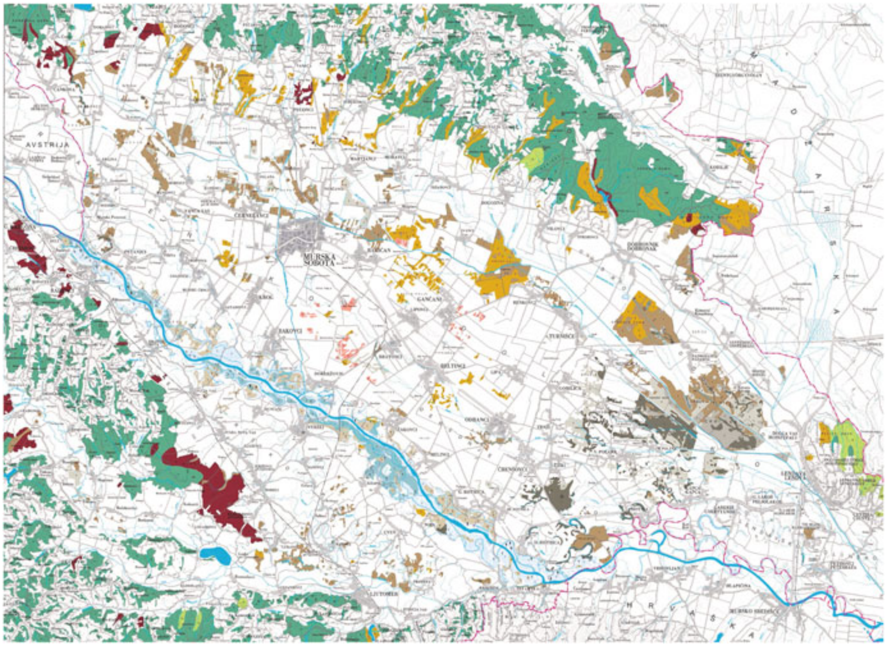

Fig. 6 Vegetation map of forest communities (after Čarni et al. 2008). Compare also comment to Fig. 5

neophytes is significantly negatively correlated with distance from the main stream, which is the main vector for the spread of species in the areas.

8.1.3 Moorland Forests

The current of the Mura River also brings sediments that are deposited in its bed. The Mura River therefore "climbs" above the surrounding landscape. Moorland forests thus occur at a certain distance from the river. Since they are lower than the river bed itself, they cannot easily drain, so the water table is high over the whole year. These forests are influenced by periodic floods on the one hand, but also by ground- and rainwater. The water table falls below the surface only in the driest part of the year. The only tree species that can survive these conditions is black alder (*Carici elongatae-Alnetum glutinosae*). On slightly elevated sites, ash forest co-dominated by black alder (*Pruno padi-Fraxinetum*) can be found and, on the edge of the alluvial plain, forest dominated by pedunculate oak (*Lonicero-Quercetum*) (Rauš 1976; Čarni et al. 2008).

Fig. 6 (continued)

9 Conclusions

The chapter presents the diversity of forests in the area along the Mura River and its hinterland in Slovenia. The forms of floodplain forest can only be found today in a narrow belt along the Mura River and its tributaries. Although much amelioration work has been done in the area, which has significantly reduced their extent and biodiversity, these forests can still be considered to be of national importance.

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The Response of Fish Assemblages to Human Impacts Along the Lower Stretch of the Rivers Morava and Dyje (Danube River Basin, Czech Republic)

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1 Introduction

Large lowland rivers and their alluvial floodplains comprise a wide range of biotopes inhabited by many animal and plant species (Adámek and Sukop 1992; Schiemer 1999; Schomaker and Wolter 2011). The lotic systems are highly dynamic, supported by a high ability to recover former, and to create new, biotopes. Natural, non-impacted lowland streams display a rich and diverse lateral and longitudinal zonation of river and alluvial biotopes, with good hydrological and ecological interconnection of pools, riffles, side arms and oxbow lakes, riparian wetlands, flooded meadows and wooded alluvial land.

This study reveal results from an assessment of fish assemblages in the rivers Morava and Dyje, which belong amongst the richest European rivers as far as the fish communities are concerned. A literature review evaluating changes that have occurred upstream of the Morava and Dyje confluence over recent decades are also included.

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2 General Characteristics of the Morava River Basin

The catchment areas of three main European rivers occur within the Czech Republic—those of the River Elbe, which empties into the North Sea (65% of land surface); the River Odra, draining into the Baltic Sea (7%); and the River Morava, which flows into the Danube and on to the Black Sea (27%). Morava River and Dyje, its main tributary, meandered in the past through large floodplains; however, both of them have been regulated and channelized in the last century.

The watershed of the Morava, upstream of its confluence with the Dyje (Fig. 1; situated 70 km upstream of the confluence with the River Danube), has an area of 21,138 km^2, and can be characterised as being densely populated (137 inhabitants per km^2) and highly exploited by both industry (machinery, food and chemical) and agriculture. Agricultural land represents around 60% of the basin's surface, forests 32% and urbanised areas around 6%. Hydrologically, the Morava river basin is poor in water sources. Average annual precipitation vary between 635 mm and mean annual catchment runoff reaches 3430 million m^3. The average annual discharge of only 1.16 m^3 for each of its 2.7 million inhabitants is only one third of the European average, and one sixth of the global average. The basin has 38 important storage reservoirs, with a total capacity amounting to approximately 568 million m^3.

The qualitative state of running waters in the Morava river basin reflects the long-term development of landscape, municipalities, agriculture, industry, forestry, water

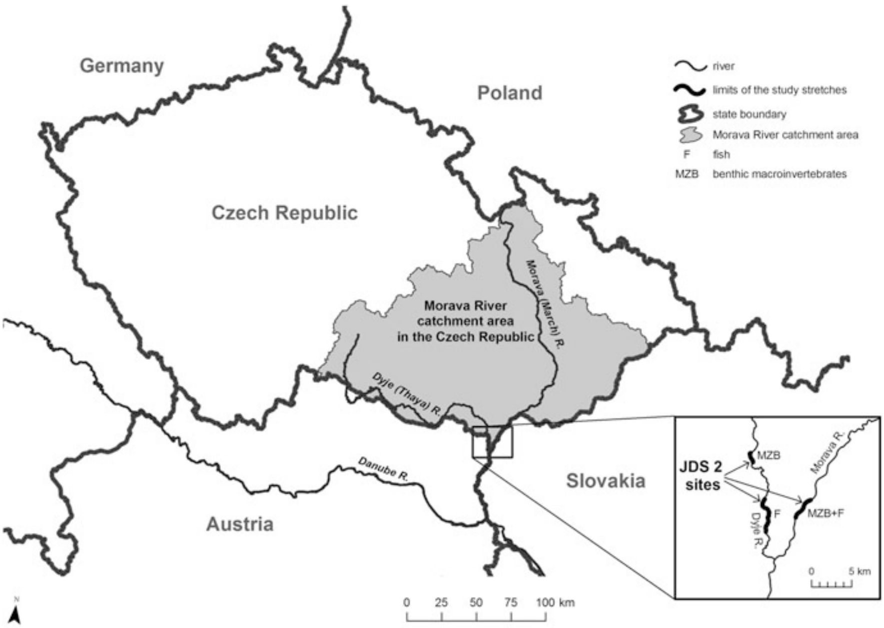

Fig. 1 The Morava River basin on the territory of the Czech Republic with the indication of Joint Danube Survey 2 (2007) sites location

management and other infrastructures. Although water quality has improved significantly over the past 20 years (e.g. all 34 towns with more than 10,000 inhabitants have been equipped with biological wastewater treatment plants), issues related to high nutrient and/or organic loading of surface waters still remain.

Historically, this river system was naturally inundated up to five times a year (Kux 1956) and the floodplains around the confluence provided extremely favourable conditions for the reproduction and nurseries of the majority of riverine fish (Jurajda and Peňáz 1994; Jurajda 1995, 1999; Jurajda et al. 2000). Between 1968 and 1982, however, the Morava was largely channelized and its meanders, disconnected from the main channel by levees, now exist as isolated oxbow lakes (Jurajda et al. 2001). Environmental conservation and maintenance of plant and animal diversity is implemented through a network of protected areas and sites, particularly in the upper mountainous and lower lowland parts of the river basin, The territory around the confluence has been designed as a Biospheric Reserve (the Soutok BR; 139 km^2), and mostly comprises floodplain forest with a rich system of canals, oxbow lakes, river side-arms and pools subject to controlled flooding during the spring.

3 Current Situation as Regards Habitat and Water Quality Degradation Along the Lower Morava and Dyje

3.1 Physical Habitat Degradation

Human activities have had a significant impact on the hydromorphological status of both the Morava and Dyje river basin districts (RBDs), with natural stream processes now rare and aquatic biocoenosis low. Around 80% of all water bodies have been modified, with stream channelization, bank strengthening, channel hardening and cross-barrier construction are the dominant factors. As such, channelized stream and impoundment length, river bank straightening and channel hardening, levee length, urbanisation along river banks, change in river cross-section, cross barrier number and length of stream transferred via flow tubes, have been included in the criteria for status assessment in the River basin Management Plan (Dyje 2009; Morava 2009).

There are important dissimilarities between the hydrological characteristics of the two RBDs (summarised in Table 1). Despite having almost the same average annual precipitation (590 and 670 mm for the Morava and Dyje, respectively), annual surface runoff for the Dyje is only half that of the Morava (109 and 206 mm, respectively). As such, the number of reservoirs in the Morava River basin (upstream of the confluence) is one third of that in the Dyje River basin (10 and 28, respectively), while total storage capacity in the Morava basin is only one twelfth that of the Dyje basin (526 million m^3). Channel straightening has been done to a much higher degree in the Morava RBD (ca. 57% of stream length), with barrier construction of greater importance in the Dyje basin (90% of streams). Overall, lack of fish

Table 1 General characteristics of the Morava/Dyje river basin districts

		Morava–Lanzhot	Dyje–Pohansko
River basin area upstream	km^2	9883	11,165
Altitude	m a.s.l.	150	155
Average discharge	$m^3\ s^{-1}$	61.1	37.5
Water reservoirs	n	10	28
Stream straightening	% of stream length	58	36
Number of inhabitants	ths	1363	1395
Cities > 10,000 inhabitants	n	22	12
Arable land	%	53.0	64.3
Number of bred pigs	ths	373	652
Number of bred poultry	ths	3078	4800

passes has greatest impact in the upper stretches of the rivers, with straightening and levee construction of greater importance in the lower stretches. Also, there is an important difference in agricultural management for the two RBDs, with both the area of arable land and number of animals bred (pigs and poultry) much higher in the Dyje RBD (Table 1).

3.2 Water Quality Development

The lower Morava and Dyje rivers actual degraded environmental status underline the historic anthropogenic pressures, including inadequately treated discharges from urban settlements and industrial areas, the effects of diffuse pollution, and hydromorphological changes.

Effluent from sugar mills had a very destructive impact on river health during the autumn months of each year (period of sugar beet processing) from the 1960s to the 1980s. In the late 1970s, the results of saprobiological monitoring performed by the T. G. Masaryk Water research Institute (TGM WRI), Brno (unpublished) indicated very poor riverine community status along these rivers (these results have since provided a baseline for future water quality status assessments of important rivers in the basin). The extremely high organic pollution levels discharged into the river system each autumn from the sugar mills resulted in an alphameso-polysaprobic status of plant and animal communities along the Morava River. Starting in the late 1980s, wastewater treatment plants were constructed for all larger cities in the RBD, resulting in a gradual improvement in water quality, not only in autumn but throughout the year. In 2007, saprobic indices that had formerly reached values of 2.8 had decreased to 2.1 in the Morava; and an even greater improvement was attained in the Dyje, where an index of 3.4 was decreased to 1.8 between 1976 and 2007. Despite the great efforts focused on decreasing point source pollution discharges in the basins, however, negative influences of diffuse pollution and hydromorphological alteration on fish communities remain a problem in both rivers.

3.3 History of Ichthyological Research

The fish fauna of the Morava River is probably the historically best known and documented of Central Europe. The first scientific list of fishes and cyclostomes were published in the mid-1800s by Heinrich (1856) and Jeitteles (1863, 1864), followed by lists and faunistic records from Kašpar (1886), Remeš (1902) and others.

Fish assemblages in both running and still waters of the lower Morava and Dyje confluence area have been surveyed since the beginning of the twentieth century (Mahen 1927). Based on historical records, recent surveys and anglers' reports, 2 cyclostomes and 55 fish species have been reported from the main channel of the Morava, 48 being indigenous and 9 exotic; such species richness is exceptional compared with most other European rivers of similar size (Peňáz and Jurajda 1993).

4 Material and Methods

4.1 Study Sites

The fish research was realised along the shoreline on river kms 79–76 of the river Morava (48′40″N, 16′59″E), and rkms 17–14 on the river Dyje (48′42″N, 16′54″E) (Fig. 1). Channel width and depth on the Morava River were 50–60 m and 0.8 m, respectively, and 30–40 m and 1.0–2.0 m on the Dyje River. The banks of the Morava River consist mainly of rip-rap, the banks of the Dyje River are mainly natural. More than that, the principal channel of the Morava River is isolated from its floodplain, whereas elements of floodplain and few backwaters remain connected along the Dyje River (Figs. 2 and 3).

4.2 Fish Monitoring

Fish were collected quantitatively from ten 300 m stretches along the right bank of the Morava and the left bank of the Dyje, by electro-fishing (one hand-held anode, EFKO FEG 13000, Honda 13 kW, ~300 V, 60 A, Hz) from a drifting boat 1–5 m from the bank. Stunned fish were collected by hand net (10 mm mesh size). With the exception of bleak, *Alburnus alburnus*, which were dominant, all fish collected were measured and weighed individually. For bleak, 18–32 specimens were measured and weighed individually at each stretch and the rest bulk-weighed and counted. After

Fig. 2 The Dyje River in the Biospheric Reserve Soutok (river km 14)

surveying, all fish were released back into the river alongside the opposite bank. The F/C ratio, indicating the relationship between non-predatory and predatory fish, was calculated as a ratio between their biomass reported in survey catches (Holčík and Hensel 1972).

Data on angling intensity and efficiency, fish species, and size composition at the Dyje 2 and Morava 2 angling grounds (which correspond to the survey sections) were obtained from regularly summarised angling records available each year at the close of the angling season. Figures on stocking and angling captures per year were offered by the Moravian Anglers Union. As fish for stocking are generally available in size and age categories that differ from 1 year to another, and even between individual stocking events during 1 year, the appropriate ministerial instruction give guidelines on how to convert individual size and age categories into one appropriate category, i.e. 2+ for carp and 0+ for other fish in this case research. Conversion rates were also supplied for mortality and survival rates for different species/categories compared to the fish category suggested by the stocking plan. Conversion to one age category enables comparability and an appropriate evaluation of stocking intensity and efficiency between years and individual water bodies. The ratio between number of fish stocked and caught is presented as a rate of return for individual species (Implementation Provision N. 197/2004 of the Czech Fishery Law N. 99/2004).

Fig. 3 The Morava River upstream of the Biospheric Reserve Soutok (river km 79)

5 Results

5.1 Species Composition

4396 and 2476 fish individuals (162.16 and 117.02 kg), were sampled in the researched stretches of the Morava and Dyje rivers (Table 2). The sampled fish species number were 24 + 1 hybrid and 23 + 1 hybrid (six families: Cyprinidae, Esocidae, Siluridae, Gadidae, Percidae and Gobiidae) in each river. Regarding the density, bleak was in both river stretches dominant. This fish species proportions on total fish numbers and biomass was of 75.02 and 16.11%, and 83.70 and 20.41% in the Morava and Dyje.

The percentage of other sampled fish species in researched stretches of the Morava river is under 5%, the most numerous among them being chub, *Squalius cephalus*, barbel, *Barbus barbus*, bitterling, *Rhodeus amarus*, and white-finned gudgeon, *Romanogobio vladykovi*, with 4.85, 3.71, 3.33 and 3.03%, respectively. Additional relevant commercial and game species over 1% (nase, *Chondrostoma nasus* and asp, *Aspius aspius* with 1.57 and 1.46%, respectively), however some of them proved a significant proportion regarding the biomass. The highest figures were recorded for common carp, *Cyprinus carpio*, which proportion on total biomass was 18.71%, whilst only 0.13% on fish density (mean individual weight 5056.7 g),

Table 2 Fish assemblage composition upstream of the confluence between the rivers Morava and Dyje, as recorded during the JDS2 survey in 2007

	River Morava				River Dyje			
Species	n	%	W	%	n	%	W	%
B. barbus	163	3.71	27,181.7	16.76	71	2.87	31,975.4	27.33
A. alburnus	3300	75.02	26,123.9	16.11	2073	83.70	23,884.3	20.41
C. nasus	69	1.57	1251.2	0.77	9	0.36	5020.0	4.29
C. gibelio	41	0.93	26,601.0	16.40	28	1.12	1491.0	1.27
A. aspius	64	1.46	1597.2	0.98	33	1.35	8330.5	7.12
S. cephalus	213	4.85	17,597.3	10.85	13	0.54	4762.0	4.07
L. idus					31	1.26	12,985.4	11.10
L. leuciscus	3	0.08	23.8	0.01				
R. amarus	147	3.33	338.1	0.21				
A. brama	11	0.25	7998.7	4.93	46	1.84	14,598.0	12.48
A. bjoerkna	22	0.51	520.9	0.32	94	3.81	3777.9	3.23
A. sapa	1	0.03	320.0	0.20				
S. erythrophthalmus					1	0.04	46.0	0.04
R. rutilus	112	2.55	2155.4	1.33	26	1.03	881.0	0.75
R. rutilus × *A. bjoerkna*	2	0.05	89.6	0.06	1	0.04	29.0	0.02
R. vladykovi	133	3.03	696.4	0.43	13	0.54	45.1	0.04
G. gobio	38	0.86	196.6	0.12	1	0.04	10.0	0.01
P. parva	1	0.03	7.0	0.04				
C. carpio	6	0.13	30,340.0	18.71				
V. vimba	2	0.05	29.4	0.02				
E. lucius	3	0.08	2682.0	1.65	6	0.22	5620.0	4.80
S. glanis	13	0.30	13,403.7	8.26	3	0.13	2094.0	1.79
L. lota	32	0.73	1569.0	0.97	1	0.04	16.7	0.01
P. fluviatilis	10	0.23	990.0	0.61	14	0.58	599.1	0.51
G. schraetser					6	0.22	175.0	0.15
S. lucioperca	8	0.18	369.0	0.23	1	0.04	290.0	0.25
Z. zingel	1	0.03	113.0	0.07	1	0.04	280.0	0.24
Z. streber					3	0.12	84.0	0.07
P. semilunaris	1	0.03	1.0	0.001	1	0.04	1.1	0.001

Note: n = total individuals, W = fish biomass in g

followed by barbel and Prussian carp, *Carassius gibelio*, with 16.76 and 16.40%, respectively. Among 25 recorded fish species in the Morava River, 3 of them (Prussian carp, topmouth gudgeon, *Pseudorasbora parva*, and tubenose goby, *Proterorhinus semilunaris*) were non-indigenous. The F/C ratio of the whole fish community corresponded to 4.24 in the researched stretch of the Morava River.

Besides dominant bleak (83.7% of total fish density—see above), the proportion of other species occurrence was much lower in the Dyje River and only rarely exceeded the 2% threshold like it happened in case of white bream, *Abramis bjoerkna*, and barbel with 3.81 and 2.87%, respectively. The proportion of other important game fish was quite low with maximum values in common bream, *Abramis brama*, chub, ide, *Leuciscus idus*, asp and roach, *Rutilus rutilus*, with 1.84, 1.35, 1.26, 1.12 and 1.03%, respectively. In terms of biomass, highest proportion belonged to barb (27.33%), followed by bleak, common bream and ide with 20.41, 12.48 and 11.10%. Two non-indigenous fish species were recorded—Prussian carp and tubenose goby. The F/C ratio of the whole fish community corresponded to 3.40 in the surveyed stretch of the Dyje River.

5.2 Angling Yield

Both stretches, belonging to angling grounds of the Moravian Angling Union, are regularly stocked with commercial and game fish species. Common carp (2+ category) dominate with respect to stocking biomass. Carp average rates of return amount to 13.6 and 18.5% in the Dyje 2 and Morava 2 angling grounds, respectively. Predatory fish (pike, zander, *Sander lucioperca*, European catfish, *Silurus glanis*, asp) are usually released as 0+ age category however their rates of return do not exceed 10% (Table 3). Game fish (chub, barb, nase, burbot, *Lota lota*, and

Table 3 Stocking level, angling yield and rate of return (ind.) for the Dyje 2 (D2) and Morava 2 (M2) fishing grounds between 2006 and 2010

	Stocking rate				Angling yield					
	Individuals		kg		Individuals		kg		Rate of return (%)	
Species	D2	M2	D2	M2	D2	M2	D2	M2	D2	M2
E. lucius	181	282	15	67	12	26	32	61	6.6	9.2
C. carpio	885	897	670	772	120	166	422	702	13.6	18.5
T. tinca					1	1	2	1		
A. brama					67	87	46	73		
L. cephalus	2420		25		6	24	22	19	0.2	
B. barbus	1000	920	10	10	8	71	17	133	0.8	7.7
C. nasus	1800		18			6		6	<0.05	
V. vimba	1500		15			3		3	<0.05	
*Herbivorous fish					4	28	34	217		
A. aspius		680		7	6	32	12	59		4.7
P. fluviatilis					3	3	1	1		
S. lucioperca		2210		22	35	39	94	74		1.8
S. glanis		463		10	12	30	147	247		6.5
A. anguilla					<1	6	<1	4		
L. lota		2040		62	<1	7	<1	6		0.3
**Others		200		20	216	308	50	130		154.0
Total					489	835	862	1737		

Note: *Herbivorous fish = grass carp, *Ctenopharyngodon idella*; silver carp, *Hypophthalmichthys molitrix*; and bighead carp, *Aristichthys nobilis*. **Others = (*R. rutilus*, *S. erythrophthalmus*, *G. cernuus*, *C. auratus gibelio*, *C. carassius*, *A. alburnus*, *L. idus* and rarely others)

others) are also stocked for the angling purposes but their rates of return range just below 1%.

On average, altogether 489 fish (862 kg) have been caught yearly by anglers in the Dyje 2 angling ground whilst in the Morava 2 angling ground these figures are twice as big (835 fish/1737 kg) (Table 3). Carp dominate in biomass comprising 49.0 and 40.4% of the total angling yield in the Dyje 2 and Morava 2, respectively. Despite low numbers of European catfish caught by anglers (12 and 30 individuals in Dyje 2 and Morava 2, respectively), their respective angling yield biomass is the second highest with 147 and 247 kg, which corresponds to the mean individual weight of 12.25 and 8.23 kg.

6 Discussion

In lowland rivers and their floodplains, it is always problematic to find methods that provide accurate estimates of fish communities. For example, representative sampling of adult fish in larger lowland rivers is almost impossible. Since all Czech streams are managed as angling grounds, they have been regularly stocked with fish from aquaculture since the middle of the twentieth century. However, ichthyological surveys proved that the key driver to formation and sustainability of original appropriate composition of riverine fish communities (particularly in lowland rivers) is their natural recruitment (Jurajda et al. 2010). In the lowest stretches of the Morava and Dyje rivers, fish originating from the natural recruitment made the vast majority of the density and biomass (Jurajda 1995, 1999; Jurajda and Peňáz 1994, 1996; Jurajda et al. 2000, 2001).

Altogether 24 fish species and 1 hybrid (*R. rutilus* × *B. bjoerkna*) were recorded in the Morava river section in the survey campaign in 2007. Despite one-time survey, the number of species recorded is almost identical with the monitoring performed by Jurajda et al. (1998) who identified 26 species from 5 families in 4-year (1991–1994) survey below and within a rocky chute on the Morava River, the upper boarder-line site of the section surveyed in 2007. In opinion of Jurajda et al. (2008), fish species richness in the Morava River increased continuously over the years 1990–2000 as a result of substantial improvement of water quality and almost reached the situation that existed 100 years ago. The up-to-date assessment of the fish assemblage composition in the Morava River section under study presented 35 fish species in 1994, of which 23 were identical and one species (tubenose goby) was new. Fish assemblage composition comprising 26 species with the same species (chub and gudgeon *Gobio gobio*) dominating before and after the flood was recorded by Jurajda et al. (2006). According to their survey, exceptionally extensive flooding in July 1997 with water discharge peaking at 2000% of long-term average and discharge $>1000\ m^3\ s^{-1}$ lasting for 20 days had a minor effect on the assemblage structure.

Bleak was by far the most abundant fish in both the river sections surveyed. Despite its high abundance amounting to 75.02 and 83.70% in the Morava and Dyje rivers, respectively, its respective contribution to the total fish biomass was quite low and corresponded to 16.11 and 20.41%. According to the survey performed by Sindilariu et al. (2006) in the Danube Delta, bleak and monkey goby (*Neogobius fluviatilis*) were most abundant and frequent, contributing together 61% to the total catch. Despite the rip-rap banks provide mesohabitat favoured by gobiids, their occurrence in this type of the Morava River bank armouring shoreline against water erosion was very rare in the survey monitoring in 1997 and actually it was limited just on sporadically record of tubenose goby individuals. Obviously, the efficiency of electro-fishing in sampling gobiids is quite low (Polacik et al. 2008) but their occurrence in interstitial rip-rap spaces was not very frequent anyhow. Currently, both tubenose goby and round goby (*Neogobius melanostomus*) are a regular part of fish assemblages both in the lower Morava and Dyje rivers despite they appeared there for the first time only in 1996 (tubenose goby, Prášek and Jurajda 2005) and 2008 (round goby, Lusk et al. 2010), respectively. Both species benefit from the suitable habitat—stony rip-rap banks providing shelters and rich food resources under conditions of high trophy and increased temperature of unpolluted water discharged from the cascade of large shallow reservoirs. Recently, their populations dominate both 0+ and adult fish assemblages in the lower Dyje and Morava rivers (Figs. 4 and 5) (Janáč et al. 2013; Valová et al. 2014).

Jurajda and Peňáz (1994) described fish community structure in the lower stretch of the Morava River in 1991–1992, 10 years after completion of regulation. Species richness and diversity depended mainly on the connectivity of the regulated section with more natural section below the studied stretch. Bitterling, bleak, gudgeon, chub, roach and white-finned gudgeon were the most abundant species in all sections of the regulated main channel, with phytophilous species occurring in very low densities. They report 27 fish species recorded in the section identical with our survey. Similarly, Valová et al. (2006) compared the 0+ fish communities in the regulated-channelized Morava River stretch without connection to the floodplain with non-interrupted stretches of the Morava and Dyje rivers connected with floodplains. Surprisingly, the total number of 0+ fish species in all of the three stretches recorded

Fig. 4 Tubenose goby (*Proterorhinus semilunaris*)

Fig. 5 Round goby (*Neogobius melanostomus*)

over 3 years was similar (22, 23, and 25 species, respectively), lowest diversity and highest density being documented in the regulated-channelized stretch.

In the Morava and Dyje river sections under study, also several rare and/or protected species were recorded. Two of them, ide and burbot belong among vulnerable fish species and four others, white-eye bream (*Abramis sapa*), yellow pope (*Gymnocephalus schraetser*), streber (*Zingel streber*) and zingel (*Zingel zingel*) are considered as critically endangered species. Due to regular stocking of these two and associated angling grounds, ide and burbot occur quite regularly in the fish assemblages of the lower Morava and Dyje rivers and recently, they have even been included into the list of fishes that anglers are allowed to take and keep. The occurrence of streber on the Morava-Dyje confluence was in 2003 recorded for the first time for almost a century (Lusk et al. 2004).

The proportion of non-predatory to predatory fish biomass (F/C ratio) is a simple expression of the balance in a particular fish community (Holčík and Hensel 1972). Values for the F/C ratio between 3.0 and 6.0 indicate optimal values, whilst values >10 demonstrate undesirable condition of fish community with strong prevalence of non-predatory fish. The F/C ratio of the whole fish community in the surveyed stretch of the Morava River corresponded to 4.24 which was considered as a value within the optimal range. However when excluding (rather) omnivorous chub from predatory species, its value increases on 7.87 which is already above the upper limit value of optimal range 3.0–6.0 (Holčík and Hensel 1972). In the Dyje River, the FC values amounted to 3.40 in the total community evaluation but when not considering omnivorous chub and ide as predators, it raised on 8.93 which is also above the upper limit value of optimal range 3.0–6.0. It is obvious that the latter values reflect more appropriately the actual situation in equilibrium of the Morava and Dyje fish assemblages.

Anglers' statistics also document a substantial increase in fish catches as a result of considerable water quality improvement in the 90s of the last century (Jurajda et al. 2008). The data presented by Baruš et al. (2000) prove that the anglers' catches in the lower Morava River (fishing ground Morava 2, 20.0 ha) rose from 23.5 to 131.0 tonnes in 1992 and 1998, respectively. Nevertheless, the rates of return in fish stocked are quite low being highest in carp as common phenomenon in the majority of fishing grounds in the Czech Republic. However, their figures are very low as compared with the other fishing grounds probably due to the lotic environment and lack of easy access (Biospheric Reserve, Czech-Austrian and Czech-Slovak border line rivers). Carp, as by far the most popular fish for Czech anglers, are usually subject to focused angling pressure resulting in considerably higher rates of return—e.g. 58.5% in the Brno reservoir (Adámek and Jurajda 2011) or even 92.4% in the Svitava 1 angling ground located largely on the territory of Brno City (www.brno3.momrs.cz/prehledy-ulovku.php). The rates of return are quite low also in predatory and game fish. Regarding predatory fishes, the reason of low rates of return consists in small fish size at stocking and poor accessibility of the angling locations. Extremely low rates of game fish return are moreover caused by quite rare focus of anglers and widely applied catch-and-release approach regarding these species.

The area of the Morava–Dyje confluence represents a unique natural environment of floodplain forest and wetland meadows. The noticeable improvement of water environmental conditions particularly in last two decades, however, concerned almost exclusively just the water quality issues, the physical habitat degradation (river channelization, limited connectivity with side arms and oxbow lakes) being *de facto* unchanged. As a consequence of improved water quality, the diversity fish assemblages has been considerably increased. Thus, continuous monitoring of this area of interest is highly desirable and worthwhile also for the future.

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Human Impacts on the Dobra River (Croatia)

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1 Introduction

The name of Dobra River is based on the feminine form of the Croatian adjective *dobro*, meaning good. However, it is more likely that the river name is a derivative of the Celtic word *dubrum* or *dubron* meaning water, the Illyrian work δυβρις (*dybris*) meaning deep or the Old Slavic dъbrъ (*dubri*, *debra*) meaning deep or valley. This river is a karst lotic system that sinks and also forms springs that runs through western part of Croatia. Its source is on the north-eastern slopes of Mlada Gora near the towns of Skrad, Kupjak and Ravna Gora, and it drains into the Kupa River, a tributary of the Sava River, just upstream of the city of Karlovac.

2 Hydrology and Speleology

One of the most interesting phenomena developed in karst areas is the disappearing of rivers, sinking underground and form caves nets. The Dobra is an excellent example of a disappearing river. In its upper course, the river flows underground over 4.5 km, forming an array of subterranean habitats. These underground waters, together with the surface waters of the Dobra River, form a single dynamic system,

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hydraulically connected through numerous karst structures that facilitate the exchange of water above and below ground. This particular combination of habitats supports a wide range of biodiversity, with numerous cryptic elements related with the underground channels and caves. However, the complex biological community is very sensitive to even small changes in water regime, habitat destruction and other anthropogenic threats.

The fundamental characteristic of the water regime of the Dobra River is pronounced fluctuation, with sudden and large variations in flow. The river runs for a total length of 107.9 km. The river catchment covers an area of 1094 km^2, and of this 302 km^2 falls within the drainage basin of the Zagorska Mrežnica River, which has been shifted into the Dobra River catchment via the Sabljaci reservoir at the Gojak hydroelectric plant (HPP). The reservoir was created by the damming of the course of the Zagorska Mrežnica River, and its water was redirected via a tunnel to the Gojak HPP, just north of Ogulin (Opala and Ožanić 2010). The precise hydrological catchment areas and boundaries between the Dobra and Mrežnica Rivers are not known due to the complex hydrogeological web. It seems that the catchments vary temporally and spatially depending on groundwater levels and the hydrological situation of open streamflows (Bonacci and Andrić 2010). The climate of the Dobra River area is continental. The climatic characteristics are strongly influenced by altitude, which ranges from 108 to 1043 m. The mean annual precipitation measured at the Ogulin meteorological station in the period 1949–2008 varied from 1076 to 2023 mm with an average of 1548 mm.

The course of the Dobra River can be considered in three sections. The first is a disappearing and sinking river called the Upper Dobra or Ogulinska Dobra, which has a length of 51.2 km from its spring to the Đula Sink (Bonacci and Andrić 2010). For most of its length, it runs through a canyon, and receives the waters of several smaller right tributaries, the most significant of which are the Kamačnik, Ribnjak and Vitunjčica. The Kamačnik stream drains into the Dobra at Vrbovsko Dobra. The Kamačnik canyon extends over 3.1 km and has been proclaimed a protected landscape due to its beauty and its hydrogeological significance. The Vitunjčica River has springs in the village of Vitunj, in the foothills of Klek Mountain, and runs for 4 km until the confluence with the Dobra River near the village of Turković. The spring of the Vitunjčica has been proclaimed a hydrological nature monument. After 30 km, the Upper Dobra reaches the Bukovnik reservoir, from where its waters flow via a 5 km long tunnel to the Gojak hydroelectric plant. Surplus waters from the Bukovnik reservoir flow to the town of Ogulin where they sink at the famed Đula Sink (Figs. 1 and 2). This sinkhole and the nearby Medvedica cave were first investigated in 1925 and 1926 by J. Poljak. The length of the cave system (Đula Sink—Medvedica) has been estimated at 15,700 m, making it the longest cave in Croatia. This underground system comprises a web of channels between the Đula Sink and Medvedica cave entrance that is dry during average water levels. The main channel branches at various levels, and several channels in the final part of the cave were formed by a strong tributary groundwater system.

The second part of the river is an underground karst river flowing from the Đula Sink in the town of Ogulin to the karst spring zone near the village of Gojak (Opala

Fig. 1 The view towards Đulin sinkhole (photo by Dalibor and Mirjana Vučić) (Vučić and Vučić 2012)

and Ožanić 2010). Sinking and disappearing streams (known also as influent streams) and their underground systems develop when they traverse soluble rocks along their courses. Various surface and underground karst forms produce unexpected water connections in the spatial layout of the karst medium. The catchment area of this second segment is about 380 km^2, with a mean annual precipitation of 1700 mm. Besides the Đula Sink and Medvedica, there is also a third entrance into this cave system, known as Badanj. The main channel of the cave is a 756 m-long subsurface water flow that ends in a siphon lake with depths greater than 25 m. Typical karstic features of the river are well expressed by the discharge ratio, which varies from 0.12 to 154 m^3/s. The mean annual flow rate is 9.7 m^3/s. There are several smaller caves in this system, some acting as periodic springs. After this underground section, the Dobra resurfaces at the strong permanent karstic spring, Gojak. Gojak also includes the 2166 m-long Spring Cave, a branched speleological structure.

The formation of this part of the karst system was influenced by climatic conditions from the Pliocene epoch to the present. From the Pliocene to the Quaternary, great quantities of water, together with glaciers, formed these terrains, shaping a strong epikarstic system of underground communications (Bonacci and Andrić 2010). The sinkhole is active, with permanent water flows within the cave system. Due to strong hydrological activity in the cave system, there is no stalactite and stalagmite development. However, many erosive formations have developed (Kuhta

Fig. 2 Entrance to Đulin sinkhole (photo by Dalibor and Mirjana Vučić) (Vučić and Vučić 2012)

and Novosel 2001). The vertical distance from the highest point of the Medvedica cave system (at its entrance, elevation 315 m) to the lowest point at the terminal siphon (called the Lake of the Skinny Frog, elevation 231.5 m) is 83.5 m. After heavy rains and snow melt, the discharge of the Upper Dobra increases to more than 100 m^3/s. Under such conditions, the discharge capacity of the cave system is too low to accept all the water, and the outflow capacity of the Gojak spring is also restricted. In such cases, the water level of the Upper Dobra rises by more than 40 m at the entrance of the Đula Sink.

Finally, part of the water flows through the fossil riverbeds toward second generation sinkholes at the north-eastern edge of the Ogulinsko Polje, activating the old underground drainage system. As a consequence, the Sodolska cave, located at an elevation of 230 m and 41 m above the Gojak spring (189 m) also becomes active, with a discharge of several m^3/s (Kuhta and Novosel 2001).

The third segment of the Dobra River is the disappearing Lower Dobra or Gojačka Dobra River, with a total length of 52.1 km (Bonacci and Andrić 2010). From the point where it resurfaces near Gojak to the settlement of Trošmarija, the river flows through a canyon, has a rocky bed and many cascades, and the banks are quite inaccessible. Downstream of Trošmarija, the Dobra is intersected by several travertine deposits and the channels of former watermills. Important tributaries to the Lower Dobra are the Bistrac, draining near the village of Gojak, and Ribnik

(Ribnjak), which drains just downstream of Trošmarija. Bistrac is a stream that has springs in the village of Kromari, and which is fed underground by waters from the Ogulin and Modruš Valleys. After flowing for 4.5 km, its course ends as it falls over a waterfall into the Lower Dobra. The Ribnik (Ribnjak) is a stream that springs north-west of Trošmarija and flows for 2.8 km until draining into the Lower Dobra (Opala and Ožanić 2010). The speleological value of the canyon part of the Dobra River is very high, including 32 caves that provide refuge for a great number of rare subterranean species.

3 Fauna of the Dobra Catchment

The Dobra River is a hydrologically interesting and dynamic river that is characterised by specific above-ground and subterranean fauna. This is a karst river, and therefore many of the species present are typical of aquatic karst habitats, and a large number of endangered, rare and endemic species have been recorded. However, as a part of the Danube Basin, the Dobra River is also inhabited by many of the typical European animal species. There are relatively few data on the fauna of the Dobra River, and these date back to the turn of the twentieth century. Over the past 15 years, numerous studies have been conducted on the above-ground and subterranean fauna of the river catchment, primarily due to the construction of the Lešće HPP that became operational in 2010. The current figure for the number of species inhabiting the various aquatic habitats in the Dobra basin is certainly not final, since many habitats and subterranean areas are yet to be investigated in detail.

3.1 Subterranean Fauna

It is well known that the Dinaric karst caves are for fauna among the most interesting subterranean habitats in the world. The high biodiversity of these karst ecosystems is likely due to rich organic input, permanent groundwater habitats, high diversity of surface streams and the changing of water flow directions in the area. The Dobra karst is among the richest underground biodiversity sites in the world, with many cave-dwelling and endemic species.

As a result of the high diversity and heterogeneity of aquatic habitats, and the hydrological and geological phenomena, the subterranean habitats of the Dobra catchment stand out for their exceptional wealth and diversity of aquatic cave fauna, which includes a large number of rare and threatened taxa. To date, more than 200 taxa of subterranean fauna have been recorded, including 65 troglobiont and stigobiont species, and 27 troglophiles (Bedek et al. 2006; Ozimec et al. 2009). Thanks to the refugee significance of the subterranean habitats of the Dobra basin, many relict species have been preserved here, including several dozen endemics. Some recently recorded species are also believed to be completely new to science, and they are currently being described. To date, 23 subterranean taxa have been described from 13 typical localities in the Dobra River basin (Bedek et al. 2006, 2009; Ozimec et al. 2009). Of these, three have been included on the IUCN Red List of Threatened Species, and more than 10 are listed in the Croatian Red Book of Cave Fauna (Ozimec et al. 2009). Below is an outline of a few of the most interesting, rare and threatened species of the subterranean habitats in the Dobra River catchment.

One of the world's best known cave organisms, the Olm (*Proteus anguinus* Laurenti, 1768) is a resident of the cave habitats around Ogulin. This is the only true European subterranean vertebrate, and is also an endemic species of the Dinaric karst. It is listed as Vulnerable (VU) on the IUCN Red List, while it is listed as Endangered (EN) on the national Red List. The subterranean habitats of the Dobra River are also home to the Ogulin cave planarian (*Dendrocoelum subterraneum* Komárek, 1919), a Critically Endangered (CR) stenoendemic species that has only been recorded in the Đula Sink-Medvedica cave system. The Ogulin cave sponge (*Eunapius subterraneus* Sket & Velikonja, 1984) is the only obligatory subterranean freshwater sponge in the world, which certainly makes it unique. This species has been the subject of many research projects and educational activities in recent years (Bilandžija et al. 2007; Bedek et al. 2008), and it has been proclaimed a conservation 'umbrella' species. Thanks to these efforts, the Ogulin region has also benefited. New genetic research has even suggested that this species should be separated from the genus *Eunapias* and described as a completely new, endemic genus (Harcet et al. 2010). According to the IUCN criteria, within the national framework, the species has received Endangered (EN) status, as a stenoendemic taxon inhabiting the waters of the upper course of the Dobra River. Other Endangered (EN) species in the national categorisation include Jalžić's eyeless shrimp (*Niphargus jalzici* G. Karaman, 1989), which is a stenoendemic of Croatia. In the Upper Dobra area, we find Babich's cave prawn (*Troglocaris anophthalmus intermedia* Babić, 1922), a species endemic to Slovenia and Croatia (Jugovic et al. 2012). At the global level, this has been categorised as Near Threatened (NT), while in Croatia it has been assessed as Endangered (EN). Croatian eyeless shrimp [*Niphargus croaticus* (Jurinac, 1887)] is a Dinaric endemic and has been assessed as Vulnerable (VU) at the national level. There is also the well known Cave tube-worm (*Marifugia cavatica* Absolon & Hrabe, 1930), which is a Dinaric endemic. It has been assessed as Data Deficient (DD) in both the national and global categorisations (Ozimec et al. 2009).

In addition to these aquatic cave organisms, the subterranean habitats of the Dobra River basin are also inhabited by the very interesting and diverse terrestrial cave fauna, particularly the beetles (Coleoptera). Tvrtković's runner (*Croatotrechus tvrtkovici* Casale & Jalžić, 1999) is a stenoendemic of Croatia that is assessed as Vulnerable (VU) in the Croatian Red Book of Cave Fauna, and its only known locality is a cave along the Dobra River near the town of Ogulin. The Narrow-necked cave beetle (*Leptodirus hochenwartii* Schmidt, 1832) has also been recorded near Ogulin (Raguž 2012) and is listed in Appendix II of the Habitats Directive and is a NATURA 2000 species. The Olm is a strictly protected species pursuant to the Nature Protection Act (OG 70/05, 139/08, 57/11).

As a consequence of the large number of speleological structures and the diversity of subterranean habitats, the Dobra River basin is also characterised by the high diversity of bat fauna (Pavlinić pers.comm.): Long-fingered bat (*Myotis capaccinii* Bonaparte, 1837), Greater mouse-eared bat [*M. myotis* (Borkhausen, 1797)], Geoffroy's bat [*M. emarginatus* (É. Geoffroy, 1806)], Schreiber's bent-winged bat [*Miniopterus schreibersii* (Kuhl, 1817)], Greater horseshoe bat [*Rhinolophus ferrumequinum* (Schreber, 1774)] and Mediterranean horseshoe bat (*R. euryale* Blasius, 1853). The Long-fingered bat and Schreiber's bent-winged bat are the two most threatened mammal species (Endangered–EN) in Croatia, and are strictly protected at the national level with all other bat species. Bats use the subterranean habitats of the Dobra River for their winter colonies, though more significantly these are important habitats for the nursery colonies of females with young. The Dragina Pećina cave in the Lower Dobra canyon is one of the largest nursery colonies of Long-fingered bats in Croatia. In addition to subterranean habitats, these species also use the above-ground habitats, feeding on insects on and above the surface of the crystal-clear karst water.

3.2 Limnofauna

In addition to the numerous subterranean organisms, the Dobra catchment is also very interesting and important for many above-ground aquatic organisms. Despite the lack of older data, many studies have been conducted in recent years on aquatic invertebrates and vertebrates, and a very rich and diverse fauna has been recognized.

Among the macroscopic aquatic invertebrates, a total of 19 taxa have been recorded, in the following groups (Pušić 2013):

Classes–Bivalvia, Gastropoda, Hydrozoa, Turbellaria,
Subclasses–Copepoda, Hirudinea, Oligocheta,

Orders

- Hydrachnidia (Class Arachnida)
- Amphipoda, Cladocera, Isopoda, Decapoda (Class Malacostraca)
- Collembola (Class Entognatha)

The cave fauna also includes Coleoptera, Diptera, Ephemeroptera, Heteroptera, Odonata, Plecoptera, Trichoptera (Class Insecta).

Recent research (Sokač 2013) of the freshwater snails of the Dobra River has resulted in records of 11 snail species from six families, including the Endangered (EN) bivalve Thick-shelled river mussel (*Unio crassus* Philipsson 1788), which is included on Appendix II of the Habitats Directive.

Throughout the Dobra catchment, some 40 species of Odonata have been recorded, representing more than 50% of all species present in Croatia (Španić et al. 2011). Along the entire course of the Dobra River, there are 81 species of Trichoptera, including 17 new species and four genera new to the Croatian fauna

(Cerjanec 2012). During research on the spring of the Dobra River, the caddisfly [*Drusus chrysotus* (Rambur, 1842)] that inhabits all of Central Europe was found for the first time. However, this find represents the first record of this species in the Dinaric and Balkan region, and the most south-eastern record to date. In addition, the Montane caddisfly [*Drusus discolor* (Rambur, 1842)] has also been recorded in the Dobra River, for the first time in the Croatian fauna (Previšić et al. 2012).

Among the crustaceans, certainly the most interesting is the threatened, stenoendemic amphipod *Echinogammarus cari* (Karaman, 1931), with a distribution limited to only 15 km of the course of the Upper Dobra and two of its tributaries (Žganec and Gottstein 2009; Žganec et al. 2013). Earlier data indicated the presence of the Stone crayfish [*Austropotamobius torrentium* (Schrank, 1803)], while in recent years, the Slender-clawed crayfish (*Astacus leptodactylus* Eschscholtz, 1823) has been reported, spreading through the watercourses of the Sava basin towards the south and west (Magiure and Gottstein-Matočec 2004; Maguire 2010).

4 Fish Fauna

The River Dobra is a tributary of the Kupa River and has a long history of fish research. The ichthyofauna of the Upper and Lower Dobra should be analysed as two different rivers, as migrations of fish between those two rivers is no longer possible. In addition to the spatial distribution, the data on the fish of the Dobra River can also be examined with regard to three different historical periods (Table 1):

- Historical period–prior to 1959 and the construction of the first hydropower plant, Gojak HPP,
- Middle period–from 1959 to 2010, under the construction of the second hydropower plant Lešće HPP,
- Recent period–after 2010, following construction of the plant.

4.1 Upper Dobra

The first surveys of the fish fauna date back to the late 1800s, with surveys conducted by the famous ichthyologists Steindachner (1866), then Brusina (1892), Hirc (1900), Medić (1901) and Langhoffer (1904, 1908). These researchers recorded the abundance of the Brook trout *Salmo trutta* Linnaeus, 1758, and also recorded Bullhead (*Cottus gobio* Linnaeus, 1758), Stone loach [*Barbatula barbatula* (Linnaeus, 1758)], Chub [*Squalius cephalus* (Linnaeus, 1758)], Spirlin [*Alburnoides bipunctatus* (Bloch, 1782)] and Italian minnow (*Phoxinus lumaireul* Schinz, 1840). Most historical data mention the endemic Croatian dace *Telestes polylepis* Steindachner, 1866 (Trgovčević 1905), which today is limited to a very small area and has been assessed to be a critically endangered species. A species often

Table 1 Historical overview of studies of the fish fauna of the Dobra River

Species	Historical data	After first dam 1959	After second dam 2010	Remarks
Upper Dobra River				
1. *Hucho hucho*	X	–	–	Extinct
2. *Salmo trutta*	X	X	X	
3. *Oncorhynchus mykiss*	X	X	X	Introduced
4. *Thymallus thymallus*	X	X	X	
5. *Barbatula barbatula*	X	X	X	
6. *Barbus balcanicus*	X			HD
7. *Alburnoides bipunctatus*	X	X	X	
8. *Phoxinus lumaireul*	X	X	X	
9. *Squalius cephalus*	X	X	X	
10. *Telestes polylepis*	X	–	–	Extinct
11. *Cottus gobio*	X	X	X	HD, SP
Lower Dobra River				
1. *Eudontomyzon vladykovi*	–	–	X	HD, SP
2. *Acipenser ruthenus*	X	–	–	Extinct
3. *Hucho hucho*	X	X	–	Extinct
4. *Oncorhynchus mykiss*	X	X	X	Introduced
5. *Salmo trutta*	X	X	X	
6. *Thymallus thymallus*	X	X	X	
7. *Esox lucius*	–	X	X	
8. *Barbatula barbatula*	–	X	X	
9. *Cobitis elongata*	–	–	X	HD, SP
10. *Cobitis elongatoides*	–	X	X	HD
11. *Sabanejewia balcanica*	–	–	X	HD, SP
12. *Alburnoides bipunctatus*	–	X	X	
13. *Alburnus alburnus*	X	X	X	
14. *Alburnus sava*	–	–	X	
15. *Barbus balcanicus*	X	X	X	HD
16. *Barbus barbus*	X	X	X	
17. *Carassius gibelio*	–	–	X	Introduced
18. *Chondrostoma nasus*	X	X	X	
19. *Cyprinus carpio*	–	–	X	
20. *Gobio obtusirostris*	–	X	X	
21. *Leuciscus aspius*	X	X	X	
22. *Phoxinus lumaireul*	X	X	X	
23. *Rhodeus amarus*	–	X	X	HD
24. *Rutilus rutilus*	–	X	X	
25. *Rutilus virgo*	X	X	X	HD

(continued)

Table 1 (continued)

Species	Historical data	After first dam 1959	After second dam 2010	Remarks
26. *Squalius cephalus*	X	X	X	
27. *Tinca tinca*	–	–	X	
28. *Vimba vimba*	–	–	X	
29. *Lepomis gibbosus*	–	–	X	Introduced
30. *Lota lota*	X	X	X	
31. *Cottus gobio*	X	X	X	HD, SP
32. *Gymnocephalus cernua*	–	–	X	
33. *Gymnocephalus schraetser*	–	X	–	HD, SP
34. *Sander lucioperca*	X	X	X	
35. *Silurus glanis*	–	–	X	

HD Habitats Directive, *SP* Strictly protected species

mentioned in the historical data is the Danube salmon or Huchen [*Hucho hucho* (Linnaeus, 1758)], which is no longer found in the Upper Dobra today (Hirc 1902). A historical species still present today in the Upper Dobra is the Grayling [*Thymallus thymallus* (Linnaeus, 1758)], though it cannot be certain whether this species is indigenous to the Dobra River, as there are data on stocking by sports fishermen (Bergleitner 1940; Taler 1944; Plančić 1952). In the early twentieth century, Rainbow trout (*Oncorhynchus mykiss* Walbaum, 1792) was introduced, and is regularly stocked in the Upper Dobra today (Mršić 1935).

With the construction of the Gojak hydropower plant in 1959, the water regime was altered and water in the upper reaches of the water were redirected. Data on ichthyofauna from the period between the constructions of the two hydropower plants (1959–2010) are scarce and primarily refer to the previously recorded species: Brook trout, Rainbow trout, Grayling, Chub, Schneider and Common minnow. In this period, the Danube salmon was no longer mentioned as present in the upper reaches of the river, while the endemic Croatian dace is mentioned only with reference to historical data and without any new research or finds (Sabioncello 1962, 1967; Pažur 1968; Sabioncello et al. 1970; Pažur et al. 1982; Mateš 2004, 2008).

In 2010, the new Lešće HPP was put into operation. The plant has had no impacts on the ichthyofauna of the Upper Dobra, since it is situated in the course of the Lower Dobra.

On the basis of the fish community and the physico-chemical properties, the Upper Dobra is marked by trout and grayling zone traits.

4.2 Lower Dobra

There are significantly more data on the ichthyofauna of the Lower Dobra, as a large number of surveys were conducted during the phases of preparation and construction of the hydropower plant. However, the ichthyofaunal data and research are unevenly distributed, both in time and space. It is known that the upper reaches of the Lower Dobra were very important as a spawning ground for Danube salmon and other salmonids, and was therefore prized as an excellent salmon fishing location.

In the period prior to 1959 (and the construction of the HPP Gojak), the literature data on the Lower Dobra list 16 species of fish (Table 1). In addition to the presence of Danube salmon, it is also very interesting to see the presence of other migratory fish species, such as Sterlet, Barbel, Nase and Danubian roach (Steindachner 1866; Brusina 1892; Hirc 1900; Medić 1901; Langhofer 1904, 1908; Car 1911; Mršić 1932; Thaller 1936; Taler 1945, 1953).

With the construction of Gojak HPP, which became operational in 1959, the natural regime of the Dobra River was already significantly disturbed, with constant oscillations in water levels. However, it is difficult to say how these changes influenced the structure of the fish community. Several surveys were constructed during the hydropower plant planning process. The final and most detailed survey on the Lower Dobra (Mrakovčić et al. 2010) was conducted prior to construction of the second plant, Lešće HPP. With regard to the literature data and the results of this survey, 27 fish species inhabit the Lower Dobra River (Sabioncello 1962, 1967; Pažur 1968; Sabioncello et al. 1970; Pažur et al. 1982; Mateš 2004, 2008). Certain species have been recorded for the first time in the Dobra River: Vladykov's lamprey (*Eudontomyzon vladykovi* Oliva & Zanandrea, 1959), Danubian loach (*Cobitis elongatoides* Băcescu & Mayer, 1969), Balkan loach (*Cobitis elongata* Heckel & Kner, 1858), Pike (*Esox lucius* Linnaeus, 1758), Danubian gudgeon (*Gobio obtusirostris* Valenciennes, 1842), Bitterling [*Rhodeus amarus* (Bloch, 1782)], Common roach *Rutilus rutilus* (Linnaeus, 1758)], Sava bleak (*Alburnus sava* Bogutskaya, Zupančič, Jelić, Diripasko & Naseka, 2017) and Schraetzer or Striped ruffe [*Gymnocephalus schraetser* (Linnaeus, 1758)].

The dam of the HPP Lešće created a new barrier on the river, forming a reservoir in the canyon section of the Lower Dobra. This led to a change in the character of the upper part of the Lower Dobra, which was also reflected in changes to the fish community (Mrakovčić et al. 2011). Though the number of fish species remained almost unchanged, due to fish stocking in the reservoir in the Lower Dobra, new species now inhabit the river: Common carp (*Cyprinus carpio* Linnaeus, 1758), Ruffe [*Gymnocephalus cernua* (Linnaeus, 1758)], Pikeperch or Zander [*Sander lucioperca* (Linnaeus, 1758)] and Wels catfish (*Silurus glanis* Linnaeus, 1758).

The Lower Dobra is fed by waters from underground, and also from two mountain streams that have a purely salmonid character. Therefore, the upper part of the Lower Dobra also has traits of the trout zone, though as the river runs downstream, it takes on traits of the grayling zone, and later the barbel zone. The final segment of the river is increasingly calmer and, near the confluence with the Kupa River, it has elements of the bream zone.

On the basis of all the historical and recent data, to date 36 species of fish from 15 families have been recorded in the Dobra River. However, this list includes three species that have since disappeared from the river: Sterlet, Danube salmon and Croatian dace. Pontian shemaya (Alburnus sarmaticus) is a very rare species that has been assessed as Endangered (EN) according to the IUCN categorisation. Nine species are listed on Appendix II of the EU Habitats Directive, while five species are strictly protected in Croatia pursuant to the Nature Protection Act (Table 1). Three alien species have been introduced into the river: Rainbow trout, Prussian carp and Pumpkinseed while several species are translocated upstream (Common carp, Ruffe, Pikeperch and Wels catfish). There are data that show Grayling was also introduced to the Dobra by stocking in the early twentieth century. Some species have been translocated upstream from the lowland sections of the river into the trout zone following the construction of barriers, habitat alteration, and changes to the physico-chemical properties of the water.

During recent surveys during the power plant planning process, in addition to the changes in the composition of the fish community, an alteration of the share of individual species within the community was also observed (Fig. 3), with Italian minnow, Chub, Bullhead, Southern barbel and Balkan loach becoming the most common species. The least common species are Rainbow trout, Grayling and Vimba.

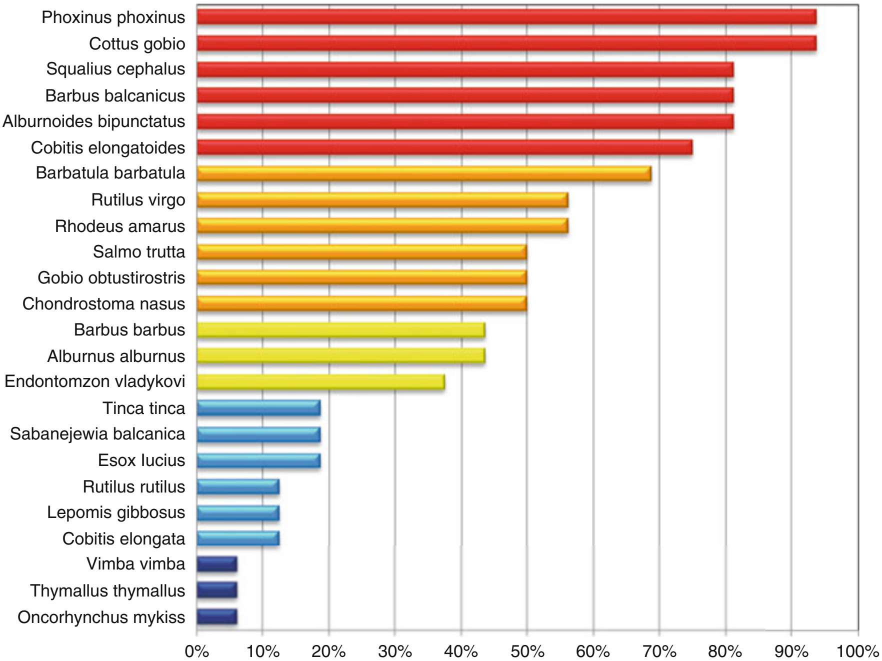

Fig. 3 Frequency of fish species in the total sample of the 2010 study on the Lower Dobra River (red: constantly present, yellow: occasionally present, blue: sporadically present)

5 Human Impacts

Karst rivers represent true wealth in the biological and ecological sense. The Dobra River is one such karst phenomenon; however, it has not been preserved in its original form.

In the Upper Dobra, no significant anthropogenic impacts have been recorded, and most of the river has retained its natural appearance. Smaller hydro-regulation works have been performed in certain sections, such as works to protect and stabilise the river banks in the construction zone of buildings. Until 1957, the Upper Dobra naturally sank at the Đula Sink near Ogulin. In that year, the overspill dam was constructed, creating the Bukovnik reservoir (volume 450,000 m^3). With this, the river was redirected into the system that would be used to produce electrical energy at the Gojak hydropower plant. Furthermore, several kilometres to the south, a second karst river, Zagorska Mrežnica, was also dammed, to form the Sabljaci reservoir (volume 3,300,000 m^3). This lake is 5 km in length and covers an area of 170 ha. The water from this lake also feeds the HPP Gojak via underground tunnels and pipes (Bonacci and Andrić 2010). Since the construction of the dam, water sinks in the natural drainage system, i.e. the Đula Sink-Medvedica Cave System only receives water during the rainy season or during exceptionally heavy rain events (Kuhta and Novosel 2001). On the other hand, the average flow of the Lower Dobra has doubled downstream of the Gojak HPP, due to increased inputs from the Zagorska Mrežnica River.

During 2005, new works to dam the river began, this time on the Lower Dobra. Construction was completed in 2010 and the Lešće HPP became operational. This is the second of the five hydropower plants planned for the Dobra River in the 1980s. The dam is 52.5 m high, and the reservoir created has a volume of 25.7 million m^3, which submerged the steep, canyon section of the Lower Dobra over a length of 12.6 km. Considering that this is a karst region, the formation of the reservoir also meant the submergence of a multitude of karst structures that simply ceased to exist as such, and the habitats of species that use subterranean areas as permanent or temporary habitats were lost forever (Hunkeler 2007).

The damming of the river significantly affected the structure of the ichthyofauna and species composition. The first species believed to have disappeared from the Dobra River, and from other tributaries to the Sava River, was the Sterlet. In the past, the Sterlet and other sturgeon species were common species in the lower sections and mouths of the Sava tributaries, but are now absent. It is believed that these vulnerable and threatened species disappeared from the Danube basin primarily due to the barriers constructed on the Danube. The construction of a dam and other hydrotechnical works on the Dobra River also particularly impacted two threatened fish species. Following the construction of the first dam (Gojak HPP), the Danube salmon population disappeared from the Upper Dobra. In the Lower Dobra, its population remained stable until it began to decline rapidly in the 1980s, due most likely to increasing water temperatures upstream of the dam. Prior to the construction of the Lešće HPP in 2010, Danube salmon n could still be sporadically found in the river, probably surviving by retreating into the colder tributaries. There was also a drastic drop in the population of the Critically Endangered (CR), stenoendemic fish species Croatian dace (*Telestes polylepis* Steindachner, 1866). Today, the Croatian dace is believed to no longer be present in the Dobra River.

With the construction of the second dam and Lešće HPP on the Lower Dobra, longitudinal migration was disabled, the ecological conditions altered, and the spawning areas for the Danube salmon were lost. As a result of these alterations, this species has not completely disappeared from the Dobra. It is also known to have two other stable populations in Croatia, in the Kupa and Una Rivers, indicating that after the dam construction, a third of the Danube salmon population was permanently lost in Croatia (Ćaleta et al. 2015).

In addition to the direct impacts on individual vulnerable and rare fish species, the composition of the fish community of the Dobra River has also been altered. Due to the anthropogenic impacts, the water regime and flow rate have changed, there has been a loss of rapids, and the formation of reservoirs, in which sediments from the upper reaches of the river are deposited. As a result of the changing conditions, and also of fish stocking and human neglect, opportunistic cyprinid species have been introduced and spread through the waters. The main sites of spread are the newly formed reservoirs, which enabled the survival of species such as Carp, Roach, Ruffe and Perch. Furthermore, in the past the Dobra River has been stocked by alien, invasive species, such as Rainbow trout [*Oncorhynchus mykiss* (Walbaum, 1792)], Pumpkinseed [*Lepomis gibbosus* (Linnaeus, 1758)] and Prussian carp [*Carassius gibelio* (Bloch, 1782)]. Following the most recent dam construction, a significant increase was recorded in the numbers and biomass of the invasive *Lepomis gibosus*.

Fish are not the only organisms to be significantly impacted by the damming of the Dobra River for the Lešće HPP. Invertebrates from the group Amphipoda have also been significantly affected by the changes in the hydrological regime of the flow. Prior to the damming, the Dobra was inhabited by two crustaceans: *Gammarus fossarum* Koch, 1836 on the rocky substrate and the endemic *Echinogammarus cari* (S. Karaman, 1931) among the mosses. After construction, downstream sections experienced changes in water quality and fluvial particles retained in the moss, and the habitats for *E. cari* began to decline, and its populations were drastically reduced. This species has since lost 52–58% of its known distribution range, while the abundance of *G. fossarum* has increased. As a consequence of the inability to adapt to the new conditions, it is questionable whether this population can recover downstream of the dam. In that case, there is a great likelihood that the threat status for *E. cari* will have to be downgraded from Endangered (EN) to Critically Endangered (CR) (Žganec et al. 2013).

Since the Đula Sink is part of the largest cave system in Croatia (Đula–Medvedica), it is necessary to address all the forms of anthropogenic pollution to the Dobra River and the underground sections of its course. The disposal of natural organic material, such as logs, branches, boards and wood shavings, into the river is very common. Furthermore, irresponsible persons consider the Đula Sink to be a disposal site for bulky waste, and at the entrance to the cave, it is possible to find discarded vehicles, stoves, wheels and tyres, various plastic materials, and animal bones. Due to the lack of an adequate sewage system, the water of the Dobra and cave system is also polluted with municipal waste waters from septic tanks. In this way, the Dobra River and its underground waters receive various detergents, oils, petroleum, and microflora typical of sewage waters.

In order to address the groundwater pollution issue, a modern waste water treatment plant was constructed in 2012 for the town of Ogulin. However, due to the poor economic situation of most households, which have primarily remained dependent on their septic tanks instead of connecting to the sewer system, the treatment plant is still not working as planned. The result is absurd: the construction of a waste water treatment plant has not contributed to improving the quality of water in the river and ground water (Rimac and Wertag 2012).

In addition to the treatment plant, the local community is also planning to construct a retention dam. The catastrophic floods of 1999 launched a series of activities to develop a feasibility study to determine how to secure the existing system to protect the town of Ogulin from high floodwaters, and to propose technical solutions that would enable this to be put into practice. The water regime of the Dobra River is marked by torrential flows, with sudden and large variations in flow. This is the main reasons for the flooding of the town, as the current natural (Đula–Medvedica cave system) and artificial (Bukovnik reservoir for HPP Gojak) drainage systems are unable to 'swallow' the incoming waters, and the result is the town is affected by flooding every 2–5 years. The expert analysis has indicated that the most suitable location for the construction of a retention dam is in the valley of the Upper Dobra, upstream of the village Turkovići, and downstream of the confluence of the Vitunjčica and the Dobra. The construction of the planned retention dam would have a positive impact in the sense of reducing the inflow of driftwood into the Đula Sink. About 10 years ago, certain technical measures were taken to prevent the inflow of driftwood from upstream into the Đula Sink system. This included the installation of a floating dam to retain driftwood upstream of the bridge at the 'Devil's pass'. Unfortunately, this dam is currently not operational, as it was damaged and sunk. This structure had a positive effect of reducing pollution into the ground waters, and also in improving the permeability of the Đula Sink, and should be reinstalled (Bedek et al. 2009) (Fig. 4).

Due to the anthropogenic impacts, in 2001/2002, the Ogulin underground was proclaimed one of the top ten endangered karst phenomena by the Karst Waters Institute, USA (Bonacci and Andrić 2010).

There are numerous causes of threat to the subterranean waters and fauna of the Dobra River. Among the most important problems are the large hydrological works and resulting changes to the water flow (construction of the Gojak and Lešće hydropower plants), the disposal of waste and release of sewage into the ground, uncontrolled use of pesticides and artificial fertilizers on agricultural land, physical threats to the Ogulin cave, and the many roads and nearby highway, with the possible spillage of hazardous chemicals following vehicle accidents.

Fig. 4 Bulky waste at the entrance to Đulin sinkhole (photo by Dalibor and Mirjana Vučić) (Vučić and Vučić 2012)

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Anthropogenic Impact and Environmental Quality of Different Tributaries of the River VRBAS (Bosnia and Herzegovina)

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1 Introduction

Vrbas watershed is one of the most important in Bosnia and Herzegovina, because of the water volume and its biodiversity. Recent increase in human population density has caused disturbance of environmental conditions over the entire watershed. Its intensity varies in different tributaries, as well as different sections of the River Vrbas.

One of the most negative anthropogenic impacts is pollution. Different types of pollution sources, point and non-point, make changes to the water environment. Industrial fasilities, toxin dumping, sewage, urban and agricultural runoff disturb environmental quality and make changes to biodiveristy.

The water quality of the Vrbas watershed has been studied by physico-chemical, microbiological, macro-zoobenthic and ichthyological analyses.

Standard physical and chemical analyses reflect the current situation, while biotic parameters provide better evaluation of environmental changes and an overall view of its state. Bioindicators can tell us about the cumulative effects of different pollutants in the ecosystem and how long a problem may have been present, which physical and chemical testing cannot do.

Another reliable and important indicator of the state of the environment is eco-physiological characteristics, primarily fish hematological parameters which indicate both the state of the fish organism and the state of the environment.

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1.1 General Characteristics of the Vrbas Watershed

Vrbas River is a right tributary of the Sava River, one of the main tributaries of the River Danube. It originates on the slopes of Vranica Mountain at an altitude of 1530 m and flows into the Sava River near the town of Srbac, at an altitude of 90 m. The total flow length is 235 km (Fig. 1). The average river bed slope is 6 m/km, making it very suitable for hydro-energy production.

The total watershed area of the Vrbas River is 6386 km^2, where 63% belongs to Republic of Srpska, and 37% to the Federation of Bosnia and Herzegovina.

1.2 Topography

The watershed has an elongated shape with a length of 150 km and width of 70 km. The average altitude is around 690 m, and the highest point lies at an altitude of 2100 m.

In the East, this watershed borders with that of the Ukrina River, in the south with the Neretva River watershed, and in the west with the Sana River.

The hydrographic net is very well developed in the upper and lower part of the watershed. The most important tributaries are: Pliva, Ugar, Crna Rijeka and Vrbanja, situated in the upper part. There are many karst springs in the upper and middle part

Fig. 1 River Vrbas (Photo R. Dekić)

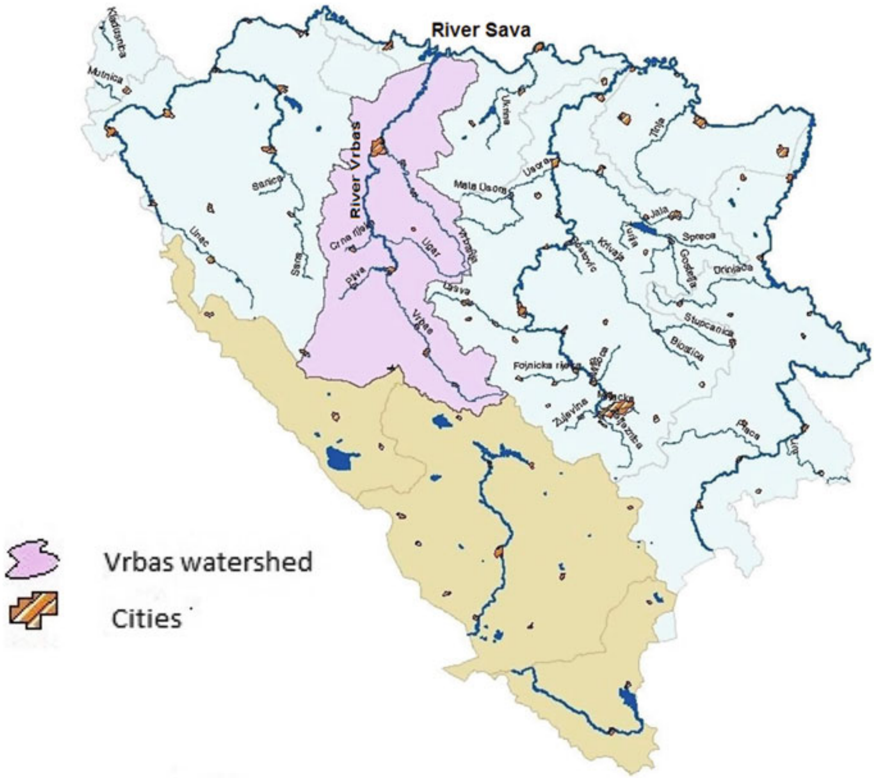

Fig. 2 Vrbas watershed in Bosnia and Herzegovina (Vrbas characterization report 2004)

of the watershed suitable for the supply of drinking water, the most important being the springs of the Pliva and Janj Rivers (Fig. 2).

In the underlying geological structure, Mesozoic, Paleozoic and Tertiary carbonate rocks predominate. Magmatic rock and Paleozoic carbonates are less widespread. Quaternary sediments have a more restricted distribution.

1.3 Climate

The Vrbas watershed opens to the Pannonian basin in the north and has a relatively high altitude within its own basin. The impact of the Adriatic Sea and parameters of general atmospheric circulation above Europe are less expressed. All these parameters cause temperate continental climate in the lower regions, while the mountain regions are characterized by subalpine and alpine climate.

1.4 Air Temperatures

The average air temperatures, besides morphological characteristics of the ground, are mostly dependent on the altitude and range from 10.8 °C to 9.4 °C in the area characterized by temperate continental climate, and from 9.0 °C to 6.0 °C in areas with sub-mountain and mountain climate.

1.5 Precipitations

The territory of the Vrbas watershed is situated on the border zone between maritime and continental pluviometric regimes. The largest part of the watershed shows maximum precipitation during autumn and winter, this being characteristic of a maritime pluviometric regime. In the coldest part of the year (from October to April), about 56% of the total annual precipitation occurs, while the lowest precipitation occurs in July and August.

The average annual rainfall is around 800 l/m^2 at the *mouth* of the *Vrbas to* the *Sava* River, varying *to* 1500 l/m^2 *in* the southern part of the basin.

2 Hydrology

2.1 Basic Hydrological Characteristics

The River Vrbas is a right tributary of the River Sava. The basin has an elongated shape except in the south-west part where the rivers Janj and Pliva drain.

The relief is mostly mountainous and hilly up to Banja Luka, except valleys along the Rivers Vrbas, Pliva and Vrbanja. The part of the watershed downstream of Banja Luka is lowland. The hydrographic net is differently developed, depending on the geological terrain and hydrogeological function of the rocks.

Almost all human activities make changes to the environment, affecting all living beings. Most of them are reversible. However, some are ireversible for the near future. These environmental changes can be recognized in biodiversity, the population and areal structure of specific species, relations between certain species, shortening of life cycle of some species, and other biological parameters.

One of the worst sorts of negative anthropogenic impact in the Vrbas watershed is pollution. Different kinds of pollution sources, point or non-point, make changes to the water environment. Industrial facilities, toxin dumping, sewage, urban and agricultural runoff disturb environmental quality.

Physico-chemical analyses are very important for determination of water quality, but these are incomplete without microbiological characteristics and other biological indicators. Biological components represent valuable indicators of environmental conditions and provide more satisfactory information about its state. River inhabitants are very sensitive to changes in any of the environmental characteristics.

Composition of the fish community represents one of the ways to characterize and estimate ecological status of a river, since the compositon of different communities is conditioned by long-term stable conditions, as well as by short-term biological modifications.

Another reliable indicator of the state of the environment is the ecophysiological characteristics of the fish organism, primarily hematological parameters indicating the state of the organism and indirectly the state of the environment (Wilson and Taylor 1993; Ivanc et al. 2005). Also, these parameters are valuable in comparative studies of different species in the same habitat, or populations of the same species in different habitats (Ivanc et al. 1994).

In this way, hematological parameters of fish represent reliable indicators of their environment (Dekić et al. 2009), and they have been used in the present study of the Vrbas watershed quality.

The studies were mostly based on characteristics of four rivers from the Vrbas watershed: Suturlija, Jakotina, Dragočaj and Crna Rijeka, as shown in the following paragraphs.

3 River Suturlija

The River Suturlija is situated in the area south-west from Banja Luka, and the mouth into the River Vrbas, as its left tributary, is situated in the settlement of Srpske Toplice (Gornji Šeher), at an altitude of 159 m (Fig. 3).

Based on Article 9 of the Law on Protection and Usage of Cultural, Historical and Natural Heritage (Official Gazette of RS, Band H, 20/1985), Suturlija watercourse, for its determined values, represents a part of conserved nature, being assumed to have a property of a natural resource, and being under official protection.

The source of the River Suturlija is situated in the village of Goleš, between parts of Pervan settlement (44°44′38” N/17°09′10″ E) in the west and Goleš in the north, at an altitude of 390 m, while the base of the sector is represented by Dedića točak, a hill rising to an altitude of 466 m.

The entire area of the River Suturlija flows though mainly karst, implying various relief shapes, such as cracks, sink-holes and small surfaces. The entire river course does not flow in the same direction. The upper and lower course flow in a west-east direction, while the middle course, being the shortest, flows from south to north.

The characteristic of this watercourse is that it never dries up, but its water flow rate varies from winter to summer months, when it is very low, to autumn and spring, when the river becomes torrential The most important tributaries of the River Suturlija are: Rijeka, Golešica, Grabešinac, Dragojević stream and Grubajić stream.

All analyses of the river Suturlija have been performed in the selected sectors (44°44′38” N/17°09′10″ E), at an altitude of 163 m.

Fig. 3 Suturlija and the moguht in to Vrbas (Photo R. Dekić)

3.1 Hydrographic Characteristics

The River Suturlija watershed has an area of 67.53 km^2, while the average water flow rate is 1.48 m^3/s (Water-economy base of the Vrbas watershed 1987). The area of a direct watershed of the River Suturlija has an area of 7.9 km^2 (Hydro-Morphological analyses of the rivers Vrbas and Vrbanja 2005).

At the river source, the water flow rate has been measured at 14 l per second (0.014 m^3/s). The length of this river is 18.35 km.

The analysis conducted of physico-chemical parameters of the River Suturlija (Table 1) during different months showed that most of the parameters analyzed indicate first class water, according to Water Classification regulation (Official Gazette of RS 42/2001).

Based on the values of dissolved oxygen concentration and oxygen saturation rate, and also on nitrate concentration, the second class was registered in several months. The values of total suspended substances in some months indicate third class water.

It is important to emphasize that the lower part of the river, shortly upstream of the mouth of the Suturlija, is under high anthropogenic influence, especially municipal wastewater, affecting the water quality to a significant degree. However, the part

Table 1 Physico-chemical characteristics of the River Suturlija—monthly values

Parameters	Month											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Water temp. (°C)	4	5	8.5	10.5	12	13.5	16	24	14	9	10	6
DO—mg O_2/l	11.4	12.87	10.81	10.10	9.64	9.48	7.91	6.64	8.56	10.30	10.39	10.49
O_2 sat. rate (%)	86.82	100.63	92.39	90.66	88.27	89.77	79.89	77.57	81.99	89.41	92.36	84.52
pH value	7.68	8.0	8.1	8.20	8.31	8.32	8.41	7.86	8.39	7.59	7.49	7.66
Ammonia nitrogen (mg/l)	–	–	–	–	–	–	–	–	–	–	–	–
Nitrite nitrogen (mg/l)	0.002	0.002	–	0.003	0.001	0.005	0.003	0.001	0.001	0.004	0.001	0.001
Nitrate nitrogen (mg/l)	0.6	0.9	2.4	1.3	1.2	1.5	0.9	0.4	0.4	1.5	0.6	0.5
COD—mg $KMnO_4$/l	3.0	3.2	3.1	5.6	4.7	8.3	4.9	4.8	3.1	6.6	7.2	7.8
Chloride—mg Cl/l	9	7	10	14	10	14	10	10	10	11	10	8
“p” alkalinity—mg 0.1 N HCl/l	0.1	0.4	0.5	0.1	0.1	0.1	–	–	0.3	1	3	2
“m” alkalinity—mg 0.1 N HCl/l	40	68	70	42	42	41	–	43	25	40	186	192
Bicarbonates mg HCO_3^-/l	220.5	228.4	212.5	259.4	256.2	237.9	237.9	–	170.8	168	240	232
Carbon. hardness—mg 0.1 N HCl/l	12.2	13.1	13.2	11.46	11.76	12.32	9.52	14.0	12.88	11.56	14	13
Total hardness (°d)	11.85	12.4	13.24	12.54	12.68	13.12	10.62	12.48	9.30	11.2	13	12
Total hardness as $CaCO_3$	212.115	221.96	236.99	224.46	226.97	234.84	190.09	223.39	166.47	200.48	232.7	214.8
Orthophosphates (mg/l)	<0.15	<0.15	<0.15	<0.15	<0.010	<0.010	<0.15	<0.15	<0.15	<0.15	<0.15	<0.15
Total suspended substances (mg/l)	6.1	5.8	4.8	4.6	5.4	4.9	5.9	2.3	5.1	5.7	4.3	4.0
Total solids (mg/l)	211	256	270	220	253	231	141	249	140	200	184	175
Electrical conductivity (μS/cm^{-1})	418	424	364.8	336.8	300.1	355.6	279.8	390.2	293.8	394	434	410
Detergents (μg/l)	<0.1	<0.1	<0.1	<0.1	<0.1	<100	<100	<100	<100	<0.1	<0.1	<0.1
Phenols (μg/l)	<0.001	<0.001	<0.001	<0.001	<0.001	<1	<1	<1	<1	<0.001	<0.001	<0.001
Sulfates—mg SO_4/l	14.2	14.8	17.4	–	–	–	11.5	–	18.8	15.1	11.5	12.6
Iron (mg/l)	0.051	0.032	0.018	–	–	–	0.049	–	0.027	0.04	0.060	0.061

(continued)

Table 1 (continued)

Parameters	Month											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Manganese (mg/l)	0.008	0.008	0.006	–	–	–	0.014	–	0.008	0.013	0.020	0.015
Calcium (mg/l)	81.54	78.25	68.75	–	–	–	65.43	–	71.76	78.54	84	78.23
Magnesium (mg/l)	9.42	8.88	5.12	–	–	–	6.76	–	7.74	7.82	8	6.3

Table 2 Microbiological characteristics of the River Suturlija in different periods

Type of analysis	May	July	September
Fecal coliform bacteria in 100 cm^3	Isolated	Isolated	Isolated
Total aerobic mesophilic bacteria count in 1 cm^3 at 37 °C	Numerous	Numerous	Numerous
Fecal *Strepotococcus* in 100 cm^3	Isolated	Isolated	Isolated
Proteus species in 100 cm^3	Not isolated	Not isolated	Not isolated
Total sulfide-reducing anaerobic bacteria count in 1 cm^3	12	10	14
Pseudomonas aeruginosa in 100 cm^3	Not isolated	Not isolated	Not isolated

where construction of sports and recreational terrain is planned is less affected by waste water.

According to most of the physico-chemical and microbiological parameters analyzed (Table 2), water from the River Suturlija belongs to the first class, except some smaller parts of the analyzed river near its mouth into river Vrbas belonging to the second class (electrical conductivity, and some analysis conducted in an earlier period).

4 River Jakotina

The source of the River Jakotina is situated in Kneževo municipality, while the biggest part of the watercourse and the mouth into river Vrbanja as its left tributary are situated in the Kotor Varoš municipality (Fig. 4). The source is at the altitude of 670 m, and the mouth at 260 m. It is a permanent watercourse with a length of 15 km and an altitude range of 410 m.

4.1 Hydrographic Characteristics

The River Jakotina watershed has an area of 57 km^2, and the average water flow rate is 0.99 m^3/s. The watershed of the River Jakotina has certain smaller tributaries and springs such as Trešnjevac, Štakanov spring and Sokoljanac, and numerous temporary streams as well.

Most of the analyzed physico-chemical parameters of the River Jakotina show that this water belongs to the first class. Only the values of nitrates and total suspended substances in certain months showed second class water (Table 3).

Also, it is important to emphasize that water from the River Jakotina is of better quality than water from the River Suturlija, according to the analyses conducted. More analysed parameters of the River Suturlija have showed second class water

Fig. 4 River Jakotina (Photo R. Dekić)

(nitrates, dissolved oxygen and electro-conductivity in certain months), while the values of total suspended substances in certain months have showed that this water belongs to third class. Water microbiological characteristics of River Jakotina are presented in Table 4.

The values of most of the parameters analysed indicate first class water, except values of nitrates and total suspended substances that, in some months, belonged to second class. It can be concluded that water from the River Jakotina is of a better quality than that from the River Suturlija.

Considering all analyzed physico-chemical parameters of water from the Rivers Suturlija and Jakotina, it can be concluded that their quality is between I and II quality class, according to the Regulation on Classification and Category of Water and Water courses (Official Gazette of RS 42/2001). However, altogether the River Jakotina has water of a better quality than that of the River Suturlija.

5 River CRNA Rijeka

The River Crna Rijeka is a very significant watercourse in the area of Mrkonjić Grad. The length of this river is 17 km and it flows into the River Vrbas at a locality called Bočac (Tijesno), as its left tributary. The flow direction is south-north. It is important

Table 3 Physico-chemical characteristics of the River Jakotina—monthly values

Parameters	Month											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Water temp. (°C)	4	5	8		11	12	16	22	14	11	8	6
DO—mg O_2/l	13.21	13.70	14.85	10.64	10.98	10.64	9.16	8.15	10.10	10.25	12.82	12.60
O_2 sat. rate (%)	98.43	107.61	125.52	94.57	98.38	97.43	92.52	91.77	96.74	93.27	108.55	101.53
pH value	8.18	8.02	8	8.23	7.81	8.31	7.55	8.26	8.38	8.13	8.22	8.24
Ammonia nitrogen (mg/l)	–	–	–	–	–	–	–	–	–	–	–	–
Nitrite nitrogen (mg/l)	0	0.001	–	0	0.003	0.002	0.003	0.004	0.001	0.001	0.001	0.001
Nitrate nitrogen (mg/l)	0.9	1.0	1.2	1	0.9	1.0	0.5	0.5	0.5	1.0	0.7	0.4
COD—mg $KMnO_4$/l	2.5	2.8	4.3	6.1	8.0	5.7	6.2	8.07	8.8	6.1	3.2	3.0
Chloride—mgCl/l	6	7	8	12	8	14	10	14	10	18	6	5
"p" alkalinity—mg 0.1 N HCl/l	0.2	0.3	0.1	0	0	0.1	0	0.3	0.3	0.3	0	0.1
"m" alkalinity—mg 0.1 N HCl/l	42	60	32	32	34	34	–	26	25	25	34	36
Bicarbonates mg HCO_3^-/l	198.5	231.8	201.3	151	207.4	195.2	–	176	170.8	170.8	186	178.4
Carbon. hardness—mg 0.1 N HCl/l	10.52	14.32	10.58	11.76	9.52	10.08	13.32	8.7	12.88	10.08	10.1	9.9
Total hardness (°d)	10.05	12.12	10.22	9.54	10.88	10.38	12.16	9.1	11.76	10	9.38	9.05
Total hardness as $CaCO_3$	180	180.79	182.94	170.76	194.75	185.80	225.54	162.89	210.50	179	168	162
Orthophosphates (mg/l)	<0.010	<0.010	<0.15	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.15	<0.010	<0.010
Total suspended substances (mg/l)	3.4	3.8	3.6	4.6	4.9	4.7	4.1	4.3	5.0	4.9	4.2	4.0
Total solids (mg/l)	176	190	180	200	217	185	162	216	220	220	184	182
Electrical conductivity (μS/cm^{-1})	358	320.6	280.2	313	243.0	285.3	362.9	335	331.5	339.3	350.2	346
Detergents (μg/l)	<0.1	<0.1	<0.1	<0.1	<100	<0.1	<100	<100	<100	<0.1	<100	<100
Phenols (μg/l)	<0.001	<0.001	<0.001	<0.001	<1	<0.001	<1	<1	<1	<0.001	<0.001	<0.001
Sulfates—mg SO_4/l	2.3	2.8	4.3	5.8	–	–	11.5	–	5.8	5.9	3.2	2.9

(continued)

Table 3 (continued)

Parameters	Month											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Iron (mg/l)	0.03	0.02	0.020	0.025	–	–	0.051	–	0.025	0.030	0.02	0.02
Manganese (mg/l)	0.002	0.001	0.004	0.007	–	–	0.013	–	0.009	0.006	0.004	0.002
Calcium (mg/l)	64.5	66.65	70.10	63.6	–	–	68.5	–	58.72	62.54	64.23	66.20
Magnesium (mg/l)	3.1	3.4	5.6	2.9	–	–	11.6	–	4.84	4.21	3.7	3.2

Table 4 Microbiological characteristics of the River Jakotina in two periods

Type of analysis	May	July
Fecal coliform bacteria in 100 cm^3	Isolated	Isolated
Total aerobic mesophilic bacteria count in 1 cm^3 at 37 °C	Numerous	Numerous
Fecal *Strepotococcus* in 100 cm^3	Isolated	Isolated
Proteus species in 100 cm^3	Not isolated	Not isolated
Total sulfide-reducing anaerobic bacteria count in 1 cm^3		10
Pseudomonas aeruginosa in 100 cm^3	Not isolated	Not isolated

Fig. 5 River Crna Rijeka (Photo R. Dekić)

to emphasize that the River Crna Rijeka has a large gravitational fall, with quite large oscillations of the water flow rate. This river is situated at an altitude of 565 m, descending to 260 m (Fig. 5).

The river used to be famous for fish species diversity and beautiful waterfalls. Today, its banks are densely populated and, as a result, it has become an open collector of city wastewaters, making it the most polluted water body in the area.

A sampling site Staro Selo has been selected at an altitude of 379 m (44°25.392′ N/17°07.416′ E). The other site has been Bjelajci (44°51.426′ N/17°19.557′ E).

The water from River Crna Rijeka is slightly alkaline and at the Bjelajci locality corresponds to second water quality class (Official Gazette 42/01). Extremely high values of electrical conductivity are significant, corresponding to third quality class. The recorded concentrations of manganese and copper correspond to second quality class, while the recorded higher concentration of iron corresponds to third water

Table 5 Physico-chemical characteristics of the River Crna Rijeka at two sites

	Site	
Parameter	Staro Selo	Bjelajci
Water temperature (°C)	13.1	13.1
Dissolved oxygen—mg O_2/l	8.29	10.36
Oxygen saturation rate (%)	81.7	100.6
COD—mg $KMnO_4$/l	7.18	2.03
pH value	8.16	8.56
Electrical conductivity (μS/cm^{-1})	799	768
Turbidity—NTU	6.59	6.52
Ammonia nitrogen (mg/l)	0.28	0.03
Nitrate nitrogen (mg/l)	0.4	0.1
Nitrite nitrogen (mg/l)	0.168	0.009
Sulfates (mg/l)	150	149
Orthophosphates (mg/l)	1.66	0.83
Suspended substances (mg/l)	17	2
Manganese (mg/l)	0.084	0.036
Iron (mg/l)	0.33	0.36
Copper (mg/l)	0.014	0.007

quality class (Table 5). Also, it has been recorded a significantly high concentration of dissolved sulfates.

At the Staro Selo site, situated just below the settlement, it should be taken into account that wastewater drains into the river, and there are stables and fertilizers along its course. Notably, concentrations of dissolved ammonia, nitrates and orthophosphates are significantly higher regarding this locality, and because of the recorded nitrite concentration of 0.168 mg/l, it could be concluded that the water corresponds to IV quality class. At this locality, high values of chemical oxygen demand have also been recorded (7.18 mg/l), corresponding to IV class.

Since psychrophilic bacteria count has been higher than mesophilic count, and facultative oligotrophs, that present normal bacterial flora of water ecosystems, are abundant comparing to total heterotrophic bacteria, it can be concluded that relation between bacterioplankton is normal and that the water has satisfactory ability to self-purify (Table 6).

A number of coliform bacteria and fecal coliforms have been isolated. However, the number of potentially pathogenic bacteria and total and fecal coliforms and aerobic mesophilic bacteria that multiply at the Staro Selo locality are a consequence of expressed anthropogenic impact. At this locality, there have also been isolated potentially pathogenic *Proteus* species, *Pseudomonas aeruginosa*, and increased amount of fecal *Strepotococcus* and *Enterococcus* too have been recorded.

Such microbiological insight shows that water from the River Crna Rijeka is in a permanent contact with fecal substances, containing bacteria that are indicators of older fecal contamination, and those found only in presence of fresh fecal

Table 6 Microbiological characteristics of the River Crna Rijeka at two sites

Type of analysis	Site	
	Staro Selo	Bjelajci
Total bacteria count (col/ml)	5400	3000
Aerobic heterotrophic psychrophilic bacteria (col/ml)	6100	2333
Facultative oligotrophic bacteria (col/ml)	9600	3875
Aerobic mesophilic bacteria (col/ml)	5100	570
Total coliform bacteria count (col/100 ml)	4500	300
Fecal coliform bacteria (col/ml)	1900	100
Proteus species	Isolated	Not isolated
Salmonella and *Shigella* (col/ml)	Not isolated	Not isolated
Sulfite-reducing *Clostridium* in 100 ml	Not isolated	Not isolated
Pseudomonas aeruginosa	Isolated	Isolated
Fecal *Strepotococcus* and *Enterococcus* (col/ml)	70	14

contamination. Downstream of the Bjelajci site, the water contains a significantly lower number of all analyzed bacterial groups indicating that, during sedimentation, different physico-chemical processes and expressed bacterial activity have been reflected in recorded values of COD. Therefore, the reason of this process has been a degradation of organic material contaminating water at the Staro Selo locality. And besides the presence of potentially pathogenic bacteria dangerous for human health, the water from River Crna Rijeka, based on microbiological parameters, corresponds to II quality class (Official Gazette RS, 42/01).

6 River Dragočaj

The source of River Dragočaj is situated on the hill Ruštevac, while its mouth into the River Vrbas is at Zalužani settlement. Its middle and lower course, where the altitude of the terrain is not over 170 m, has a lowland character (Fig. 6). It winds a lot, making numerous meanders.

The length of the River Dragočaj is 21 km and it has four tributaries: Živaja, from the right, and Taraševac, Bukovac and Ivaštanka, from the left.

The water level of the River Dragočaj is uneven over the year. In the summer period, the average depth is 0.50 m, and in the period of heavy precipitation the river rises and overflows its banks, flooding the surrounding terrain.

Based on the values of electrical conductivity, the water from the River Dragočaj corresponds to second quality class according to valid regulation (Official Gazette of RS 42/01), while other parameters have not showed a significant deviation (Table 7).

Microbiological analyses (Table 8) showed that water from the River Dragočaj corresponds to third quality class (Kohl 1975).

Fig. 6 River Dragočaj (Photo R. Dekić)

Table 7 Physico-chemical characteristics of the River Dragočaj

Parameter	September
Water temperature (°C)	20
Dissolved oxygen—mg O_2/l	8.04
Oxygen saturation rate (%)	90.50
pH value	7.85
Electrical conductivity (μS/cm^{-1})	490
Turbidity—NTU	3.91

Table 8 Microbiological characteristics of the River Dragočaj and its categorization by Kohl (1975)

Total bacteria count in 1 ml	River Dragočaj
Aerobic heterotrophs	50,120
Category by kohl	III class
Facultative oligotrophs	107,408
Mesophilic heterotrophs	37,775
Psychrophilic heterotrophs	13,500
Index M/P	2798
Coliform bacteria	1822
Fecal coliform bacteria	430

The relation between mesophilic and psychrophilic heterotrophs presents an indicator of anthropogenic impact on water quality and the process of eutrophication. As has been seen, M/P index is high in the River Dragočaj, meaning this river suffers significant anthropogenic impact. Based on the fecal coliform count, the River Dragočaj is one of the most highly contaminated watercourses.

7 Biodiversity

7.1 Zoobenthos

The samples for macrozoobenthos analyses have been taken with a Surber net (frame dimensions 34 cm x 32 cm, mesh size 1260 μm) and fixed in 4% formalin solution. After that, taxonomic determination of all organisms present has been carried out. Saprobic index and water classes have been determined by the Pantle-Buck saprobic system (1955), and its modification that introduces transitional categories (modified by Lange-Bertalot 1994) have also been calculated (Table 9).

The analysis of macrozoobenthos was performed in two of the four rivers analyzed, the River Suturlija and River Jakotina. The results are presented in Tables 10 and 11.

The analysis of macro-zoobenthos organisms in the River Suturlija has shown that individuals from the phyla Platyhelminthes, Mollusca, Annelida and Arthropoda are present (Table 10).

From the phylum Platyhelminthes, one family Dugesiidae (subclasses Turbellaria) with two species is present. Phylum Mollusca is represented by the class Gastropoda and two families of Lymnaeidae (with three species) and Hydrobiidae (one species). The presence of phylum Annelida is recorded within two classes Oligochaeta (three families were present—Lumbriculidae, Lumbricidae and Tubificidae) and Hirundinea (families Erpobdellidae and Glossiphoniidae).

Phylum Arthropoda is represented by two subphyla—Crustacea and Hexapoda. From subphylum Crustacea the class Malacostraca is represented by the orders Amphipoda (family Gammaridae) and Isopoda (family Asellidae). Subphylum Hexapoda is represented by just one class, but the most numerous classes in the analyzed locality is the class Insecta. This class is represented by 15 families in six

Table 9 Water classes distinguished on the basis of the Pantle and Buck saprobic index modified by Lange-Bertalot (1994)

Saprobic index—s	Pollution	Water class
1.0 to <1.5	Unpolluted or slightly polluted	I
1.5 to <1.8	Slightly polluted	I–II
1.8 to <2.3	Moderate polluted	II (beta-mesosaprobic)
2.3 to <2.7	Critically polluted	II–III (alpha-mesosaprobic)
2.7 to <3.2	Very polluted	III (alpha-mesosaprobic)
3.2 to <3.5	Heavy polluted	III–IV (alpha-meso-polysaprobic)
3.5 to <4.0	Extremely polluted	IV (polysaprobic)

Table 10 Macrozoobenthos and saprobic index (Pantle and Buck 1955) in the River Suturlija in different months

Jan–June													
	Species indicator	I		II		III		IV		V		VI	
Type	value (s)	h	s∗h	h	s∗h	h	s∗h	h	s∗h	h	s∗h	h	s∗h
TURBELLARIA													
Dugesiidae													
Dugesia gonocephala	1.2												
Dugesia sp.	1.9												
GASTROPODA													
Lymnaeidae													
Galba palustris	2.0											1	2.0
Lymnaea auricularia	2.3			1	2.3	1	2.3						
Lymnaea sp.	2.3							2	4.6				
Hydrobiidae													
Bithinya sp.	2							1	2.0	3	6.0	2	4.0
ANNELIDA													
OLIGOCHAETA													
Lumbriculidae													
Lumbriculus variegatus	3.1												
Lumbricidae													
Eiseniella tetraedra	2.1					2	4.2	1	2.1				
Tubificidae													
Stylodrilus heringianus	2.4												
Tubifex tubifex	3.6												
HIRUDINEA													

Erpobdellidae													
Erpobdella octoculata	2.9			1	2.9								
Glossiphoniidae													
Glossiphonia complanata	2.5												
CRUSTACEA													
Gammaridae													
Gammarus sp.	2.25	2	4.5	1	2.25			1	2.25				
Rivulogammarus sp.	1.8												
ISOPODA													
Asellidae													
Asellus aquaticus	2.8												
INSECTA													
EPHEMEROPTERA													
Ephemeridae													
Ephemera danica	1.6											7	11.2
Ephemera sp.	2												
Baetidae													
Baetis sp.	1.7	2	3.4										
Caenidae													
Caenis horaria	2.2												
Heptagenidae	2.0									1	2.0		
Ecdyonurus sp.	1.6					4	6.4						
Heptagenia sp.	1.8												
Leptophlebidae													
Habrophlebia sp.	1.5											7	10.5
Leptophlebia sp.	1.8												

(continued)

Table 10 (continued)

Jan–June													
		I		II		III		IV		V		VI	
Type	Species indicator value (s)	h	s*h	h	s*h	h	s*h	h	s*h	h	s*h	h	s*h
Paraleptophlebia sp.	1.6												
ODONATA													
Gomphidae													
Gomphus vulgatissimus	2												
COLEOPTERA	1.0												
Haliplidae	1												
PLECOPTERA	1									1	1.0		
Perlodidae													
Isoperla rivulorum	1												
TRICHOPTERA	1.0												
Glossosomatidae													
Glossosoma sp.	1	1	1.0					2	2.0				
Hydropsychidae	2.0									1	2.0		
Hydropsyche sp.	2.5	2	5.0	3	7.5	1	2.5	2	5.0				
Polycetropodidae													
Plectrocnemia conspersa	1.5												
Polycentropidae	2												
Leptoceridae													
Athripsodes sp.	1.8												
DIPTERA													
Dixidae													
Dixia sp.	1.7	2	3.4	3	5.1							1	1.7

Chironomidae													
Chironomus sp.	3.3					3	9.9						
Simulidae													
Simulium sp.	2.0												
Total		9	17.3	9	20.05	9	20.5	9	17.95	6	11	18	29.4
Saprobic index		1.92		2.23		2.28		1.99		1.83		1.63	
Saprobic class		II		II		II		II		II		II	
Saprobic level		β-mesosaprobic		β-mesosaprobic		β-mesosaprobic		β-mesosaprobic		β-mesosaprobic		β-mesosaprobic	
July–December													
	Species indicator	VII		VIII		IX		X		XI		XII	
Type	value (s)	h	s*h	h	s*h	h	s*h	h	s*h	h	s*h	h	s*h
TURBELLARIA													
Dugesiidae													
Dugesia gonocephala	1.2			1	1.2	1	1.2						
Dugesia sp.	1.9												
GASTROPODA													
Lymnaeidae													
Galba palustris	2.0					2	4.0						
Lymnaea auricularia	2.3												
Lymnaea sp.	2.3												
Hydrobiidae													
Bithinya sp.	2	7	14	2	4.0	3	6.0	1	2.0				
ANNELIDA													
OLIGOCHAETA													
Lumbriculidae													

(continued)

Table 10 (continued)

July–December													
Type	Species indicator value (s)	VII		VIII		IX		X		XI		XII	
		h	s*h	h	s*h	h	s*h	h	s*h	h	s*h	h	s*h
Lumbriculus variegatus	3.1			1	3.1	1	3.1						
Lumbricidae													
Eiseniella tetraedra	2.1					2	4.2	1	2.1				
Tubificidae													
Stylodrilus heringianus	2.4									1	2.4		
Tubifex tubifex	3.6											1	3.6
HIRUDINEA													
Erpobdellidae													
Erpobdella octoculata	2.9												
Glossiphoniidae													
Glossiphonia complanata	2.5									1	2.5		
CRUSTACEA													
Gammaridae													
Gammarus sp.	2.25											1	2.25
Rivulogammarus sp.	1.8	5	9.0	1	1.8	4	7.2	2	3.6				
ISOPODA													
Asellidae													
Asellus aquaticus	2.8	2	5.6	1	2.8								
INSECTA													

EPHEMEROPTERA													
Ephemeridae													
Ephemera danica	1.6												
Ephemera sp.	2												
Baetidae													
Baetis sp.	1.7												
Caenidae													
Caenis horaria	2.2									1	2.2		
Heptagenidae	2.0												
Ecdyonurus sp.	1.6					1	1.6	1	1.6				
Heptagenia sp.	1.8									1	1.8		
Leptophlebidae													
Habrophlebia sp.	1.5												
Leptophlebia sp.	1.8									1	1.8		
Paraleptophlebia sp.	1.6									1	1.6		
ODONATA													
Gomphidae													
Gomphus vulgatissimus	2									1	2.0		
COLEOPTERA	1.0			2	2.0							1	1.0
Haliplidae	1			1	1.0	2	2.0						
PLECOPTERA	1					1	1.0					1	1.0
Perlodidae													
Isoperla rivulorum	1												
TRICHOPTERA	1.0	2	2.0									5	5.0
Glossosomatidae													
Glossosoma sp.	1							1	1.0				
Hydropsychidae	2.0												

(continued)

Table 10 (continued)

July–December													
	Species indicator	VII		VIII		IX		X		XI		XII	
Type	value (s)	h	s*h	h	s*h	h	s*h	h	s*h	h	s*h	h	s*h
Hydropsyche sp.	2.5												
Polycetropodidae													
Plectrocnemia conspersa	1.5									1	1.5		
Polycentropidae	2												
Leptoceridae													
Athripsodes sp.	1.8					2	3.6						
DIPTERA													
Dixidae													
Dixia sp.	1.7												
Chironomidae													
Chironomus sp.	3.3	7	23.1	12	39.6	4	13.2			1	3.3		
Simulidae													
Simulium sp.	2.0											13	26.0
Total		23	53.7	21	55.5	23	47.1	6	10.3	9	19.1	22	38.85
Saprobic index		2.33		2.64		2.05		1.72		2.12		1.76	
Saprobic class		II		III		II		II		II		II	
Saprobic level		β-mesosaprobic		α-mesosaprobic		β-mesosaprobic		β-mesosaprobic		β-mesosaprobic		β-mesosaprobic	

Table 11 Macrozoobenthos and saprobic index (Pantle and Buck 1955) of the River Jakotina in different month

January–June: First Part

Type	Species indicator value (s)	I		II		III		IV		V		VI	
		h	s*h	h	s*h	h	s*h	h	s*h	h	s*h	h	s*h
TURBELLARIA													
Dugesiidae													
Dugesia gonocephala	1.2									2	2.4		
Dugesia tigrina	2.2			3	6.6	3	6.6						
Dugesia sp.	1.9							1	1.9				
GASTROPODA													
Hydrobiidae	1.5												
ANNELIDA													
OLIGOCHAETA													
Lumbriculidae													
Lumbriculus variegatus	3.1												
Lumbricidae													
Eiseniella tetraedra	2.1												
HIRUDINEA													
CRUSTACEA													
Gammaridae													
Gammarus sp.	2.25												
ARACHNIDA													
ARANEA	1.0												
INSECTA													
COLEMBOLLA													
Poduriidae													

(continued)

Table 11 (continued)

January–June: First Part													
	Species indicator	I		II		III		IV		V		VI	
Type	value (s)	h	s∗h	h	s∗h	h	s∗h	h	s∗h	h	s∗h	h	s∗h
Podura aquatica	0.1												
EPHEMEROPTERA	1											4	4.0
Ephemeridae													
Ephemera danica	1.6												
Ephemera sp.	2							4	8				
Baetidae													
Baetis pumilus	1.6			3	4.8								
Beatis muticus	1.4												
Cloeon dipterum	2.1			3	6.3	3	6.3						
Heptagenidae	2.0									1	2.0		
Ecdyonurus torrentis	1.3			1	1.3								
Ecdyonurus venosus	1.5												
Ecdyonurus sp.	1.6							2	3.2	4	6.4		
Epeorus sylvicola	1.1	1	1.1	1	1.1	1	1.1						
Habroleptoides modesta	1.4			5	7								
Habrophlebia fusca	1.6												
Habrophlebia sp.	1.5												
Heptagenia flava	2	1	2										
Heptagenia sulphurea	1.9			3	5.7	3	5.7						
Heptagenia sp.	1.8												
Leptophlebidae													
Leptophlebia sp.	1.8							1	1.8				
ODONATA													

Gomphidae													
Gomphus vulgatissimus	2.0			1	2								
Gomphus sp.	2.0												
COLEOPTERA								1					
Elmidae													
Limnius wolckmari	1.5												
PLECOPTERA	1.0	3	3.0										
Taeniopterygidae													
Brachyptera braueri	1.5	3	4.5										
TRICHOPTERA													
Glossosomatidae													
Agapetus sp.	1.0												
Glossosoma boltoni	1.2												
Glossosoma sp.	1.0												
Hydropsychidae													
Hydropsyche fulvipes	2.0			1	2								
Hydropsyche sp.	2.5							1	2.5				
Hydropsyche instabilis	1.8									1	1.8	1	1.8
Hydropsyche angustipennis	2.5												
Philopotamidae													
Wormaldia subnigra	1.0											1	1.0
Polycetropodidae													
Plectrocnemia geniculata	1.5			5	7.5								

(continued)

Table 11 (continued)

Type	Species indicator value (s)	I		II		III		IV		V		VI	
		h	s*h	h	s*h	h	s*h	h	s*h	h	s*h	h	s*h
January–June: First Part													
Polycentropus flavomaculatus	1.7							4	6.8	7	11.9		
Holocentropus sp.	1.8			3	5.4								
Polycentropidae	2.0												
Limnephilidae	2.0												
Limnephilus bipunctatus	1.5											1	1.5
L. latipennis	1.5											2	3.0
Anabolia nervosa	2.1												
Odontoceridae													
Odontocerum albicorne	1.0												
Leptoceridae													
Athripsodes aterrimus	1.0												
Sericostomatidae													
Lepidostoma hirtum	1.6												
Sericostoma sp.	1.5												
HETEROPTERA													
January–June: Second Part													
Hydrometridae													
Hydrometra stagnorum	1.0											1	1.0
DIPTERA													
Dolichopodidae	1.0									1	1.0		

Dixidae	2.0												
Culicidae													
Chaborus pallidus	1.5			3	4.5								
Chironomidae													
Chironomus thumii	3.5			1	3.5					1	3.5	6	21
Chironomus sp.	3.3							1	3.3	2	6.6	2	6.6
Rheotanytarsus sp.	1.8												
Tanypus kraatzi	2.2	5	11										
Tanypus punctipennis	2.2			7	15.4								
Tanypus sp.	2.4											4	9.6
Paratrichocladius fluviatilis	2.0	3	6										
Tipulidae													
Pedicia sp.	1.0												
Tipula sp.	1.9							1	1.9				
Simulidae													
Simulium sp.	2									41	82	1	2
Blefariceridae													
Liponeura sp.	1												
Tabanidae												1	
Total		16	27.6	40	73.1	10	19.7	16	29.4	60	117.6	24	51.5
Saprobic index		1.73		1.83		1.97		1.84		1.96		2.15	
Saprobic class		II		II		II		II		II		II	
Saprobic level		β-mesosaprobic		β-mesosaprobic		β-mesosaprobic		β-mesosaprobic		β-mesosaprobic		β-mesosaprobic	

(continued)

Table 11 (continued)

July–December: First Part													
	Species indicator value (s)	VII		VIII		IX		X		XI		XII	
Type		h	s∗h	h	s∗h	h	s∗h	h	s∗h	h	s∗h	h	s∗h
TURBELLARIA													
Dugesiidae													
Dugesia gonocephala	1.2					1	1.2	1	1.2	2	2.4		
Dugesia tigrina	2.2												
Dugesia sp.	1.9												
GASTROPODA													
Hydrobiidae	1.5			1	1.5								
ANNELIDA													
OLIGOCHAETA													
Lumbriculidae													
Lumbriculus variegatus	3.1			1	3.1								
Lumbricidae													
Eiseniella tetraedra	2.1					1	2.1						
HIRUDINEA													
CRUSTACEA													
Gammaridae													
Gammarus sp.	2.25												
ARACHNIDA													
ARANEA	1.0	1	1.0										
INSECTA													
COLEMBOLLA													

Poduriidae													
Podura aquatica	0.1					1	0.1						
EPHEMEROPTERA	1					9	9						
Ephemeridae													
Ephemera danica	1.6									1	1.6	2	3.2
Ephemera sp.	2											2	4
Baetidae													
Baetis pumilus	1.6												
Beatis muticus	1.4	6	8.4			1	1.4						
Cloeon dipterum	2.1												
Heptagenidae	2.0												
Ecdyonurus torrentis	1.3												
Ecdyonurus venosus	1.5					1	1.5			3	4.5		
Ecdyonurus sp.	1.6			3	4.8	11	17.6	2	3.2				
Epeorus sylvicola	1.1												
Habroleptoides modesta	1.4												
Habrophlebia fusca	1.6					2	3.2						
Habrophlebia sp.	1.5							1	1.5				
Heptagenia flava	2												
Heptagenia sulphurea	1.9												
Heptagenia sp.	1.8					1	1.8	2	3.6			3	5.4
Leptophlebidae													
Leptophlebia sp.	1.8												
July–December: Second Part													
ODONATA													
Gomphidae													

(continued)

Table 11 (continued)

July–December: First Part													
Type	Species indicator value (s)	VII		VIII		IX		X		XI		XII	
		h	s*h	h	s*h	h	s*h	h	s*h	h	s*h	h	s*h
Gomphus vulgatissimus	2.0												
Gomphus sp.	2.0					1	2.0						
COLEOPTERA													
Elmidae													
Limnius wolckmari	1.5	2	3.0										
PLECOPTERA	1.0			3	3.0					2	2.0	2	2.0
Taeniopterygidae													
Brachyptera braueri	1.5												
TRICHOPTERA													
Glossosomatidae													
Agapetus sp.	1.0	1	1.0										
Glossosoma boltoni	1.2					1	1.2						
Glossosoma sp.	1.0					1	1.0	1	1.0				
Hydropsychidae													
Hydropsyche fulvipes	2.0												
Hydropsyche sp.	2.5							2	5.0	2	5.0		
Hydropsyche instabilis	1.8												
Hydropsyche angustipennis	2.5					1	2.5			1	2.5		
Philopotamidae													

Wormaldia subnigra	1.0												
Polycetropodidae													
Plectrocnemia geniculata	1.5												
Polycentropus flavomaculatus	1.7			1	1.7	2	3.4						
Holocentropus sp.	1.8												
Polycentropidae	2.0												
Limnephilidae	2.0												
Limnephilus bipunctatus	1.5												
L. latipennis	1.5			1	1.5								
Anabolia nervosa	2.1			1	2.1	1	2.1						
Odontoceridae													
Odontocerum albicorne	1.0					1	1.0						
Leptoceridae													
Athripsodes aterrimus	1.0					2	2.0						
Sericostomatidae													
Lepidostoma hirtum	1.6					1	1.6						
Sericostoma sp.	1.5			3	4.5								
HETEROPTERA													
Hydrometridae													
Hydrometra stagnorum	1.0												
DIPTERA													
Dolichopodidae	1.0												
Dixidae	2.0					1	2.0						

(continued)

Table 11 (continued)

July–December: First Part

Type	Species indicator value (s)	VII		VIII		IX		X		XI		XII	
		h	s∗h	h	s∗h	h	s∗h	h	s∗h	h	s∗h	h	s∗h
Culicidae													
Chaborus pallidus	1.5												
Chironomidae													
Chironomus thumii	3.5												
Chironomus sp.	3.3	2	6.6	4	13.2	8	26.4						
Rheotanytarsus sp.	1.8	1	1.8	4	7.2	2	3.6	1	1.8				
Tanypus kraatzi	2.2												
Tanypus punctipennis	2.2												
Tanypus sp.	2.4												
Paratrichocladius fluviatilis	2.0												
Tipulidae													
Pedicia sp.	1.0					1	1.0						
Tipula sp.	1.9			1	1.9			1	1.9				
Simulidae													
Simulium sp.	2	1	2			3	6	2	4			3	6
Blefariceridae													
Liponeura sp.	1	1	1										
Tabanidae													
Total		15	24.8	23	44.5	54	93.7	13	23.2	11	18	12	20.6
Saprobic index		1.65		1.93		1.74		1.78		1.64		1.72	
Saprobic class		II		II		II		II		II		II	
Saprobic level		β-mesosaprobic		β-mesosaprobic		β-mesosaprobic		β-mesosaprobic		β-mesosaprobic		β-mesosaprobic	

orders: Ephemeroptera, Odonata, Coleoptera, Plecoptera, Trichoptera and Diptera (Table 9).

Macro-zoobenthos organisms from the River Jakotina have showed much more diversity than those from the River Suturlija (Table 11).

The subclass Turbellaria is represented by one family Dugesiidae and three species. The class Gastropoda is represented by just the one family Hydrobiidae. The class of Oligochaeta has been registered with two species, belonging to families Lumbriculidae and Lumbricidae.

Four classes from phylum Arthropoda are represented: Malacostraca, Arachnida, Entognatha and Insecta. Malacostraca is represented by one family, Gammaridae. The class Arachnida is represented by just one order Aranea, the class Entognatha by one subclasses Colembolla and one family Poduriidae, while the class Insecta is represented by 24 families, divided into seven orders: Ephemeroptera, Odonata, Coleoptera, Plecoptera, Trichoptera, Hemiptera (with suborder Heteroptera) and Diptera.

Based on the values of the saprobic index, it has been obvious that water from both analyzed rivers belonged to the β-mesosaprobic, more precisely II water quality class. Therefore, it needs to be emphasized that the average saprobic index values have been higher in the River Suturlija.

However, by observing seasonal and monthly aspects, the water has often been in a transitional category between two water quality classes. The system used by Lange-Bertalot (Rakowska 2004) enables more accurate and more efficient distinction between similar water bodies, representing different habitats. The need for including transitional categories is supported by the other biological indices (Attila 2004). Based on this classification, it is obvious that water from the River Suturlija often belongs to the oligo-β-mesosaprobic class.

8 Ichthyofauna

Composition of a fish population is very important for detecting changes in aquatic environments, especially in those affected by human activities. This has been the reason why the analyses of fish assemblage have been performed in the chosen tributaries.

At each tributary, fish sampling has been achieved by pulsed direct current electro-fishing (brand IG 600, 1.2 kW) at two sites of 100 m^2 each. After galvanonarcosis, the fish have been collected by a landing net.

For taxonomic determination of the fish that were caught, keys by Vuković and Ivanović (1971), Simonović (2001), Bănărescu and Bogutskaya (2003), Kottelat (2007) have been used. After determination, all fish has been returned to the water, except for those used for hematological study.

The state of fish communities has been evaluated by species diversity and species evenness as commonly used measures. For that purpose, Shannon-Wiener indices have been calculated for each river. Also, based on specific saprobic value of fish species, the saprobic index has been estimated for each tributary.

8.1 River Suturlija

Among 9 fish species, the family Cyprinidae has been the most dominant in the assemblage composition with 95.81%, followed by Cobitidae and Cottidae with 1.80% each and Balitoridae with 0.6%.

Based on the saprobic values of fish species inhabiting the River Suturlija, its Saprobic index has been 1.73 which corresponds to the β-mesosaprobic category (second water quality class). This has been indicated by the species: chub (*Squalius cephalus*), bleak (*Alburnus alburnus*), dace (*Leuciscis leuciscus*) and stone loach (*Nemachilus barbatulus*) (Table 12).

8.2 River Jakotina

The analysis of the fish community in the River Jakotina has showed that among 7 fish species, the most dominant in the assemblage has been the family Cyprinidae with 61.90%, followed by Cotidae with 24.60% and Salmonidae with 13.49%.

It is important to emphasize that chub individuals, on the basis of their number and biomass, have been numerous in the lower course, just before the mouth of River

Table 12 Proportion of present fish species in different rivers from Vrbas watershed

	River Suturlija	River Jakotina	River Crna Rrijeka	River Dragočaj
Species	Proportion of present fish species (%)			
Rhodeus amarus, Bloch 1783				6.75
Gobio gobio (Linnaeus 1758)	3.59		10.61	9.20
Barbus balcanicus Kotlik, Tsigenopulos Rab, Berrebi, 2002	12.57	23.81	16.67	1.23
Alburnoides bipunctatus Bloch 1782	25.15	9.52	11.36	25.15
Alburnus alburnus Linneaus 1758	11.38	11.11	15.15	9.20
Chondrostoma nasus (Linneaus 1758)				3.07
Leuciscus leuciscus Linneaus 1758			6.82	10.43
Phoxinus phoxinus, Linneaus 1758	7.19	8.73		3.68
Squalius cephalus, Linneaus 1758	35.93	8.73	39.39	31.29
Nemachilus barbatulus (Linnaeus 1758)	0.60			
Cobitis taenia, Linnaeus 1758	1.80			
Salmo trutta, Linnaeus 1758		13.49		
Cottus gobio, Linnaeus 1758	1.80	24.60		

Jakotina into the River Vrbanja. In the analyzed profile, no pollutants at all are found, because it is a part of the watercourse that is not directly affected by communal waste or any industrial pollution. Also, the physico-chemical and microbiological analysis of the water from the research area have showed that it belongs to the first class of water, based on the most of the parameters. A somewhat worse situation has been recorded upstream the river mouth, where the river settlement is situated, thus some of the parameters showed certain deviation.

The Saprobic index (Pantle and Buck 1955) for the River Jakotina has been 1.07, which shows that this water belongs to the oligosaprobic category (first quality class water). This has been indicated by the presence of the species brown trout (*Salmo trutta*), Bullhead (*Cotus gobio*) and Minnow (*Phoxinus phoxinus*) (Table 12).

8.3 River Crna Rijeka

During the ichthyological research of the River Crna Rijeka, five fish species from family Cyprinidae have been recorded—(gudgeon (*Gobio gobio*), Danube barbel *Barbus balcanicus*, spirlin (*Alburnoides bipunctatus*), *Alburnus alburnus*, *Leuciscus leuciscus* and *Squalius cephalus*. Of these, on the basis of to its numbers and biomass, the most abundant species has been chub.

The calculated saprobic index for the River Crna Rijeka has been 1.98 and it corresponds to β-mesosaprobic category (second water quality class). The abundant species have been *Squalius cephalus* and *Alburnus alburnus* indicating β-mesosaprobic waters, while *Gobio gobio* indcates β-α mesosaprobic habitat.

8.4 River Dragočaj

The analysis of the fish community in the River Dragočaj has shown the presence of 9 fish species from just one family (Cyprinidae)—bitterling (*Rhodeus amarus*), *Gobio gobio, Barbus balcanicus, Alburnoides bipunctatus, Alburnus alburnus,* nase (*Chondrostoma nasus*), *Leuciscus leuciscus, Phoxinus phoxinus* and *Squalius cephalus*.

In the River Dragočaj, a second quality class (β-mesosaprobic category) with a saprobic index of 1.85 has been recorded, where indicators of this category have been represented by *Squalius cephalus*, *Alburnus alburnus* and *Leuciscis leuciscus.* The indicators of transitional β-α category are *Gobio gobio* and *Rhodeus amarus,* while *Chondrostoma nasus* represents an indicator of oligo-β-saprobic conditions (Table 12).

The results presented in Table 13 show that species richness, evenness and diversity have been similar in four of the rivers analyzed. The Rivers Jakotina and Dragočajhad have the highest values of species diversity. On the other hand, the lowest value of this index has been recorded in the River Crna Rijeka.

Table 13 Species richness, species evenness, species diversity index and saprobic index in different rivers from Vrbas watershed

	River Suturlija	River Jakotina	River Crna rijeka	River Dragočaj
Species richness (S)	9	7	6	9
Species evenness (E)	0.78	0.95	0.90	0.84
Species diversity (H′)	1.71	1.85	1.62	1.85
Saprobic index	1.73	1.07	1.98	1.85

At the same time, the highest value of species evenness has been recorded in the River Jakotina and the lowest in the River Suturlija.

The recorded values indicate that these rivers have relatively even distribution of species and low level of biodiversity, with the highest diversity in the River Jakotina.

Such low species diversity can be correlated with the fact that some of the rivers analyzed are highly contaminated (River Dragočaj) or in a permanent contact with fecal substances (River Crna Rijeka) and, as such, they do not represent a good environment for fish life. Physico-chemical and microbiological analyses have showed that the River Jakotina has the best water quality and, at the same time, the highest species diversity.

Here one should mention that the research of Lyons et al. (1996) reported that environmental degradation in cold water habitats resulted in increased species richness within some fish families. Also, Mundahl and Simon (1999) used minnow richness in an evaluation of coldwater stream assessment.

8.5 *Water Quality and Hematological Parameters of Fish Inhabiting the Vrbas Watershed*

The simple measures of fish community composition, such as species richness and evenness, are seldom precise enough to reflect subtle differences in environmental conditions.

The individual-level effects of environmental degradation can be established by monitoring organisms for changes (biochemical, physiological, or behavioral), indicating a problem within their ecosystem.

For that reason, a reliable indicator of environmental state is ecophysiological fish characteristics, primarily hematological parameters that yield adequate information on the state of an organism, and also the state of its environment (Wilson and Taylor 1993; Ivanc et al. 2005). In that way, hematological parameters of fish represent reliable indicators of their environment (Dekić et al. 2009).

Also, these parameters are especially valuable in comparative studies of different species in the same habitat, or the same species in different habitats (Ivanc et al. 1994).

A hematological response to environmental conditions depends on time of exposure (a short time or chronic exposure), metabolic rate, age, sex, life cycle phase and species. All this should be comparable when fish hematology is used as an environmental indicator.

It is also important to be aware of seasonal and life cycle conditioned oscillations of physiological functions, not influenced by the water quality. Comparisons of hematological parameters of a fish species inhabiting different rivers in order to evaluate the state of their environments are correct, only if it has been done in same season and/or a life cycle stage.

Therefore, erythrocyte parameters of Danube or large-spot barbel from the Rivers Suturlija and Jakotina have been monitored, together with physico-chemical and hydrobiological characteristics of the water. Fish hematological characteristics have been monitored throughout the year, and blood samples have been taken at regular monthly intervals.

The following parameters have been analyzed: hemoglobin concentration (Hb), Packed Cell Volume (PCV), red blood cell count (RBC), Mean Corpuscular Volume (MCV), Mean Corpuscular Hemoglobin (MCH) and Mean Corpuscular Hemoglobin Concentration (MCHC). Descriptive statistics of monitored parameters are expressed by season in Table 14.

The comparison of mean values of hematological parameters of fishes from different rivers in the same season has showed the existence of differences, tested on significance at 0.05 level.

The fish from the River Suturlija have had higher values of erythrocyte count than those from the River Jakotina. This difference has been significant in winter and autumn.

The values of hemoglobin concentration and MCV have showed higher values in every season in fish inhabiting the River Jakotina.

PCV and MCH values have been higher in the River Jakotina in every season, while significant differences have been recorded in three of them (for PCV—winter, spring and summer; for MCH—spring, summer and autumn).

On the contrary to other parameters, the values of MCHC have had higher values in individuals from the River Suturlija in spring and summer.

These values have showed that fish living in the River Suturlija, under conditions of reduced oxygen concentration (Tables 1 and 3), for a long period, had changes in blood parameters where the efficiency of oxygen transport improves. These changes occur in two ways: by increasing number of circulating erythrocytes and/or increasing blood hemoglobin concentration.

The poor water quality of the River Suturlija has caused increased production of young, smaller erythrocytes (a lower MCV), where hemoglobin concentration has been impaired—a low MCH. The low hemoglobin concentration in individual erythrocytes has been compensated by increase of their number to sustain satisfactory oxygen transport.

The results of conducted analyses of physico-chemical water quality have showed that summer months had lower values of dissolved oxygen and oxygen saturation rate, and the water from the River Suturlija has been of a lower quality than the water from the River Jakotina.

Table 14 Hematological characteristics of *Barbus balcanicus* from the Rivers Suturlija and Jakotina in different seasons

Descriptive statistics	Season	Hematological parameters Hb g/l	PCV l/l	RBC $\times 10^{12}$/l	MCV fl	MCH pg	MCHC g/l ery.
River Suturlija							
Mean	Winter	68.70	0.387	1.250	310.28	55.07	178.69
Standard deviation		4.876	0.032	0.062	29.32	4.77	19.92
Minimum		59.26	0.320	1.150	251.95	43.29	141.19
Maximum		81.48	0.462	1.540	366.96	67.34	235.88
Coefficient of variation %		7.1	8.2	5.0	9.5	8.7	11.2
Mean	Spring	71.14	0.420	1.197	352.39	59.57	170.87
Standard deviation		9.47	0.057	0.076	51.24	7.60	22.57
Minimum		51.85	0.318	1.060	249.28	43.94	109.63
Maximum		88.89	0.588	1.380	470.19	73.46	214.82
Coefficient of variation %		13.3	13.5	6.4	14.5	12.8	13.2
Mean	Summer	74.22	0.445	1.315	340.69	57.14	168.51
Standard deviation		7.75	0.057	0.157	38.94	8.43	22.93
Minimum		55.56	0.340	1.060	244.03	38.05	128.82
Maximum		92.59	0.583	1.710	422.73	79.14	217.86
Coefficient of variation %		10.5	12.9	11.9	11.4	14.8	13.6
Mean	Autumn	70.73	0.403	1.314	309.49	54.16	177.78
Standard deviation		6.19	0.045	0.126	44.74	5.58	25.92
Minimum		55.56	0.333	1.160	226.77	38.58	118.20
Maximum		85.19	0.526	1.650	394.92	63.85	242.35
Coefficient of variation %		8.8	11.1	9.6	14.5	10.3	14.6
River Jakotina							
Mean	Winter	68.86	0.407	1.204	338.83	57.62	172.46
Standard deviation		7.32	0.050	0.108	40.03	7.93	32.03
Minimum		51.85	0.320	1.000	280.00	42.41	118.21
Maximum		81.48	0.510	1.400	460.78	71.35	243.03
Coefficient of variation %		10.6	12.3	9.0	11.8	13.8	18.6
Mean	Spring	72.78	0.450	1.168	390.05	63.14	162.61
Standard deviation		7.89	0.046	0.135	46.84	9.22	20.89
Minimum		44.44	0.327	1.000	225.26	35.08	111.10
Maximum		88.89	0.535	1.900	495.05	85.47	226.79
Coefficient of variation %		10.8	10.3	11.5	12.0	14.6	12.9
Mean	Summer	81.17	0.514	1.298	398.88	63.39	159.36
Standard deviation		5.47	0.051	0.149	41.24	8.44	17.81
Minimum		66.67	0.406	1.100	274.17	46.95	119.05
Maximum		96.29	0.629	1.600	495.69	85.21	209.71
Coefficient of variation %		6.7	9.9	11.5	10.3	13.3	11.2

(continued)

Table 14 (continued)

Descriptive statistics	Season	Hematological parameters Hb g/l	PCV l/l	RBC $\times 10^{12}$/l	MCV fl	MCH pg	MCHC g/l ery.
Mean	Autumn	73.23	0.401	1.214	330.71	60.81	185.69
Standard deviation		5.76	0.058	0.108	37.14	6.17	24.59
Minimum		62.96	0.307	0.880	251.79	50.51	144.95
Maximum		81.48	0.511	1.400	415.45	75.00	243.03
Coefficient of variation %		7.9	14.6	9.0	11.2	10.1	13.3

Hb hemoglobin concentration, *PCV* packed cell volume, *RBC* red blood cell count, *MCV* mean corpuscular volume, *MCH* mean corpuscular hemoglobin, *MCHC* mean corpuscular hemoglobin concentration

Higher values of MCHC recorded in individuals from the River Suturlija during spring and summer correspond to higher water temperature and spawning season, both characterized by increased energy expenditure and increased tissue oxygen demand.

The changes of similar type have been found out in research of hematological parameters of carp (Ivanc et al. 1993), grayling (Ivanc et al. 1994) and brown trout (Kekić et al. 1985), living under different environmental conditions.

The ecophysiological evaluation of the state of an environment has also been applied in studies of three rivers of Vrbas watershed: Jakotina, Dragočaj and Crna Rijeka where hematological parameters have been analyzed in chub (*Squalius cephalus*). They are expressed in Table 15.

The comparison of values of hematological parameters analyzed in fish inhabiting different rivers has showed the presence of significant differences indicating disturbed environmental conditions.

In chub, as in *Barbus balcanicus*, the MCHC value has been the highest in fish inhabiting water of lower quality (Table 15). Besides high MCHC chub from the river Dragočaj, there have also been low PCV and MCV values. The River Dragočaj is characterized by unfavorable microbiological conditions (Table 8). In such environments, fish obviously need more efficient blood oxygen transport.

Another type of hematological reaction has been determined in chub from Crna Rijeka, i.e. large erythrocytes (a high MCV) with low hemoglobin content per volume unit (low MCHC). This is an adaption mechanism in fish where hemoglobin synthesis occurs in mature erythrocytes (Speckner et al. 1989).

Both types of hematological reactions are indicators of a degraded environment and, at the same time, they are different, depending on the type of environmental health disturbance.

The River Crna Rijeka is characterized by frequent changes of its water quality, influenced by additional sporadic pollution.

Opposite to the situation found in the rivers Dragočaj and Crna Rijeka, in chub from the River Jakotina, all hematological parameters have been in a normal range and characteristic for undisturbed waters as reported by Mitrašinović et al.

Table 15 Hematological characteristics of *Sqalius cephalus* from the RIVERS Jakotina, Dragočaj and Crna Rijeka

	Hb g/l	PCV l/l	RBC $\times 10^{12}$/l	MCV fl	MCH pg	MCHC g/l ery.
River Jakotina						
Mean	75.02	0.423	1.464	289.59	51.39	182.93
Standard deviation	7.78	0.068	0.159	43.37	6.36	39.51
Minimum	59.25	0.215	1.210	153.57	38.98	118.50
Maximum	85.19	0.531	1.630	388.72	64.05	312.76
Coefficient of variation %	10.4	16.1	10.8	15.0	12.4	21.6
River Dragočaj						
Mean	78.70	0.393	1.484	265.37	53.67	205.34
Standard deviation	7.97	0.068	0.204	37.44	7.01	35.64
Minimum	59.26	0.250	1.220	191.93	35.84	151.61
Maximum	88.89	0.513	2.230	335.29	69.99	296.30
Coefficient of variation %	10.1	17.3	13.8	14.1	13.1	17.4
River Crna Rijeka						
Mean	82.67	0.474	1.525	314.71	54.92	176.15
Standard deviation	10.51	0.055	0.203	45.99	8.79	26.72
Minimum	59.26	0.333	1.200	229.89	40.44	133.33
Maximum	92.92	0.547	1.890	381.44	74.07	233.33
Coefficient of variation %	12.7	11.7	13.3	14.6	16.0	15.2

Many experimental studies on fish hematology status under different ambient conditions have confirmed an applicability of hematology in evaluation of fish environment.

Such studies are also invaluable in interpreting adaptation mechanisms achieved by changes in fish hematology and their importance for the fish organism to function in the given environment.

Ivanc et al. (1997) found out that in perch (*Perca fluviatilis*) kept in water with 30% oxygen saturation rate for 3 days, changes occurred in blood parameters improving oxygen transfer efficiency. They have been twofold: the increase in number of circulating erythrocytes and the increase in total hemoglobin concentration. The increase in MCH and MCHC values has not occurred under those conditions.

The authors found out that hematological status of this fish species has been a valuable indicator of both temporary and periodical deterioration of dissolved oxygen saturation and can be used as a reliable test for water quality evaluation. The hematological parameters analyzed have been tested for their sensitivity and reliability as indicators of water quality changes. The values of different parameters have been given for perch kept under optimal and unfavorable conditions of water oxygen saturation.

The same authors showed (Ivanc et al. 1994, 1995, 1997) that a chronic exposure to conditions of unfavorable oxygen regime of habitat caused an increase in MCH and MCHC values that had also been recorded in carp in similar ambient conditions.

At the same time, it can be noted that short-term exposure to unfavorable conditions has not caused an increase of MCH and MCHC, which occurs with longer exposure. Speckner et al. (1989) found out that hemoglobin synthesis may occur in mature erythrocytes of carp kept in water with a low dissolved oxygen concentration.

9 Conclusion

The results of the analyses that were conducted have shown that the tributaries of the River Vrbas analyzed are subject to different anthropogenic impacts. A higher level of environmental disturbance has been determined for the Rivers Suturlija, Crna Rijeka and Dragočaj, while no anthropogenic influence has been recorded in the River Jakotina. This situation is confirmed by the results of the physico-chemical, microbiological, hydrobiological and hematological analyses that were conducted. That is, the results show that water from the Rivers Suturlija, Dragočaj and Crna Rijeka are under anthropogenic pressure and are, according to valid regulative descriptors, classified into second and third water quality classes. At the same time it has been noted, based on microbiological analysis, that these rivers are in permanent contact with fecal material, since they contain bacteria that indicate older fecal contamination, as well as those found only in the presence of fresh fecal contamination. It is necessary to emphasize that these rivers have a major part of their watercourse flowing through settlements and, in most cases, household sewage and industrial wastewaters without previous treatment are discharged into them. Also, it should be borne in mind that after discharge of waste water into the recipient waters, a process of self-purification occurs. Under the influence of physical (dilution, sedimentation), physico-chemical (colloid coagulation), chemical (hydrolysis, oxide-reduction processes) and biological processes, water quality in such a contaminated water ecosystem improves after a certain period of time.

On the other hand, the River Jakotina suffers significantly lower anthropogenic impact along most of its watercourse, being confirmed by the results of the present analyses, and by macro-zoobenthos diversity. Also, the species of fish present in the water of this river represent indicators of unpolluted water, while in the three other rivers analyzed they have not been recorded. Besides the stated results, the hematological status of fish as reliable mean for detecting the state of an organism, and indirectly the state of the environment, gives clear insight into the higher pressure to which fish are exposed in the rivers subject to higher anthropogenic impact.

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Hidrološka-morfološka analiza rijeka Vrbas i Vrbanje (rijeke Vrbas na području grada Banja Luke, od granice sa opštinom Laktaši pa uzvodno do lokaliteta Tijesno na dužini od 26.00 km i Vrbanje na dužini od 3.00 km), Zavod za vodoprivredu d.o.o Bijeljina, Ministarstvo poljoprivrede, šumarstva i vodoprivrede, Republička direkcija za vode Bijeljina, Kancelarija riječnog sliva Vrbas Banja Luka, Bijeljina, 2005

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Assessment of Long-Term Changes in the Szigetköz Floodplain of the Danube River

Gábor Guti

1 Introduction

The 417 km-long Hungarian section of the Danube River lies in the upper part of the Middle Danube (river km 1433–1850). Its mean annual discharge is 2080 $m^3 s^{-1}$, and its natural bed formation has lowland features and is characterised by a progressively decreasing slope and finer load in the downstream direction. It can be divided into three main sectors, based on successional downstream geomorphic patterns (Tőry 1952; Pécsi 1959).

The upper part of the Hungarian section of the Danube (river km 1790–1850) is in the lower Alpine foothills zone. It is an aggrading and anabranching sector, formed on a large alluvial cone, with extensive floodplains. Its coarse load mainly originates from the Upper Danube. The main arm of the river has a relatively high slope (0.12–0.35%), the lateral wandering of the anabranches has been intensive, and the floodplains are partitioned by abandoned channels. The central part of the Hungarian section (river km 1586–1790) has a somewhat wandering, sinuous channel with irregular islands and narrow floodplains. Its slope is 0.05–0.10% and the river bed is composed of gravel. The lower stretch of the Danube in Hungary (river km 1433–1586) stretches over the Pannonian Plain, and it is characterised by a single, meandering channel with low flow velocities, slow lateral movement and extensive floodplains. Its slope is 0.05%; the main materials of the bed are sand and silt.

The Danube provides substantial economic benefits for society, but its ecological importance remains grossly neglected. The river and its associated floodplains, which support a considerable proportion of the fluvial biodiversity in the Hungarian Lowland ecoregion, suffer the impacts of a great number of human activities. From the nineteenth century onwards, the practices of modern river regulation have

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created a straightened and channelized riverbed, in order to avoid the formation of ice packs and to ensure a more suitable route for navigation. The construction of flood control dykes has reduced the devastating effects of floods and, as a result, more land has become available for agricultural activities and the development of settlements.

2 The Natural System of the Szigetköz Floodplain

2.1 Hydrology

In the Danube floodplain, below the Devin gate, along the upper part of the Kisalföld region (i.e. Little Danube Plain), water and sediments are the most important landscape-forming factors, playing an essential role in the creation of surface formations and the evolution of certain landscape ecological facies (Pécsi 1959; Göcsei 1979).

The driving forces of riverine ecosystems are the dynamics of the flow regime and the associated processes of the erosion, transportation and deposition of sediments. The essential characteristics of the flow regime in the natural system are: the seasonal variations of flows and the associated surface water levels at natural stages; the corresponding variations of groundwater levels with the associated processes of infiltration and exfiltration of river water; the occurrence of flood flows, filling branches to a varying extent and occasionally inundating the adjacent flood plain for days, weeks or even months.

The majority of the river's water discharge and the water regime are determined by precipitation and water originating from snow and glacier thawing in the 131,000 km^2 water catchment area of the northern part of the Alps and the Alpine foothills. The Danube water regime is basically stochastic in nature; however, generally from spring to the middle of summer, several consecutive flood pulses arrive. The melting of snow and glaciers in the Alps, and the simultaneous significant precipitation from the end of May and throughout June generally result in larger flood pulses. A period of low water usually develops by October, followed by a weak increase in discharge. From December, a new low water period begins, as the high mountain parts of the catchment area no longer provide water due to freezing. The fluctuation of the discharge and the associated sediment transport are the governing forces in the evolution of the riverbed. In the natural system, the main flow changed its course frequently during major flood events, producing a channel network at various elevations, with arbitrary distributions of flows at different stages. The seasonal variations of the flow at the Dunaremete gauge, as shown in Fig. 1, reflect the Alpine flow regime with flood flows in spring and early summer.

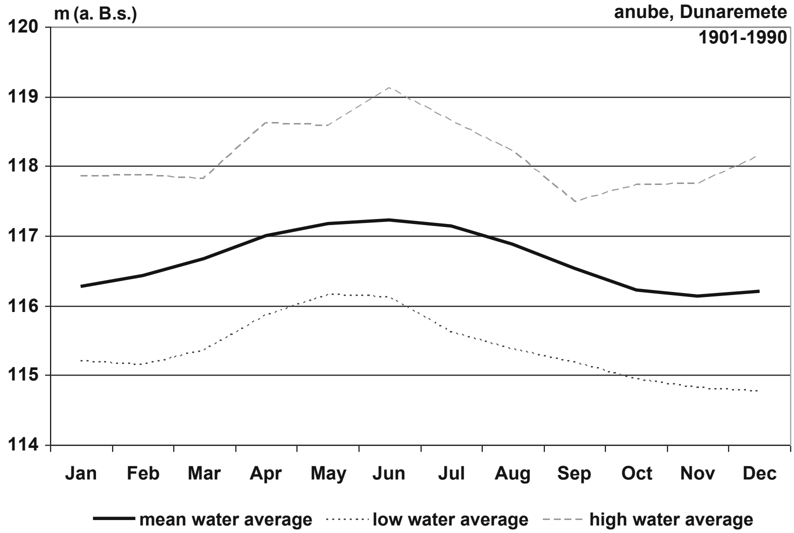

Fig. 1 Seasonal variation of average monthly flows at the Dunaremete gauge (1901–1990)

2.2 Hydro-Morphology

The Danube entered the plain of the Kisalföld about 2–2.5 million years ago, at the end of the Pliocene era. The significant fall of its bed load transport capacity resulted in the deposition of sediment originating from the Alps. The sedimentation process had been continuously filling up the lowland, and a huge alluvial cone had been deposited by the mid-Pleistocene. Since then, the river has been flowing in its own alluvium, and the surface of the floodplain has been constructed by sediment deposition and covered by Holocene formations (Pécsi 1959; Göcsei 1979).

Under undisturbed conditions, the Danube changed its course on a broad scale, forming a delta-like, anabranching channel pattern, characterized by multiple channels, bars and unstable islands in the Szigetköz floodplain area (Figs. 2 and 3). The deposition of the sediment load of 400,000–500,000 m^3 per year, arriving from the Upper Danube (Károlyi 1962), was a factor of decisive significance in the development of the branch systems. The surface of the floodplain is a perfect plain with a slight north-east–south-west slant, with a few metre-high outcrops. Its highest point is 127 m a.s.l (Baltic), while its lowest is 110 m a.s.l.

According to the classification based on channel patterns, two main sectors can be distinguished in the Szigetköz section of the Danube. Both sectors can be divided into two subsectors by the distribution of channel islands (Fig. 4):

1. *Anabranching sector*

   (1/A) *Braiding—anastomosing subsector*: The upper part of the anabranching sector between Rajka and Sap has a high slope (30–35 cm km^{-1}) (Tőry

Fig. 2 The Szigetköz section of the Danube before the extensive river regulations, on the basis of the first military surveys, carried out between 1763 and 1785

1952) and is characterized by multiple channels, bars, and unstable islands. The accumulation of sediment and the fast reorganisations of terrain surface have regularly interrupted the ecological succession.

(1/B) *Anastomosing—splitting subsector*: The lower part of the wandering sector between Sap and Gönyű has a slope of 12–18 cm km^{-1} (Tőry 1952). It splits into some large branches and has a greater degree of lateral stability. Its morphological changes do not permit the complete development of ecological succession.

2. *Meandering sector*

(2/A) *Peripheral subsector with occasional islands*: A large tortuous side-arm along the margin of the alluvial cone (the Mosoni-Danube) with *junctions* of three tributaries (Lajta, Rábca, Rába). The relatively wide and deep riverbed has been formed by the floods arriving from the Danube and the adjoining tributaries. The succession of the abandoned oxbow lakes is complete.

(2/B) *Inner subsector without islands*: Several meandering side-arms between the wandering sector and the peripheral meandering subsector. The succession of the abandoned oxbow lakes is complete.

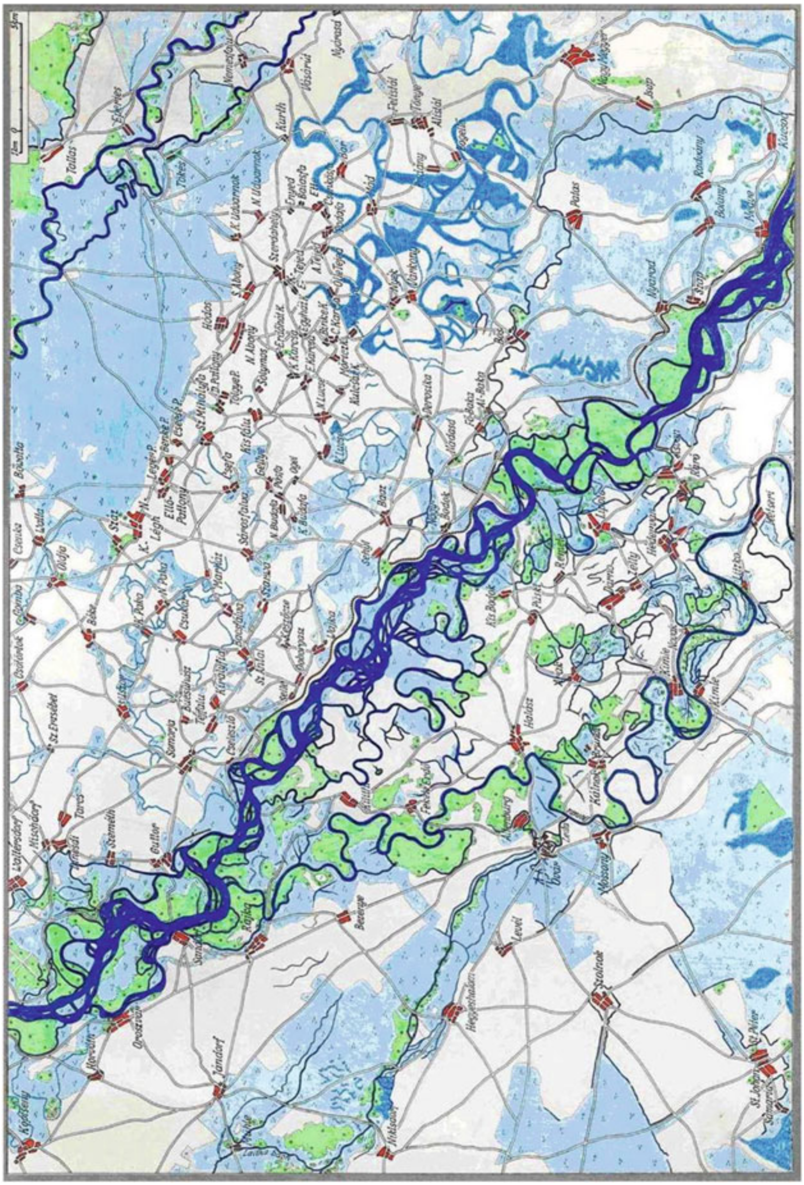

Fig. 3 The regularly flooded lower floodplain (in light blue) in the upper part of the Szigetköz before the extensive river regulations, on the basis of the first military surveys, carried out between 1763 and 1785 (from the collection of the Danube Museum, Esztergom)

Fig. 4 Characteristic stretches of the main sectors in the Szigetköz section of the Danube: (**1/A**) the upper braiding and anastomosing main arm, (**1/B**) the lower braiding and anastomosing main arm, (**2/A**) peripheral meandering side-arm (Mosoni Danube), (**2/B**) inner meandering side-arms

In the anabranching sector, net sedimentation surpasses the erosion process and the river aggrades (raises its bed). Several mid-channel bars are formed by sediment deposition in the wider branches. Bars develop into islands when their surface is bound by vegetation and channels split into branches. During overbank flooding, the anastomosing channels tend to become active, and create new branches and abandon some old branches. The central areas of large channels often hold relatively hostile environmental conditions, where the concentrated sediment transport maintains unfavourable substrate for aquatic organisms. The channel patterns of the anabranching sector are mostly unstable.

In the meandering sector, sedimentation is in balance with erosion. The erosion destroys the concave (external) banks of the meanders, and, after a short distance, the eroded material is deposited, adjoining the convex banks. The concave banks are usually steep, while the convex banks are moderately sloping sandy point bars. Over a long period, the meanders migrate downstream along the river, their breadth increasing until the thinning neck is cut off by a large flood, and the meander loop becomes an oxbow lake or dead arm. The abandoned oxbow lakes gradually lose their connection with the river as sedimentation closes their upstream and downstream mouths, and are subject to aggradation, due to biological sedimentation and the deposition of suspended river sediment after floods. Over two to three centuries, this morphological succession may lead to the complete disappearance of the former meander, leaving only a narrow depression on the floodplain surface (Amoros et al. 1987).

2.3 Aquatic Habitats

The river-floodplain system includes aquatic, semi-aquatic and terrestrial habitats within the alluvial plain, which are interconnected with the river. The seasonal pattern of the hydrological regime is accompanied by a seasonal cycle of high and low water levels on most parts of the floodplain. For this reason, the physical, chemical and biological characteristics of the floodplain water bodies undergo significant changes, giving rise to a constantly shifting pattern in a variety of habitats that make up the floodplain ecosystem (Fig. 5).

Floodplain water bodies can be subdivided into four main habitat types according to the 'functional sets' concept (Amoros et al. 1987) based on hydrological, hydromorphological and ecological analysis. The typology of the aquatic habitats of the Szigetköz floodplain (Table 1) follows the definitions used for the Austrian section of the Danube (Hohensinner et al. 2005), with minor modifications.

Eupotamon River branch with permanent flow (main channel, side-arms). Bed material is course-grained, often gravelled. Suspended load content is high; especially significant during floods. Vertical stratification of temperature and oxygen are not characteristic, water conductivity is low. Phytoplankton content is low, primarily formed by drifting diatoms, and macro-vegetation content is insignificant. The dominant elements of the zooplankton are protozoa and rotifers, representing a low amount of biomass. Zoobenthos and fish, which are relatively rich in species, are characterized primarily by rheophilic species, which represent a low amount of biomass.

Parapotamon Periodically flowing side-arm permanently connected to the main arm of the river at the confluence. Its flow can be fed both by surface and ground water, and the rate and direction of the flow may vary depending on water level fluctuations of the river. Suspended load content is low in low-water periods. The bottom contains less coarse-grained gravel, often mixed with sand and silt. There is a periodical occurrence of vertical stratification of temperature and oxygen content, depending on the water depth. Water conductivity is intermediate. Phytoplankton is species rich, the biomass of diatoms and green algae is significant, but macro-vegetation is poor. Zooplankton represents a large biomass; its dominant elements are protozoa and rotifers. Biomass of zoobenthos is significant. Fish fauna is less demanding with respect to habitat characteristics. Eurytopic and, to a lesser extent, rheophilic species prevail and represent a medium biomass.

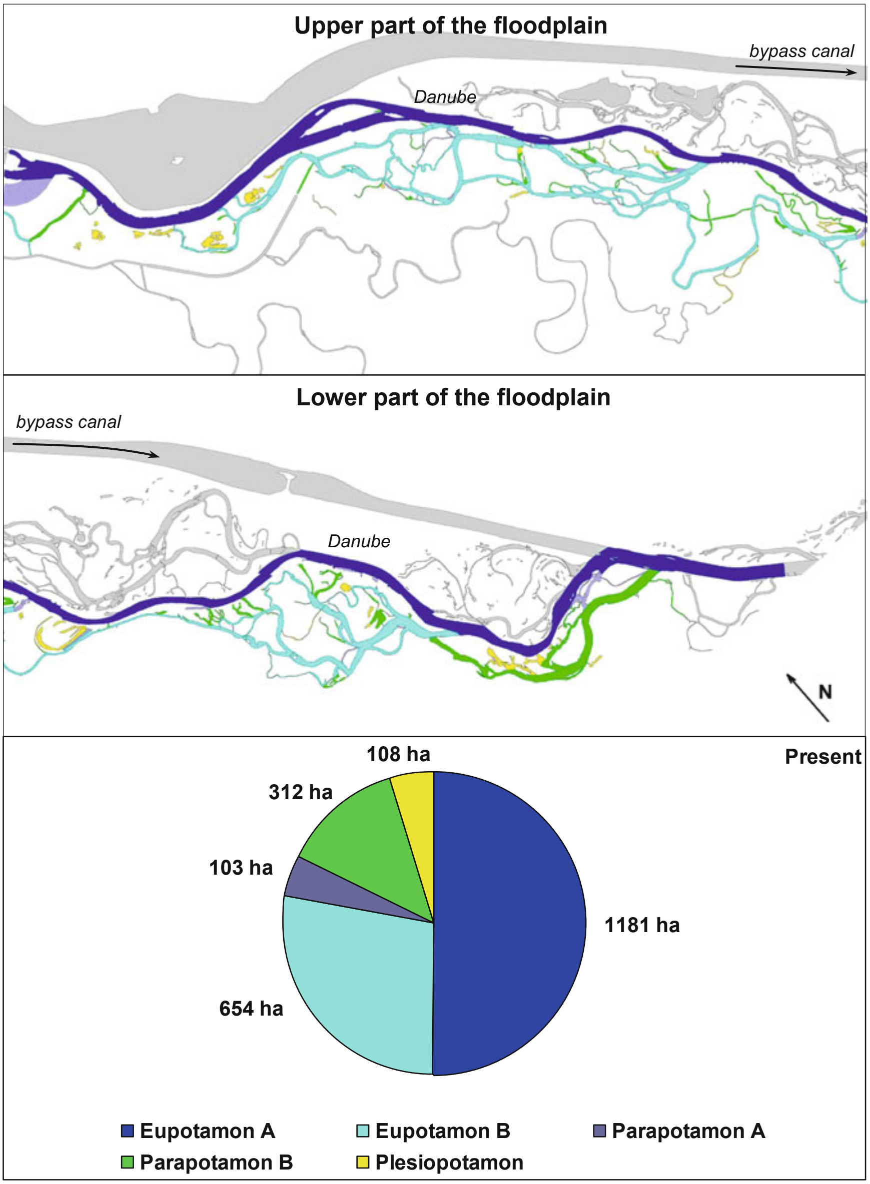

Fig. 5 Map and areal extent of the distribution of aquatic habitats along the active floodplain of the Szigetköz in 2008

Plesiopotamon Periodically isolated still-water oxbow lake or abandoned loop; the extension and water mass varies depending on the water level of the river. Bed material is composed of silt and sand. Suspended load content is generally low.

Table 1 Definitions of the aquatic habitat types in the anabranching and meandering sectors of the Szigetköz floodplain

Habitat type	Definition
Eupotamon A	Main stream
Eupotamon B	Always connected side channels, with permanent flow
Parapotamon A	Highly dynamic side arms, intact downstream connection, blocked upstream by bare gravel/sand deposits
Parapotamon B	Less dynamic side arms, intact downstream connections, blocked upstream by vegetated deposits
Plesiopotamon	Isolated water bodies, close to the main channel, often connected
Paleopotamon	Isolated water bodies (oxbows in the meandering sector), seldom connected

Vertical stratification of temperature and oxygen is characteristic. Water conductivity is high. It has a great mass of phytoplankton; plankton bloom is a frequent phenomenon. Macro-vegetation is abundant. Dominant elements of the zooplankton are rotifers and crustaceans, which represent an especially large biomass. Biomass of zoobenthos is significant. Fish fauna is characterized by eurytopic and limnophilic species. As a result of the periodically extreme environmental conditions, the fish population is often mono- or bispecific. Biomass of the fish fauna varies between extreme limits; it may even be especially large.

Paleopotamon Permanently isolated still-water oxbow lake or abandoned loop. Direct surface connection with flowing-water branches occurs only in the case of the highest water levels. Water supply mostly ensured by infiltration of groundwater through the alluvium and precipitation. The bottom composed of silt and clay, the organic material content of the surface of the sediment is very high. Suspended load content is low. Daily vertical stratification of temperature and oxygen is significant, water conductivity is very high. Phytoplankton contains a low number of species and its biomass is not significant. Macro-vegetation is especially abundant. Dominant organisms of the zooplankton are crustaceans, representing a low amount of biomass. Biomass of zoobenthos is not significant. Fish fauna composed of a relatively low number of limnophilic species, representing a significant biomass.

3 Biota, Biodiversity

3.1 Ecological Processes

With regard to the natural conditions of the Szigetköz floodplains before extensive river engineering, the biodiversity of characteristic river-floodplain associations was high, due to the high habitat diversity resulting from the fluvial dynamics, the frequent flood-controlled resetting towards early successional stages, and the large lateral extension of the floodplains. The analyses of historical maps clearly indicate a broad range of habitat conditions, such as hydrological connectivity to the main river stem, flow retention characteristics; furthermore the predominance of habitats in the early successional stages, such as bare gravel bars and areas with finer sediment depositions. Shallow islands were constantly formed and eroded. Habitat turnover rate was high, and the extent of terrestrialisation processes was reduced. According to historical records and the available knowledge of autecological requirements of characteristic species, the biodiversity of rheophilic species, early pioneer and mid-term successional species of plants, which require raw riverine sediments for early growth and are tolerant to frequent flooding, were enhanced.

3.2 Vegetation

The high biodiversity was expressed by the broad representation of plant associations (Rakonczay 1996; Borhidi 2003). Raw alluvial soils formed on the gravel beds, which were deficient in humus but rich in nutrients. Soils were saturated with water during floods, and water reached the roots of the plants from the ground water through capillary rise. Along the shoreline of shallow islands and side-arms, normally low willow scrubs were formed with the species composition depending on the quality of the soil. On the gravel shallows, purple willow scrub communities (*Rumici crispi-Salicetum purpureae*) were established. In sections with a lower flow, where fine sand and silt formed islands, almond-leaved willow scrub (*Polygono hydropiperi-Salicetum triandrae*) developed. In closed-drainage areas with a good water supply, swamp willow and alder woods (*Calamagrostio-Salicetum cinereae, Carici elongatae-Alnetum*) were formed. On higher terrain, where the regular floods lasted for 1–2 months, larger willows and poplars created softwood forests. Forested habitats of willow groves (*Leucojo aestivi-Salicetum albae*) occurred in regularly flooded areas. Black poplar groves (*Carduo crispi-Populetum nigrae*) developed in forest habitats also regularly flooded with water, but with the soil formed on sand-gravel underlay, which dries out more rapidly in flood-free periods. Among the species of hardwood groves, the European white elm (*Ulmus laevis*) often appears in this association.

At higher levels of the floodplain terrain, which are inundated only in the case of larger floods, white poplar groves (*Senecioni sarracenici-Populetum albae*) developed. Further up in the rarely flooded areas, various hardwood associations became predominant: alder groves (*Paridi quadrifoliae-Alnetum*), oak–ash–elm groves (*Pimpinello majoris-Ulmetum*), hornbeam–oak forests (*Majanthemo-Carpinetum*), and closed and open dry oak forests (*Piptathero virescentis-Quercetum roboris, Peucedano alsatico-Quercetum roboris*) created a vegetation mosaic.

Typical associations of the aquatic vegetation include a variety of pleustonic plant communities (*Lemnetea: Salvinio-Spirodeletum, Lemno-Utricularietum vulgaris, Hydrocharitetum morsus ranae, Ceratophylletum demersi*) and submerged and emergent macrophyte communities (*Potametea: Nymphoidetum peltatae, Nymphaeetum albo-lutea, Hottonierum palustris, Ranunculetum fluitantis*).

Semi-aquatic vegetation and reeds also occur, with high diversity (*Phragmitetum communi, Sparganietum erecti*, *Glycerietum maximae, Typhetum angustifoliae* and *Typhetum latifoliae*, *Butomo-Alismatetum plantaginis-aquaticae* and *Hippuridaetum vulgaris*). In oxbows not affected by the floods—primarily in the Upper-Szigetköz—moors of grey willow scrub (*Calamagrastio- Salicetum cinereae*) and black alder marshy woods (*Thelypteridi–Alnetum*) were formed. Beside these, swamp- and fen-meadows (*Carici flavae-Eriophoretum*) and the fen-meadow of calciferous grounds (*Succiso-Molinietum hungaricae*) were prominent.

3.3 Aquatic Invertebrates

In the aquatic fauna, rheophilic guilds dominate among invertebrates. Prior to river regulation, due to the larger lateral extent of the floodplains, both the rheophilic and the characteristic limnophilic guilds found better habitat conditions than in the present situation. The richness and the diversity of the invertebrate fauna may be amply illustrated by some taxa.

About half of the mollusc species of the Hungarian Lowland Ecoregion have permanent populations in the Szigetköz region. This species-rich fauna depends on isolated, fragmented and vulnerable habitats of the floodplain. Not only the presence of rare species has a great importance, but several local species, characterised by high abundance, also significantly contribute to the special, dynamic equilibrium, which is a characteristic feature of the mosaic-like habitats. In addition to the typical floodplain species, occasionally colonizing species periodically appear in the fauna from the surrounding areas (Majoros 2010).

The presence of almost a hundred micro-crustacean species (Cladocera, Copepoda) indicates an exceptionally rich crustacean fauna in the floodplain. This is due to the high diversity of aquatic habitats and the dynamic fluctuation of the water level.

More than half of the species of the Hungarian dragonfly fauna are known from the Szigetköz area. The high number of dragonfly species may be explained by the slow flow of the side arms and the sediment deposition. As dragonfly larvae respire dissolved oxygen from the water, water quality plays a decisive role in the establishment of the species. One third of the species of the Hungarian caddisfly fauna can be found in the Szigetköz. This high diversity is the result of the favourable water quality, bed material and flow conditions in the floodplain branch systems, as indicated by the number of rheophilic species.

3.4 Fish

The fish fauna of the Szigetköz floodplain is characterised by a high number of species (Holčik et al. 1981; Holčik 2003; Guti 1993, 1997). This phenomenon can be explained by the following factors:

- the zoogeographical significance of the Danube basin (Bănărescu 1991)
- the transitional zone between foothill and lowland zones, i.e. hyporhitron–epipotamon
- the continuously changing river-floodplain ecosystem (Welcomme 1985), characterised by a great variability in geomorphological and hydrological conditions, and high diversity of aquatic habitats with different degrees of spatio-temporal connectivity

The native fish fauna includes 51 species (Table 2), according to historical records (Marsigli 1726; Kramer 1756; Grossinger 1794; Reisinger 1830; Heckel and Kner 1858; Herman 1887; Ortvay 1902), and recent surveys (Balon 1967; Tóth 1970; Holčik et al. 1981; Jancsó and Tóth 1987; Guti 1997, 2008). It contains elements from the montane stretch of the Upper Danube (Danube Salmon *Hucho hucho*, Brown Trout *Salmo trutta*, etc.); and Black Sea migratory species, such as anadromous sturgeons (*Huso huso, Acipenser gueldenstaedti, A. stellatus*).

The fish fauna of the eupotamon type riverbed is dominated by rheophilic fish species (*Acipenser ruthenus, Barbus barbus, Chondrostoma nasus, Cottus gobio, Gymnocephalus cernuus, Zingel zingel*, etc.). The connected backwaters represent the parapotamon type habitats; their fauna includes several rheophilic and eurytopic species (*Rutilus rutilus, Alburnus alburnus, Blicca bjoerkna, Perca fluviatilis*, etc.). The disconnected plesiopotamic or paleopotamic backwaters are populated with eurytopic and limnophilic fish species (*Scardinius erythrophthalmus, Carassius carassius, Tinca tinca, Misgurnus fossilis, Umbra krameri*, etc.) that are bound to the standing waters of the floodplain. In general, the diversity of fish species is greatest in the eupotamon and parapotamon, and tends to decrease in the plesio- and paleopotamon, while fish biomass shows an opposite trend.

The hydrological variety of the Szigetköz section of the Danube is favourable for fish reproduction. In the spawning period, several fluvial species migrate instinctively against the current, sometimes covering a distance of 100–200 km, before they find a suitable habitat for reproduction. For most of the migratory species, the high gradient upstream of the Szigetköz is hard to overcome, but fish can spread into floodplain waters during the spring and early summer inundations. The slow-flowing, large sidearm systems serve as ideal spawning and nursery habitats, and provide a rich feeding area for several fish species.

4 Historical Overview of River Utilisation and Land Use

Social, demographic and economic development generates driving forces of river utilisation and land use. The driving forces (river engineering, navigation, hydropower utilisation, fishery, agriculture, forestry, etc.) provide several benefits for society and provoke changes in the economic production; however, these needs put pressure on the riverine environment.

Table 2 Native fish fauna of the main habitat types in the Szigetköz section of the Danube. +++ abundant (estimated relative abundance >5%), ++ common (estimated relative abundance >1%), + rare (estimated relative abundance <1%)

Fish taxa	Habitat type			
	Eupotamon	Parapot.	Plesiopot.	Paleopot.
Eudontomyzon mariae	+	+		
Acipenser ruthenus	++	+		
Acipenser nudiventris	+	+		
Acipenser gueldenstaedtii	++	+		
Acipenser stellatus	+	+		
Huso huso	++	+		
Anguilla anguilla	+	+		
Rhodeus amarus	+	++	+++	++
Gobio obtusirostris	+	++		
Romanogobio vladykovi	+++	++		
Romanogobio kesslerii	+	+		
Barbus barbus	+++	++		
Carassius carassius			+	++
Cyprinus carpio	++	++	+	+
Abramis brama	++	+++	+	
Alburnoides bipunctatus	+			
Alburnus alburnus	+++	+++	++	+
Aspius aspius	++	++	+	
Ballerus ballerus	++	+		
Ballerus sapa	++	+		
Blicca bjoerkna	++	+++	+	
Chondrostoma nasus	+++	++		
Leucaspius delineatus			+	++
Leuciscus idus	+++	++	+	
Leuciscus leuciscus	++	+		
Pelecus cultratus	+			
Rutilus rutilus	++	+++	+++	++
Rutilus virgo	++	+		
Scardinius erythrophthalmus	+	+	++	++
Squalius cephalus	++	++	+	
Vimba vimba	++	+		
Tinca tinca		+	++	++
Cobitis elongatoides		+	++	+
Misgurnus fossilis		+	++	++
Sabanejewia balcanica	+	++		
Barbatula barbatula	++	+		
Silurus glanis	++	++	+	
Esox lucius	+	++	++	++
Umbra krameri				++
Salmo trutta fario	++	+		

(continued)

Table 2 (continued)

Fish taxa	Habitat type			
	Eupotamon	Parapot.	Plesiopot.	Paleopot.
Hucho hucho	+			
Lota lota	++	++		
Cottus gobio	+	+		
Gymnocephalus cernuus	++	++	+	
Gymnocephalus baloni	++	++		
Gymnocephalus schraetser	++	+		
Perca fluviatilis	++	++	++	+
Sander lucioperca	++	++	+	
Sander volgensis	+	+		
Zingel streber	++	+		
Zingel zingel	++	+		

4.1 River Engineering

The first written record concerning river regulation in the Szigetköz region dates back to 1426, when King Sigismund appointed a commissioner to control the construction works of the flood prevention dykes. In the seventeenth century, many settlements were protected by a surrounding dyke (Károlyi 1973). Besides flood protection, an inland water drainage network was constructed, the total length of which was 92 km in 1850. Significant changes have occurred in the river system of the Szigetköz region during the past 150 years. The most important interventions of river engineering from the end of the nineteenth century were as follows:

- *1886–1896*: The overall flow regulation of the Szigetköz Danube section was carried out with the aim of improving navigation possibilities and improving the passage of ice-floods. At this time, the main channel was created with a width of 300–380 m. The banks of the main riverbed were stabilised with stone protection, extending up to the mean-flow level, the footings of which were protected against under-washing by rock fill. More than 3 million m^3 of stone was used, in many places changing the composition of the bottom material (Károlyi 1973; Várday 1987).
- *1892–1895*: Comprehensive flood protection work was carried out in the Szigetköz Danube section. The flood protection dykes protected 80% of the right-hand, 375 km^2 floodplain from flooding. In high water, because of the cross-section being bound by embankments, the passage of the flood pulses accelerated, therefore the duration of flooding dropped.
- *1886–1900*: The majority of the drainage channels were built on the protected side. The drainage of rising water became a demand with the construction of the flood protection dykes. To facilitate this work, the streams and the earlier anabranches were connected together with channels, the total length of which was 157 km (with the later extensions this is now nearly 400 km). Weirs and

sluices were constructed where the embankments were crossed, and it was here that later on pumping stations were established.

- *1888*: Inflow to the Mosoni Danube was regulated by training works and later by a sluice. The sluice controlled the water supply from the Danube during the floods since 1908.
- *1899–1940*: Low-flow regulation was accomplished by constructing cross-dykes, the further closing of side-arms and the extensive dredging of fords. These regulation works deepened the section of the main channel, but the scoured sediment deposited in the downstream sections. Due to the continued rising of the riverbed, the guide banks and bank protection works became too short and the structures ensuring low-flow regulation were filled up. As a consequence of weir construction in the branch systems, the flow in the side-arms slowed down and the deposition of suspended sediment increased.
- *1963–1983*: A new, comprehensive mean-flow regulation project was undertaken in the section between Rajka and Sap. The intervention became necessary owing to the rising of the riverbed, due to sediment deposition. During the regulation work, the upper intake weirs of side-arms were constructed for a water discharge rate of 2500 $m^3\ s^{-1}$, therefore the flushing of the branch systems was significantly restricted by the 1980s (by an annual average of 20%). With the reduction of the frequency of through-flow, there was an increase in suspended sediment deposition at the upstream end of the anabranches (Károlyi 1973; Várday 1987).
- *Second half of twentieth century*: Dredging was carried out in the Szigetköz section of the Danube in order to achieve gravel for industrial mass-production of concrete both in Hungary and Slovakia. The mass of gravel excavated annually many times exceeded the amount of the bed-load transport of the Danube, causing a significant incision of the riverbed. For flood protection purposes, intensive dredging occurred in Bratislava. Dredging also occurred in the Austrian reach downstream of Vienna, to improve navigation conditions. From the 1980s, the sediment retention effect due to upstream dredging and the barrages constructed in the Austrian section of the Danube contributed to the riverbed incision process. Approximately 30–40% of the suspended sediment is deposited by the Austrian dams, and they retain the entire bed-load (Rákóczi 1993).
- *1992*: The Gabčíkovo barrage was put into operation and 80% of the average discharge of the Danube was diverted into its 29 km-long bypass canal. As a result of the diversion, the water level in the main arm of the Danube dropped by 4 m compared to the previous mean water levels, and by 1.5–2 m compared to the previous minimum levels in the river stretch between Rajka and Dunaremete. Higher discharge than 600 $m^3\ s^{-1}$ rates only occurred in the main channel when the total discharge rate of the river exceeded the maximum capacity of the Gabčíkovo Hydropower Station. As a consequence of the discharge diversion, 80% of the active floodplain branch system dried out in the Szigetköz. In the following 2 years, the flow practically stopped in the floodplain branches which were closed off from the main riverbed.
- *1995*: An underwater weir was constructed in the main riverbed of the Danube at Dunakiliti with the aim of providing water for the floodplain side-arm system via

gravitation. The amount of diverted water using the weir gates at Dunakiliti can be controlled between 40–130 $m^3 s^{-1}$. The majority of the water discharge arriving through the Čunovo reservoir seepage canal provides the water for the Mosoni-Danube The water supply for the side-arms and canals of the flood-protected area comes partially from this system. In order to make the active floodplain water recharge more flexible, a drainage facility was established between the main riverbed of the Danube and the floodplain side-arms at Dunasziget in 1998. The facility also includes a fish ladder, which creates a direct passage between the main stream and the floodplain waters.

4.2 Fisheries

Several historical records indicate the importance of fisheries in the Szigetköz section of the Danube from the Palaeolithic age. Sturgeon were among the most important subjects of fishing between the eleventh and sixteenth centuries. Despite the considerable fishing activity in the sixteenth to eighteenth centuries, there is no information about fishing guild centres in the Szigetköz. Two commercial fishing companies were formed at the end of the nineteenth century (in the Győr-Region and in the Mosoni Danube). The waters of the Szigetköz provided good fishing conditions for fishermen working with different kinds of small equipment, but were less suitable or even totally unfit for groups of fishermen working with larger equipment. Information about their catch is scarce (94.9 tons of fish from 3500 ha in 1940; 0.6% pike-perch, 1.8% carp and 88% other cyprinid fish, Solymos 1965).

The current fishing area of the Szigetköz is more than 3000 ha and it has been exploited by the commercial fishing company of Győr since 1951. Beside the professional fishery, a number of small water bodies in the flood-free floodplain are utilised by local angling clubs.

The statistical data for the commercial fishery indicate a decreasing trend of catch between 1967 and 1992. Annual catch was 207.5 tons in 1967, only 77.4 tons in 1992, with the decline being well-marked from 1988. The total catch of the sport-angling clubs increased by 75% between 1968 and 1986, but this was, above all, due to the fact that the number of sport-anglers doubled in the Szigetköz area. Consequently, the annual catch per person decreased from 8.52 kg to 6.93 kg during this period. Commercial fishery lost its former importance at the beginning of the twenty-first century, and, according to the new legislation, it has been terminated along the Hungarian section of the Danube after 2015.

4.3 Agriculture

In the Middle Ages, the Szigetköz floodplain was mainly covered with forests, and its meadows were best suited to extensive animal stock rearing. The frequent floods did not allow extensive arable farming. The earliest written records of the local extensive stock rearing originate from the thirteenth century. The villages were established on the higher areas, in forest clearings and meadow breaks. The houses in the settlements stood on island rises or on the highest points of the floodplain. The villages were surrounded with zones of garden, orchard, arable land, meadow and forest.

The comprehensive river regulation, carried out at the end of the nineteenth century, fundamentally changed farming in the Szigetköz. Stock keeping became more intensive, and the practice gradually spread of keeping the animals in stables. Fallow land and rotation farming disappeared, to be replaced by crop rotation. Arable farming became possible, and increasing areas were involved in cereal farming. Owing to the favourable water conditions of the soils, the level of production security was relatively high. In the 1980s, 91% of the arable land received herbicide through land-based mechanical spraying. Nearly 30% of the arable land was affected by plant protection spraying carried out during the production period. The artificial fertiliser active agent amount used annually was on average 120 kg ha^{-1} N, 90 kg ha^{-1} P, and 157 kg ha^{-1} K (Ijjas et al. 2010).

At the end of the twentieth century, with the rearrangement of ownership conditions, the farming structure also changed. Free market aspects—coming to the foreground—influenced the planting structure and the use of artificial fertilisers, etc. Stock keeping lost a great deal of its significance, since animal production using intensive methods is not competitive on the European markets.

4.4 Forestry

Intensive forest management started in the 1920s in the Szigetköz floodplain. Planted forests were established, using propagated material, giving a greater yield in the place of the natural forests. In the 1950s, willow was the dominant tree in terms of covered area, and deciduous hardwood stands and domestic stands of poplar also covered significant areas. At this time, improved varieties of poplar began to be planted to a greater extent. The popularity of the improved poplar varieties remained until the 1980s, at which time they covered 68% of the forest areas of the Szigetköz. Natural forest communities had been significantly suppressed. The willow-poplar-alder (*Saliceto-Populeto-Alnetum*) groves, which demand a significant variation in water level and lower floodplain locations, can hardly be found today in their original form. Due to the changed habitat conditions, alder marsh forests (*Alnetum glutinosae*) have completely disappeared, and elm–poplar grove forests (*Ulmeto-Populetum*) hardly occur at all. Today, the elm–ash–oak grove forests (*Ulmeto-Fraxineto-Roboretum*) can only be found in small areas and in artificial form.

In the 1990s, as a result of a conceptual change in forestry, there have been endeavours to set up near-natural forests. This has not changed the earlier conditions spectacularly, but renewals have taken place using naturally native tree species in a 100 ha range. The hybrid poplar woods covered 61% of the forest areas of the active floodplain in Hungary in 2006 (T. Limp personal communication).

5 Alterations of the River-Floodplain Ecosystem

River utilisation and land use resulted in alterations of the river-floodplain system, transformations of environmental conditions (connectivity, gradient, hydraulics, etc.), as well as changes of the natural resources (discharge, riparian forest, fish stock, etc.) and natural processes (water regime, bed load transport, ecological succession, etc.).

5.1 Hydrological and Hydro-Morphological Dynamics

The effect of the various river regulation interventions can be observed on the hydrological behaviour of the river. From the end of the nineteenth century, inshore formation of the main arm was altered by creation of the navigation channel and the construction of rip-rap embankments. These interventions reduced the lateral erosion of river banks and the formation of gravel bars.

The impact of flood protection measures and the construction of flood protection dykes can be demonstrated in the long-term changes of the water regime. The incoming sediment, which was spread out earlier over the entire region of the Szigetköz floodplain, was subsequently seen as rapidly filling up the unprotected land between the dykes, resulting in the continuous rise of the high water levels in the twentieth century. With the increase of the height of the waters covering the dry land areas, the extent of quickly warming and shallow habitats along the banks has been reduced. Allogenic processes have markedly come to the foreground in the succession of the aquatic habitats. The passing of floods has accelerated, and the peak levels of the flood waves have increased the frequency of disturbances in general.

The riverbed incision process—due to the sediment retention effect of upstream dredging and the Austrian barrages—can also be seen in the gauge data series (Fig. 6). From the middle of the 1970s, the riverbed in the Szigetköz section of the Danube deepened at an average of 3 cm year^{-1} as compared to the previous riverbed rising rate of 1.5–8 cm year^{-1}. In recent decades, as a result of the local dropping of low-flow water levels by more than 1.5 m, surface connections between the active floodplain branch systems and the main riverbed of the Danube have become restricted.

Since the beginning of the 1970s, the amount of annual suspended sediment has reduced significantly (Láng et al. 1993). This has been accompanied by the increasing of the transparency and light transmissibility of the waters. This may improve the ability of plants to photosynthesize, and increase the level of aquatic primary production and autogenic succession of the aquatic habitats.

Since the operation of the Gabčíkovo Hydropower Plant, the diversion of 80% of the Danube discharge has been causing major changes in the water regime of the main arm and the sidearm system. The artificial water supply system can only

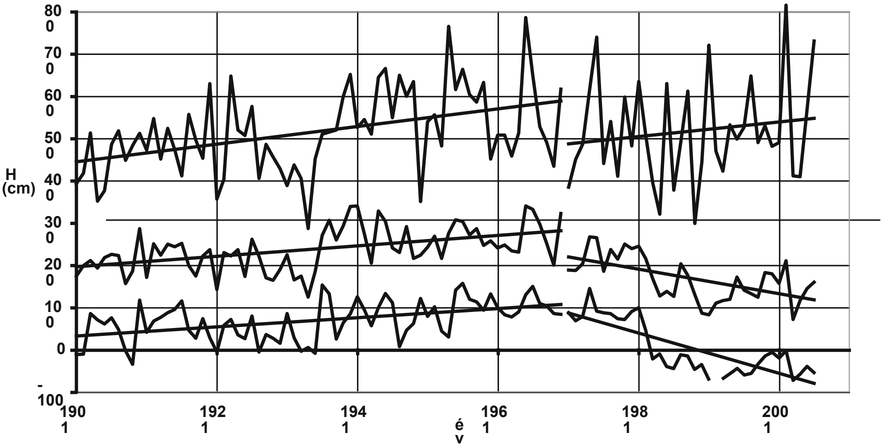

Fig. 6 Trend analysis of annual levels of water at the gauge of Gönyű in the twentieth century

provide a limited quantity of water for the floodplain branches. Periodic flooding is only partly ensured, and the natural dynamic character of the water regime is missing. On the one hand, the modification of the natural discharge has resulted in the very weak movement of the bed load compared to the pre-construction situation, also limited in space, due to the very short period of competent flow levels. On the other hand, suspended sediments were deposited in large quantities in side-arms. The long-term changes of the natural hydrological and hydro-morphological processes altered the hydro-biological character of the river-floodplain ecosystem.

5.2 *Aquatic Habitats*

The extensive flood protection measures and the changes in land use have had significant impact on the lateral connectivity between the river system and its floodplain. The flood-protected area has been cut off from the periodic water supply and it has been transformed into agricultural land, thus cannot fulfil its original role as a functioning floodplain.

The historical change of the habitat structure in the active floodplain indicates a decreasing trend in the areal extent of the aquatic area (Figs. 7 and 8). Before the extensive river regulations (until the end of the 1880s), dynamic habitat equilibrium was a characteristic feature of the habitat structure, with the dominance of the eupotamon type habitats. The creation of the navigation channel and the blocking of upstream inlets of the branch system changed the natural structure of the aquatic habitats. From the end of the nineteenth century, the main channel became a stable eupotamon-A type of habitat and the proportion of the eupotamon-B type of side-arms decreased. Areal extent of temporal stagnant waters increased, and advanced

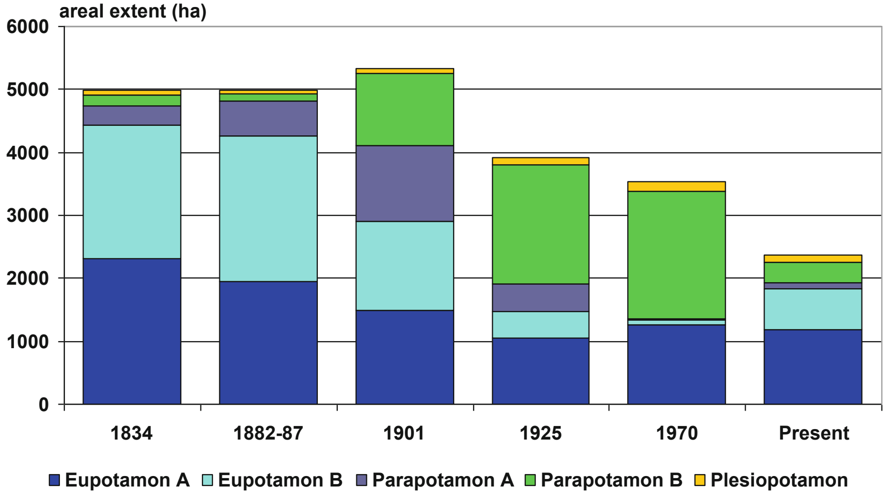

Fig. 7 Changes of aquatic habitat structure in the Szigetköz area from the first half of the nineteenth century

stages of the ecological succession of the aquatic habitats, as parapotamon-A and -B and plesiopotamon were characteristic in the side-arm systems.

In the twentieth century, instream formation of the side-arms was modified by cross-dykes, and consequently, the gradient of side-arms was reduced and their longitudinal connectivity became fragmented during low-water periods. The gradient reduction resulted in a shift in flow velocity and shear stress distribution to the lower values in several branches, but the temporal flushing during the floods maintained the gravel substrate and kept the bed free from aquatic vegetation in most of the parapotamon-type side-arms.

Since the middle of the 1990s, the proportion of the eupotamon type habitats has increased and the areal extent of parapotamon type side-arms has decreased by the operation of the permanent artificial water supply (Fig. 5). Most of the cross dykes within the branch systems were opened in order to improve the flow of the water recharge system, and the longitudinal connectivity improved within the branch system. At the same time, connections (tributaries) between the main arm of the Danube and the branch system were completely closed by dykes and their lateral connectivity was significantly reduced.

The Gabčíkovo and the Čunovo barrages are the basic obstacles of the longitudinal continuity of the Danube along the Szigetköz region. The barrages were built without any adequate facilities to provide access for the migrating fish species. The extensive flood protection measures and the changes in land use have also significant effects on the lateral continuity of the river system. The floodplain has been transformed into agricultural land behind protecting dykes and so cannot fulfil its original role as a functioning floodplain.

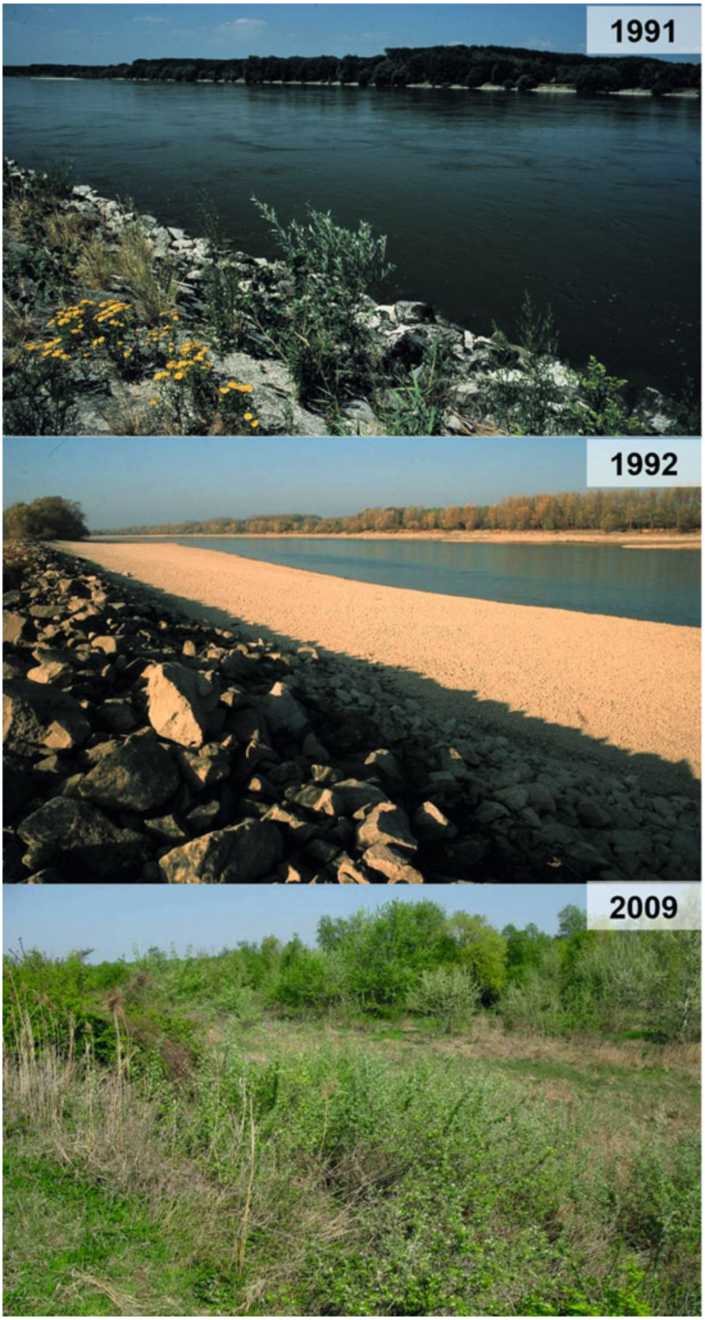

Fig. 8 Changes of the main arm: 1991—before the diversion of the river, October 1992—after the diversion of the river, 2009—progress of terrestrial vegetation on the dry river bed

5.3 Long-Term Changes of the Fish Fauna

Alterations in the fluvial environment have caused a decline of the ecological integrity of the river-floodplain ecosystem (Karr 1991; Jungwirth et al. 2000; Schiemer 2000) along the Szigetköz section of the Danube. Under the pressure of river utilisation and land use, the deterioration of the pristine fish fauna has been manifested in species extinction, the high number of endangered species, the decline of fisheries, the change of species composition from habitat specialists to eurytopic forms and the increase in the number of non-native fish species. Habitat loss and modification due to river engineering, as well as fishery exploitation were the most important factors threatening fishes in the Szigetköz region.

Over-fishing played a primary role in the decay of certain sturgeon species. Historical archives prove the prevalence and economic importance of sturgeon fishery in the region. For instance, in 1553, 77 specimens of great sturgeon were caught on a single day at one fishing site (Unger 1931). Sturgeon catches began to decline from the sixteenth century and, in the nineteenth century, sturgeon were only rarely caught in the region (Kriesch 1876; Károli 1877; Herman 1887; Khin 1957; Hensel and Holčik 1997; Guti 2008). Excessive fishing reduced the number of anadromous sturgeon not only in their spawning area at the Szigetköz but also on their 2000 km-long migratory journey from the Black Sea. Fishery mortality rate (referring to individuals which are removed from the stock by fishing) proportionally related to the extent of the spawning runs in the rivers, and the survival of migrants spawning in the Middle Danube could be several times lower than the survival of individuals in the Lower Danubian short-migratory sub-populations (Guti 2014). Great sturgeon (*Huso huso*) and stellate sturgeon (*Acipenser stellatus*) can now be regarded as extinct faunal elements in the Szigetköz section of the Danube, and other sturgeon species, such as Danube sturgeon (*A. gueldenstaedti*) and ship sturgeon (*A. nudiventris*) are on the verge of extinction.

The age-old river engineering has resulted in several negative impacts on the fish habitats:

- Loss of floodplain habitats and lateral interaction between the river and its floodplain
- Loss of longitudinal connectivity of the river section, caused by dams
- Change in the hydraulics, flow regime and sediment transport
- Change in the thermal pattern, due to faster runoff and reduced inshore retention
- Loss of riverine inshore structure

The construction of flood protection systems at the end of the nineteenth century divided the Szigetköz floodplain into an active floodplain and a flood-free area. The extent of the original inundated area decreased by nearly 80%. The loss of lateral interaction between the river and the former floodplain resulted in the fragmentation and the destruction of aquatic habitats. The flood-free branches and abandoned oxbows have, on the one hand, lost their direct connections with the Danube, and on the other hand, many of them were even buried. Water supply of the abandoned branches was principally ensured by infiltrating groundwater and precipitation. Due to the general disconnection of water bodies, their habitat features transformed to the paleopotamon type. The pristine composition of communities has changed, the rheophilic species disappeared, and the limnophilic elements became characteristic in the fish fauna, such as crucian carp (*Carassius carassius*, tench (*Tinca tinca*), weatherfish (*Misgurnus fossilis*) and mudminnow (*Umbra krameri*). Since the middle of the 1990s, water supply of the branches in the flood-free area has been directly provided from the temporal floodplain water replenishment system. This has resulted in the shifting of habitat character and the dominance of eurytopic species in the fish fauna.

The reduction of flood pulses and the limited range of water level fluctuation have restricted the ecological function of the aquatic-terrestrial transition zone, as well as the food resources and the spawning and nursery grounds for a number of species. These alterations affected the fish production of the Szigetköz area from the mid-1980s, as indicated by changes in the total annual catch of commercial and recreational fisheries between 1968 and 1996 (Fig. 9).

Many of the rheophilic species (*Acipenser ruthenus, Barbus barbus, Chondrostoma nasus*, etc.) migrate considerable distances during the spawning season, looking for suitable habitats in which to reproduce. For numerous fish species, longitudinal migration means a feeding strategy which, by reducing competition, enables the development of fish populations with a high number of individuals. Interrupting the connectivity between the main arm of the Danube and the floodplain side-arms has resulted in a blockage of fish migration into the floodplain spawning habitats, feeding grounds and winter refuges. This may mean a serious threat to the reproductive success and recruitment of the migratory species and can lead to a decline in their populations.

The impact of the deposition of suspended sediment on the fish habitats of the floodplain side-arms is indicated by the long-term changes of the sterlet (*Acipenser ruthenus*). Its annual catch increased to 2000 kg in the 1980s, but declined sharply, to 10 kg by the beginning of the operation of the Gabčikovo hydropower dam in 1992. Changes of hydraulic conditions, caused by the running of the hydropower

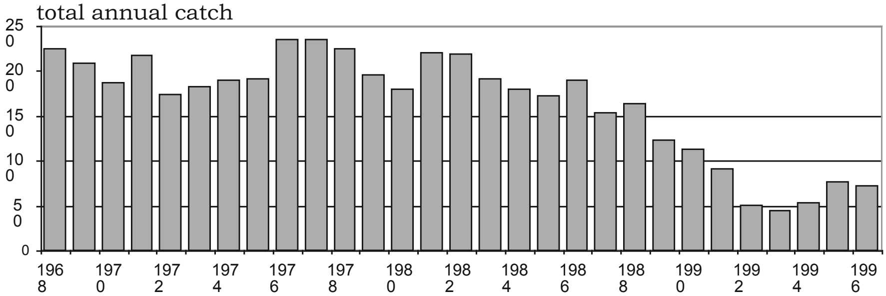

Fig. 9 Changes of the total annual catch of commercial and recreational fisheries in the Szigetköz section of the Danube between 1968 and 1996

station resulted in intensive sedimentation and the accumulation of 346,000 m^3 silt between 1992 and 2005 on former gravel substrate in a 4 km-long side-arm, which was the only spawning site left for the sterlet. Deterioration of the spawning ground would be a reason for the disappearance of the sterlet in the Szigetköz section of the Danube (Guti 2008).

Climate change may be an important factor in the spreading of non-native biological invaders. The Danube is an important spreading route for alien organisms. Rapidly changing climate might favour species which are able to extend their ranges quickly or which can tolerate a wide range of climatic conditions. Invasive species tend to be generalists, and this may increase their success and threaten some native species. Since the beginning of the twentieth century, occurrences of 19 non-native fish species have been observed, 13 of which have a permanent population in the Szigetköz region of the Danube. Since the beginning of the 1990s, four Ponto-Caspian gobiid species (*Ponticola kessleri, Neogobius melanostomus, Neogobius fluviatilis, Babka gymnotrachelus*) have appeared and multiplied. The effects of invasive, alien species on the native fish populations can be demonstrated by the disappearance of the bullhead (*Cottus gobio*) population after the appearance of the Ponto-Caspian gobiid species. Bullhead is known for its sensitivity to temperature, however, it was most probably affected by biotic interactions with the other gobies.

6 Environmental Objectives of River Restoration

Successful rehabilitation of river-floodplain systems requires knowledge of how hydrological dynamics and geomorphic processes lead to a dynamic equilibrium of habitat composition which determines the characteristic biodiversity and the ecological processes of the river ecosystem (Schiemer et al. 2007). Over the past two decades numerous concepts have been elaborated that explain the functioning of river ecosystems (Thorp et al. 2006). These concepts represent a useful background for describing the natural river system of the Szigetköz section of the Danube and the formulation of an evaluation system for restoration.

The increasing human pressure on the catchment of the Danube, impacts of century-old river engineering and the social and economic needs of modern societies generally prevent the restoration of pristine conditions. In addition, irreversible changes, e.g. extinction of species and the impact of climate change, have to be accepted as the framework condition for rehabilitation planning. Thus, environmental objectives do not aim at the reconstruction of a historical landscape nor should the main effort concentrate on the fostering of selected species or species groups: the definition of environmental objectives should rather focus on the hydrodynamic and morphological processes governing the natural riverine ecosystem with its resultant pattern of habitats and diversity of species.

In general terms the goal is to foster hydrological and hydro-morphological dynamics, accepting irreversible changes and intergenerational human needs. This general objective has to be put in practical terms of flow regime predicted hydromorphological dynamics and the resulting habitat composition and habitat quality, which has to be evaluated by biotic indicators. The environmental objectives of river restoration can be defined as a dynamic state of habitat composition and landscape structure, which finally will result in a characteristic pattern of ecological integrity, biological diversity and ecological functions.

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Anthropogenic Pressures on Watercourses of the Danube River Basin in Montenegro

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1 Introduction

The surface area of Montenegro's portion of the Black Sea drainage basin is 7075 km^2, or 0.9% of the entire basin, and is made up of the rivers Tara, Piva, Lim, Ćehotina and Ibar, and Lake Plav. The major polluters of watercourses are wastewaters and solid waste from inhabited settlements. According to water categorization regulations, the rivers of the Danube Basin in Montenegro are, based on the status quo, classified into four quality classes. Thus, the mid- and lower courses of the larger rivers fall within quality classes II and III. The water quality of the Lim, downstream of Berane, worsens at its exit from Montenegro and falls into quality class III. The Ibar profile downstream of Bać is largely out of a prescribed class. The Ćehotina downstream of Pljevlja is in water quality class III, and occasionally out of a prescribed class. The Tara belongs to the Durmitor National Park, but its water quality is class I only at its most upstream profile; its profiles downstream of Kolašin are from class II to class III. These findings are confirmed by analyses of their aquatic macroinvertebrate communities, i.e. Oligochaeta, as bioindicators of water quality. The ichthyofauna of the Danube Basin rivers in Montenegro comprises 20 fish species. Hydromorphological alterations of watercourses, such as dam construction, have a significant effect on fish populations. Thus, the dam on the Piva river has a

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negative effect on the fish population, presenting a barrier to migration routes, as is the case with huchen or Danube salmon (*Hucho hucho*).

Hydromorphological activity, pollution of watercourses and the introduction of alien species pose a major threat to the biota of the Danube Basin watercourses of Montenegro.

2 Anthopogenic Pressures that Affect Surface Waters

The main sources of pollution of surface waters are partially treated and untreated industrial and urban wastewaters, and runoff from agricultural lands. River and lake monitoring mostly comes down to measuring the physical and chemical parameters of water, without an assessment of the effect of these on living organisms. In addition, the concentrations determined as threshold values of the pollutants relate to toxic values and usually do not consider the risk involved in chronic exposure to lower concentrations, nor to a complex mixture of these substances, which may potentially produce a genotoxic effect. Biological, as opposed to physico-chemical, parameters integrate information over a longer time period and describe aquatic ecosystem conditions better.

The functioning of an aquatic system is complex, bearing in mind the various chemical compounds present in the water and sediments, the population of aquatic organisms, water temperature, and the nature of the surrounding land. The major effects of discharging heavily loaded wastewaters, as well as industrialization and urbanization, on surface waters are a decrease in dissolved oxygen, eutrophication and the appearance of toxic substances (Shun 2007). The substances that cause these effects can be of inorganic origin, such as heavy metals, or organic, such as the organic matter from various pesticides used in agriculture.

Water quality assessment requires tracking a broad spectrum of physical, chemical and biological parameters. Monitoring the increasingly prevalent anthropogenic influence/pressure on the environment is one of the priorities of current European studies. The quality of the surface waters in Montenegro is under the constant influence of insufficiently treated municipal wastewaters that are released into watercourses, as well as waters from industrial plants.

3 The Danube Basin in the Territory of Montenegro

The surface area of Montenegro's portion of the Black Sea drainage basin is somewhat larger than the country's Adriatic drainage basin, and covers 7260 km^2 or 52.5% of its territory (Ivanovic et al. 2011). Montenegro contributes to the Danube Basin 0.9% of its territory, an area with 200,000 inhabitants, i.e. 30% of the population (DRBMP 2015). The rivers that run off from that surface are the Tara,

Fig. 1 Danube River Basin in Montenegro

Piva, Lim and Ćehotina, as well as a small part of the Ibar river (Strategic Environmental Assessment 2016). Lake Plav is also part of this drainage basin (Fig. 1).

The majority of Montenegrin rivers are characterized by a high stream gradient (large drop in elevation) which makes them suitable for hydropower exploitation. Nevertheless, only a small part of that potential is utilized. River water levels depend on rain (pluvial) and snow (nival) factors. The Piva, Tara and Lim have a pluvial-nival regime with two maxima (spring and autumn) and two minima (summer and winter) (Bulletin ecologist 2008).

4 The Most Important Rivers of the Danube Basin

The northern and north-eastern areas of Montenegro provide water to the Black Sea, via the Piva, Tara, Ćehotina, Lim and Ibar watercourses (Radulović 1977).

The TARA emerges beneath the peaks of Maglić Kariman (around 2400 m.a.s.l.). It is a typical mountain river. From its source to the Drcka confluence, the right-bank basin is far more developed than the left. The surface area of the Tara river basin belonging to Montenegro amounts to 1900 km^2 (Radulović 1977). The length of the Tara course, together with its tributary the Veruša, equals 150.6 km (Radulović 1977). The Tara is a true canyon river with a 78 km long canyon, in places deeper than 1000 m (Radulović 1977; Nikolić 2000). In addition, the Tara is a water-rich and complex river system, not so much according to average flow, but rather for the complex hydrological phenomena found in the canyon (numerous short tributaries and strong karst springs) (Nikolić 2000). Measuring points for water quality monitoring on the Tara are Crna Poljana, Trebaljevo, Bistrica and Đurđevića Tara (http://www.dinarskogorje.com/rijeke-crnomorskog-sliva-slijeva.html).

The **Durmitor National Park** covers an area of 32,100 ha. It is on the UNESCO World Heritage list—as a Natural Site of Outstanding Universal Value (Nikolić 2000). The Tara requires water quality classification I, because it belongs within a protected area, the Durmitor National Park. However, its water quality is class I only at its most upstream profile. The profiles downstream of Kolašin are class II to III, only to improve at its final profile in Šćepan polje (where it merges with the Piva to form the Drina), to water quality class I to II (Tomović 2008).

The PIVA formed a drainage basin in the high massifs of the mountains of Montenegro. The watercourse is around 31.8 km long. Most of the water supplied to the Piva comes from the Komarnica river (Radulović 1977). The Piva basin surface area is estimated to be around 1784 km^2 down to Šćepan Polje, where it joins the Tara river to form the Drina. There is a high dam in the Piva canyon, a 220 m high construction that enabled the formation of an artificial lake (Mratinje) (Radulović 1977). The Mratinje reservoir is the largest artificial lake in Montenegro, with a surface area of 12.5 km^2 and a maximum depth of 188 m. Measuring points for water quality monitoring on the Piva are Bukovica-Šavnik, Komarnica-Duži and Komarnica-Lonci (http://www.dinarskogorje.com/rijeke-crnomorskog-sliva-slijeva.html).

It can be said that the waters of the Piva are of excellent quality. Water temperatures during all measurements (seasonally) never exceeded 9 °C, and it is still cited as the river with the highest water quality out of all the watercourses monitored (www.meteo.co.me).

The **ĆEHOTINA** course runs for a length of 95.7 km through Montenegro. It flows north-west past Pljevlja and Gradac, and into the Drina river at Foča (Radulović 1977). The section of the river below Pljevlja has been classified as a polluted watercourse for a long time. Even the upstream section, above Pljevlja, is polluted. The state of water quality is affected by agricultural activities, the slowing of the water flow and upstream reservoirs. The Ćehotina is primarily threatened by city sewage waters. Its tributary Vezišnica is most affected by the wastewaters of the Pljevlja thermal power plant, various human activities along its course, as well as low water levels (http://mladi-ekoreporteri.org.me/2014/osnovci-clanci/mer-t-zagadjenje-rijeka.pdf).

The **LIM**, a right-bank tributary of the Drina that emerges from Lake Plav, is around 196.3 km long, of which 87.3 km, or 83.6 km [http://www.meteo.co.me], belong to the territory of Montenegro (Radulović 1977). The river forms a composite valley with alternating gorges and river valleys, and the surrounding area is called *Polimlje*. The Lim basin within Montenegro covers an area of 2880 km^2 up to Dobrakovo (http://www.dinarskogorje.com/rijeke-crnomorskog-sliva-slijeva.html).

The **IBAR** flows through Montenegro for a length of 32 km (Radulović 1977). It is threatened by the wastewaters of Rožaje. It is often turbid and has large amounts of waste.

The basic parameters and data related to the hydrological stations (HS) of the Danube Basin rivers are presented in Table 1. Quantitative hydrological indicators from selected HS are defined on the grounds of measured and calculated data by the "Institute of Hydrometeorology and Seismology of Montenegro" (www.meteo.co.me).

LAKE PLAV is located at the beginning of the Plav-Gusinje valley, between the Prokletije and Visitor mountains, at an altitude of 906 m. It is the largest glacial lake in Montenegro. It has a surface of 2 km^2, an average depth of 3.85 m and a maximum depth of 9.15 m. The lake, which is 2 km long and up to 1.5 km across at its widest point (Nikolić 2000), receives its water supply from the powerful, clear and cold river Ljuča, and the river Lim flows out of it. Therefore, it has great circulation and self-regulation capacities. As a rule, it falls into class I of water quality. But despite this, the lake is exposed to strong anthropogenic pressures from the coastal zone and Gusinje, via the Ljuča river. A particular problem is the accumulation of eroded material that the Ljuča discharges into the lake, sediments that originate from tributaries disposed to torrential flooding (Nikolić 2000). The fish population of this lake, especially burbot (*Lota lota*), its relation with the lake's abiotic factors and ecological characteristics of fish, have been investigated by Nikčević et al. (1995, 1998, 1999).

5 Sources of Watercourse Pollution

Economic development has brought with it increasing pollution of surface and ground waters. The economic development of Montenegro in the 1950s caused significant migration of the population from rural to urban environments, which are mostly on the banks of large watercourses. Numerous enterprises were also established in these areas with business activities that pollute the environment (Radulović 1977).

Montenegro is rich in surface and ground waters, but they are mainly threatened by pollution from untreated communal and waste waters from production lines and inadequate management of water bodies, as well as substantial summer droughts (Ecoremediation strategy in Montenegro 2014). The biggest polluters of Montenegro watercourses are wastewaters and solid waste from inhabited settlements. The water qualities of the upper courses of the Tara, Piva, Ćehotina, Lim and Ibar fall within the prescribed class, with quality decreasing in the downstream sections. The negative water quality is greatly affected by the expansion of populated areas without developed sewage systems and the establishment of small enterprises that release waste waters without oversight or wastewater treatment facilities. The most polluted watercourses in Montenegro are those that belong to the Black Sea drainage basin (Tomović 2008). According to the prescribed categorization of waters, the

Table 1 Hydrological parameters of Danube Basin Rivers in Montenegro

Watercourse	HS	Basin catchment (km^2)	Analysis period	Typical flow rates (m^3/s)				
				Qmin	Qmin sr	Qsr	Qmaxsr	Qmax
Lim	Plav	364	1948–2012	0.244	3.212	19.23	145.5	324
	Bijelo Polje	2183	1948–2014	8.20	12.14	57.14	512.8	1077
Tara	Crna Poljana	247	1957–2014	0.72	1.448	12.01	175.7	468
	Trebaljevo	506	1959–2014	1.55	2.668	24.64	307.8	701
Ćehotina	Ćirovići	120	1978–2006	0.248	0.487	2.117	38.41	106
	Pljevlja	361	1948–2007	0.320	1.274	6.31	65.11	145
	Gradac	810	1963–2011	2.10	3.737	12.90	160.6	414

rivers of the Danube Basin in Montenegro are, based on the status quo, classified into four quality classes. Thus, the larger rivers, in their middle and lower courses, fall within quality classes II and III (Nikolić 2000). While mining and industrial facilities are active, the Ćehotina river downstream of Pljevlja is continuously in quality class IV, due to its small tributary the Breznica taking in untreated communal waters in the city, and the Vezišnica taking in industrial wastewaters. Therefore, the river is practically a dead river in that part of its course, down to its confluence with the Ćehotina. The Ibar is also of poor quality downstream of Rožaja (Ecoremediation strategy in Montenegro 2014). The Ibar waters are polluted by wastewaters primarily from the lumber industry (Radulović 1977).

Sources of pollution can be classified into two groups: concentrated (point) and diffuse (scattered). Point sources of pollution have an identified location from which increased release of pollutants into ecosystems occurs (settlements, industry, agriculture). According to their potential polluting capacity, the following industries belong to this category: the food, chemical, leather, textile, cellulose and paper industry, the surface treatment of metals industry, energy production—thermal power plants, artificial fertilizer production, iron and steel industries, petrochemical industry and mines. Also in the "point" category of polluters are wastewater treatment plants, rainwater drainage channels in settlements if they are not properly maintained and cleaned, and the disposal of contaminated soil (Ritter et al. 2002).

Diffuse sources of pollution represent unidentified sources of ecosystem pollution and usually cover large areas. Agriculture has traditionally been considered a diffuse source of pollution, however, when intensive livestock farming is the case, with large agricultural properties—farms where a large number of cattle are raised in a small space, such farms representing a concentrated source of pollution. The significance of diffuse sources of pollution in Montenegro has still not been quantified in a satisfactory way, regarding its share in the total pollution load, and the non-existence of appropriate by-laws prevents quality management of areas identified as sources of diffuse water pollution. Agriculture is one of the most important diffuse sources of pollution, as well as livestock, the planting and exploitation of forests, landfills, tailings, all forms of transportation and causeways, and tourism (Strategic Environmental Assessment 2016).

In Pljevlja, the biggest concentrated polluters are the "A.D. Pljevlja" coal mine, with the Jagnjilo landfill in the Pljevlja river valley (the largest deposits of lead, coal, zinc, copper, marble, mercury) and the "Šuplja stijena" lead and zinc mineral flotation in Gradac (over an area of 15 ha with over 3.9 million tons of hazardous waste containing heavy metals—lead, zinc, arsenic, etc.) (Radulović 1977). As for the river Lim, the biggest concentrated polluter is the cellulose and paper industry in Berane. Also notable are the textile and cotton industry, and the soft drink and beer industry in Bijelo Polje, as well as the coal mine in Berane (Radulović 1977).

The diffuse polluters of the Lim are, in addition to some 900 sewage pipes that transport fecal and other waste directly into the Lim, effluent and waste from slaughter-houses and poultry farms (http://mladi-ekoreporteri.org.me/2014/osnovci-clanci/mer-t-zagadjenje-rijeka.pdf). A review of the sources of pollution of watercourses is presented in Table 2.

Table 2 Sources of pollution of Danube basin watercourses in Montenegro

City	Economic activity	Watercouses, part of its
Pljevlja	Production of electricity	Vezisnica (2 rkm); Ćehotina (70 rkm)
Pljevlja	Opencast coal mine	Vezisnica (2 rkm); Ćehotina (70 rkm) Water obtained by draining coal mine, discharged in Ćehotina and Vezišnica.
Pljevlja	Opencast mine for the extraction of lead and zinc (started in May 2010)	Ćehotina (43 rkm)
Berane	Wood processing; leather processing	Zlorečica (2 rkm); Lim (175 rkm)
Bijelo Polje	Slaughter-house and wheat packing	Lim (64 rkm)
Kolašin, Mojkovac	Aluminium processing for glass windows	Tara (100 rkm)
Kolašin, Mojkovac	Wood processing	Tara (100 rkm)
Mojkovac	Lead and zinc mine	Tara (100 rkm)
Bijelo Polje	Milk processing	Lim (95 rkm)

Moreover, hydromorphological alterations hold an important place among anthropogenic pressures. These include physical changes to watercourses, as a result of various human activities, which may cause damage and even loss of wildlife habitats, with the loss of plant and animal species that inhabit watercourses. The human activities that lead to such outcomes are watercourse regulation and the construction of regulation facilities, riverbank reinforcement, flood protection structures, exploitation of riverbed and bank materials, the construction of dams and levees and the creation of reservoirs for various purposes (municipal and industry water supply, hydropower exploitation etc.), navigation, tourism, recreation, aquaculture, etc. Dam construction causes major physical alterations to watercourses, slows their flow, increases sedimentation, and has a negative effect on the migratory movements of fish. Thus, the dam on the Piva river has a negative effect on fish populations, as is the case with the huchen or Danube salmon (*Hucho hucho*). Habitat degradation is the most serious negative factor impacting huchen populations. Dam construction, pollution, and river regulation have led to the loss and degradation of spawning sites (Witkowski et al. 2013).

In addition to the pollution of surface waters, there is a lack of understanding of the role of flood plains, marshes and the morphology of natural rivers. Numerous existing regulations of rivers, as well as future plans for regulation of water bodies, do not include ecological measures aimed at evaluating ecosystem services from the ecological and economic perspectives (Ecoremediation strategy in Montenegro 2014).

Also among anthropogenic pressures are small hydropower plants (HPP) that have been increasingly planned in recent years for small watercourses. Renewable energy sources are characteristic in that they enable the exploitation of natural resources in ways that generally endanger the environment less than conventional energy sources do. The development of mini-hydropower plants should be included in other sectors, just as this sector should be included in defining the manner of water resource utilization, environmental protection, spatial planning etc. (Rakočević et al. 2015). The effects of constructing mini HPPs generate numerous construction activities, such as the construction of water intakes, channels and other infrastructure, as well as many accompanying activities, including noise, which affects animal life, obstacles to animal movement, danger of erosion due to vegetation loss, increased water turbidity due to excavation activities and downstream accumulation of sediments. During the working phase of mini HPPs there are potential effects on the flora and fauna due to river course alterations that were not present before. This is especially true for fish, followed by aquatic vegetation, but also the possibility of certain birds losing their riverbank habitats. Potentially, all downstream users of waters who have acquired rights to using a natural/public resource such as a river course may be jeopardized (Strategic Environmental Assessment 2016).

6 Biological Indicators of Water Quality

6.1 Oligochaeta, as Representatives of Aquatic Macroinvertebrates

Aquatic macroinvertebrates are often used as bioindicators in the assessment of water quality and monitoring the status of surface waters for two reasons: the biological characteristics of the groups/species and for technical, i.e. practical, reasons (Martinović-Vitanović et al. 2004, 2007; Jakovčev-Todorović et al. 2005; Đikanović 2007; Paunović et al. 2010). They have the following advantages: they are sedentary or slightly mobile organisms, and thus are typical representatives of the microhabitat conditions they inhabit; they are present in the majority of watercourses; they have a long life cycle, long enough to estimate habitat quality; they have diverse sensitivity to pollutants—their responses cover a wide range; sampling is easy, using simple, inexpensive equipment. The disadvantages are: determination of individual organisms is complex and lengthy; high spatial heterogeneity, and they inhabit a large number of diverse microhabitats (Rosenberg and Resh 1993).

Analyzing the presence of freshwater Oligochaeta in Montenegrin waters, it is notable that out of 82 species, 56 (from 31 genera and 8 families) are found in Black Sea drainage Basin. Of these, *Potamothrix hammoniensis* is the most frequent species in this drainage basin (48.93%). The highest density of Oligochaeta in rivers of Black Sea drainage basin was recorded in the Ibar River, the next highest was the Ćehotina River. The smallest total number was recorded in the Piva River. Also, in the rivers belonging to the Black Sea drainage basin the most abundant species was *Nais elinguis*; in second place was *Limnodrilus hoffmeisteri*, then *Nais barbata* and

Nais communis. At lowest density were the species *Chaetogaster diaphanous* and *Limnodrilus profundicola*. Ćehotina and Vezišnica rivers are characterized with water of α-mesosaprobic level. In the Lim river, the saprobic level ranged from β-mesosaprobic to α-mesosaprobic level (Šundić and Radujković 2012). The water of the Ibar is classified within categories I–II, II and II–III based on the value of saprobic index. In the rivers Tara and Piva β-α-mesosaprobic level prevailed, indicated by values of saprobic index. The Ćehotina River is exposed to a significant pressure of toxic materials of organic and inorganic nature from municipal and industrial waste water. Anthropogenic activities, such as opencast coal exploitation, industrialization, urbanization and agriculture, have negative influence on the Ćehotina river and its wildlife. All the released waste waters contain various concentrations of hazardous and noxious substances (Šundić and Radujković 2012).

7 Other Group of Aquatic Macroinvertebrates, as a Bioindicators

With the exception of Oligochaeta, the other groups of macroinvertebrates have rarely been used as bioindicators of water quality in the watercourses of the Montenegro part of the Danube Basin. Płóciennik and Pešić (2012) studied chironomid fauna of Montenegro river (Ćehotina). Assemblages in the Ćehotina river are of taxa typical for unpolluted cold, fast-flowing streams with stony bottoms, mainly with Orthocladiinae from *Cricotopus* and *Orthocladius* group as well as with *Synorthocladius semivirens* and *Eukiefferiella ikleyensis*. Numerous too are *Nilotanypus dubius*, *Diamesa* and *Polypedilum convictum*. The occurrence of amphibiotic taxa in these waterbodies may be associated with temporary lowering of water level and presence of semi-terrestrial habitats (Płóciennik and Pešić 2012). On the other hand, in the fisheries management plans, for the watercourses of the Montenegro part of the Danube Basin the most commonly used index is EPT%. This is one of the most often used indexes for quality assessment and the level of organic pollution. For example, a study of the fisheries management plan for the Tara river (Marić 2016) showed that the quality of the Tara river during both investigated seasons (spring and summer) was excellent (>70%) at all localities, with the exception of the locality downstream of Kolašin where the quality was good.

A large number of endemic and threatened species of macroinvertebrates have been registered in the Black Sea drainage basin of Montenegro, of which at least four are protected by law (Official Gazette RM N. 76/06a): *Dina lineata montana* Sket, 1968, a species of leech that inhabits mountain streams of the northern part of Montenegro (Grosser et al. 2015), *Hydroporus discretus* Fairmaire & Brisout 1859, a species of aquatic beetle that inhabits mountain springs (Pavićević and Pešić 2011), *Stygohydracarus karanovici* Pešić 2001, a species of aquatic mite (Hydrachnidia) that inhabits ground waters of Lake Plav (Pesic 2001), and

Niphargus carcerarius Karaman 1989, a troglobiontic amphipod species known from a single cave on the banks of the Tara river.

8 Fishes as an Adequate Bioindicators for Water Quality Assessment

According to the Water Framework Directive (WFD 2000), fish represent one of the most important elements of the biological quality of aquatic ecosystems. The species content, abundance and age structure are the minimal data that need to be utilized in ecological status assessment. In addition, condition factors, data on fish population replacement and parasites are also recommended by the WFD as additional parameters that ought to be analyzed (Morina et al. 2016).

The Tara-Piva-Drina system, as part of the Danube system, is important as a system of highland waters that enables the preservation of the gene-pools of fish species such as the brown trout, huchen and grayling. These three species are exceptionally valuable, and are important for development of sport fishing tourism. So far, 8 fish species have been registered in the Tara, 9 in the Piva and around 15 in the Drina (Janković and Krpo-Ćetković 1995).

There are 20 autochthonous fish species registered in the Black Sea drainage basin of Montenegro (Marić and Milošević 2011). A list of fish species in the watercourses belonging to the Black Sea drainage basin is given in Table 3.

The huchen or Danube Salmon is a sensitive indicator species for some of the most ecologically valuable rivers in the Danube drainage. Core areas, representing the largest and healthiest huchen populations have been identified and include the Lim river in Montenegro. The most important river in terms of habitat length is the Drina, together with its major tributaries the Lim and Tara, totalling 30% (553 km) of the Balkan huchen distribution. For the Balkan region, by country, and counting frontier rivers twice, 240 km lies in Montenegro. Self-sustainable Huchen populations in Montenegro are found in the Tara river (70 km) and Lim river (157 km) with decreasing and increasing population trends, respectively. While hydropower development is already responsible for considerable loss of habitat in the Balkan region (the Piva river in Montenegro), much of the historical decline is thought to be the result of pollution. Habitats lost by pollution and overfishing could be restored. In some rivers in Montenegro, for example, increased awareness and the economic benefits of tourist fisheries have helped to bring some of the illegal fishing in that region under control, resulting in stable or even increased huchen and grayling stocks in the Lim and Ćehotina rivers, the latter considered Montenegro's best current huchen habitat (Freyhof et al. 2015).

The construction of industrial plants, numerous hydromorphological activities on watercourses, the creation of reservoirs, as well as the introduction of alien (allochthonous) fish species, represent a serious threat to the destruction of the autochthonous biodiversity of fish populations in Montenegro. The introduction of

Table 3 Fish species in the watercourse of the Danube basin in Montenegro

Fish species	Aquatic ecosystem	Record
Family:Salmonidae		
Hucho hucho	Lim (mostly lower part), Tara (mostly lower part), Ćehotina	Taler (1954), Drecun (1962), Krivokapić and Marić (1993)
	Piva	Knežević and Marić (1989)
	Lake Plavsko	Marić and Milošević (2011)
Salmo labrax	Lim (upper part) Tara Ćehotina	Janković (1964), Vuković and Ivanović (1971), Marić (1995), Krivokapić and Marić (1993)
Thymallus thymallus	Tara	Krivokapić and Marić (1993)
	Piva Ljuča (tributary of the Lake Plavsko) Ćehotina (upper part)	Marić and Milošević (2011)
Family:Esocidae		
Esox lucius	Lake Plavsko	Taler (1954), Drecun (1962)
Familija: Cyprinidae		
Alburnus alburnus	Lim (lower part)	Marić and Milošević (2011)
Alburnoides bipunctatus	Piva (no after 1962)	Knežević and Marić (1989)
	Tara (no after 1962)	Krivokapić and Marić (1993)
	Lim	Drecun (1962), Marić and Milošević (2011)
	Ćehotina	Marić and Milošević (2011)
Barbus balcanicus	Tara Ćehotina Lim	Marić and Milošević (2011)
Barbus barbus	Tara Lim	Taler (1954), Drecun (1962)
	Piva Tara	Drecun (1962)
	Ćehotina	Marić et al. (2010)
Chondrostoma nasus	Tara	Drecun (1957, 1962), Krivokapić and Marić (1993)
	Lim Ćehotina (lower part)	Drecun (1962), Marić and Milošević (2011)
	Plavsko jezero	Marić and Milošević (2011)
Gobio obtusirostris	All Danube basin	Drecun (1962)
	Piva	Knežević and Marić (1989)
	Lim Ćehotina	Marić and Milošević (2011)
Phoxinus phoxinus	All Danube basin	Drecun (1962)
	Tara	Krivokapić and Marić (1993)
	Piva	Knežević and Marić (1989)
	Lim Ćehotina Lake Plavsko	Marić and Milošević (2011)

(continued)

Table 3 (continued)

Fish species	Aquatic ecosystem	Record
Rutilus rutilus	Lake Plavsko	Knežević (1980)
Scardinius erythrophthalamus[a]	Lim (not after 1962)	Drecun (1962)
Squalius cephalus	Piva (prior to immersion)	Knežević and Marić (1989), Marić and Milošević (2011)
	Lake Plavsko	Stevanović (1953)
	Lim Ćehotina	Marić and Milošević (2011)
Telestes agassii	Tara (lower part)	Krivokapić and Marić (1993)
	Piva (prior to immersion)	Knežević and Marić (1989)
	Lim Ćehotina Ljuča (tributary of the Lake Plavsko)	Marić and Milošević (2011)
Familija: Balitoridae		
Barbatula barbatula	Lim	Drecun (1962)
	Ćehotina	Drecun (1962), Marić and Milošević (2011)
Familija:Cobitidae		
Cobitis elongata	Lim	Marić and Pavlović (2006)
Misgurnus fosilis[a]	Lim (new data not cited)	Drecun (1962)
Sabanejewia balcanica	Lim (downstream of Bijelo Polja)	Marić et al. (2010)
Familija:Cottidae		
Cottus gobio	Piva and tributaries	Knežević and Marić (1989)
	Tara and tributaries	Krivokapić and Marić (1993)
	Lim (upper part) Ćehotina Lake Plavsko	Marić and Milošević (2011)
Familija: Lotidae		
Lota lota	Lake Plavsko	Drecun (1962)
	Lim	Marić and Milošević (2011)

[a]These two species, which were reported by Drecun (1962), were not identified in the watercourses belonging to the Black Sea basin in Montenegro

alien species should be reduced to minimal levels and without any negative effect on the autochthonous ichthyofauna. One must by no means perform the introduction of fish species that will be useful in only one basin, because any accidental or intentional translocation can be detrimental to other organisms. If possible, the material for fish repopulation should be cultured in special fishponds that are designated for those purposes (Marić and Milošević 2011).

Montenegro has the smallest total area of all Balkan countries, but has a very rich and diverse ichthyofauna. The basic principle of endangered species protection is based on the knowledge and investigation of species' characteristics. This means that conservation of ichthyofauna is only possible by preserving the species and its unique parental gene pool. That requires the protection and conservation of fish within their natural habitats, the conservation of those habitats, and improving legal regulation (Marić and Milošević 2011).

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Human Impacts on Fish Fauna in the Danube River in Serbia: Current Status and Ecological Implications

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1 The Danube River in Serbia

In Serbia, the Danube River extends over a distance of 588 km and covers the middle and the lower part of the Danube basin. The Danube flows through different sections with regard to geological, climatic, vegetational and hydrological conditions, which significantly influences the diversity of its local characteristics (Behr 1991). The major part of the Danube flow through Serbia belongs to the Panonian basin. In this section, Danube is a typical lowland river. The Tisza River is the longest Danube tributary (966 km), and the sub-basin of the Tisza River is the largest one within the Danube River basin (157,186 km^2). The Sava River is the second largest tributary of

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the Danube in Serbia, and represents one of the most significant basins in the region. The third largest tributary is the Velika Morava River, with the total basin area of 37,444 km^2, which also comprises two major tributaries, Južna and Zapadna Morava.

The Danube River basin represents a hotspot for the European freshwater diversity (Sommerwerk et al. 2009). The high level of biodiversity richness in the Danube is mainly caused by its position and natural history conditions. Diverse habitats provide conditions for the presence of rich flora and fauna, which also includes over 100 different fish species, among them six endangered sturgeon species. The Danube watershed within Serbia has 390 protected areas of national and international importance (Paunović et al. 2007), which makes this part of the Danube of particular importance for the preservation of biological diversity.

In the following text, major adverse anthropogenic impacts on the Danube fish communities in Serbia are presented, such as water pollution, unsustainable fishery, habitat fragmentation and non-native species invasions, and the critical management measures are discussed, such as those related to supportive stocking and other conservation efforts. Key elements of fish fauna are also described, and the recommendations are given for achieving effective protection and sustainable utilization of fish resources in the Danube.

2 Water Quality

Given that the Danube flows through numerous industrial and urban centres, it receives a significant amount of pollution. The steady degradation of the Danube's environment destroyed much of the aquatic biodiversity. Besides urban and industrial waste, the river is also a recipient of agricultural land runoff. According to available data, water quality was particularly impacted between the 1950 and 1970s downstream from cities and industrial areas in the Upper Danube. Nowadays, the main flow of the Danube has relatively good water quality classes II to II–III (Sommerwerk et al. 2009). However, deterioration of the environmental quality near large cities and poor water quality in some tributaries are still contributing to the poor environmental conditions in the entire basin.

Nutrient pollution, particularly by nitrogen (N) and phosphorus (P), can cause an accelerated growth of algae and plants and lead to a disturbance of the ecosystem balance and to the water quality deterioration. Based on estimations for the period 1988–2005, about 35,000 tones of P and 400,000 tones of inorganic N were on average introduced by the Danube into the Black Sea each year. Organic pollution is mainly caused by the emission of partially treated or untreated wastewater from settlements, industry and agriculture. The most serious organic pollution problems are occurring in tributaries, which regularly receive untreated or inadequately treated wastewater from industrial plants and municipalities. Organic pollution can cause significant changes in the oxygen balance of surface waters. As a consequence, it can impact the composition of aquatic species and populations. Pollution by hazardous

Table 1 Prescribed maximum allowable concentrations (MAC, mg/kg) of heavy metals and trace elements in fish meat in the Republic of Serbia (Official Gazette of RS, No. 28/2011)

Pb	Cd	Hg	As	Fe	Cu	Zn
0.3	0.05	0.5	2.0	30.0	30.0	100.0

Table 2 Prescribed maximum residue levels (MRL, mg/kg) of organic pollutants in fish meat in the Republic of Serbia (Official Gazette of RS, No. 25/2010, 28/2011 i 20/2013)

∑ PCB	Trans/cisheptachlor epoxide, dieldrin, HCB	∑DDT + DDD + DDE	γ-HCH
3.0	0.02	0.1	0.01

substances can remain in the environment for a long time and accumulate along the food chains, seriously damaging riverine ecosystems and consequently impacting human health, even at low concentrations. Hazardous substances include man-made chemicals, naturally occurring metals, oil and its compounds, endocrine disruptors and pharmaceuticals.

Fish are often exposed to high levels of pollution in the water and sediment, which can lead to a multitude of various consequences, such as biological changes and population-level shifts, and ultimately to a biodiversity loss (Bernet et al. 1999; Shparyk and Parpan 2004). The major pollution sources are agriculture, communal waste waters, industry and mining, with most common types of pollutants being represented by nutrients, metals and trace elements, chlorinated pesticides (OCP), polychlorinated biphenyls (PCB) and polycyclic aromatic hydrocarbons (PAH; Kumar Singh et al. 2007; Nie et al. 2012).

Fish are at the very top of the food chain in aquatic ecosystems (Yilmaz et al. 2007) and are considered to be among the most sensitive organisms to the presence of toxic substances in the water (Alibabić et al. 2007). Given that the level of contamination of fish can serve as an indirect indicator of the degree of contamination of an ecosystem (Trbović et al. 2011), the monitoring of contamination in commercially important fish species has an exceptional significance (Erdoğrul and Erbilir 2007; Yilmaz et al. 2007). Metals and trace elements, due to their ability to transfer and accumulate along the food chains, are considered as key pollutants of the aquatic ecosystems (Olojo et al. 2005; Erdoğrul and Erbilir 2007). The group of Persistent Organic Pollutants (POP), which includes PAH, PCB, dioxins and pesticides, represents a group of complex organic compounds. The greatest human exposure to chlorinated pollutants is through diet, as about 90% of these pollutants enter the body through food products of animal origin, primarily fish (Baldassari et al. 2007; Cole et al. 2009).

Republic of Serbia established maximum allowable concentrations (MAC) by the national regulation for the following metals and trace elements (Table 1): arsenic (As), cadmium (Cd), copper (Cu), mercury (Hg), lead (Pb), iron (Fe) and zinc (Zn). They are prescribed mainly for the muscle tissue, given that this is the main tissue utilized in the human diet (Baltić and Teodorović 1979). National regulation also comprises established maximum residue levels (MRL) for key organic pollutants (Table 2).

City Institute of Public Health of Belgrade regularly monitors the concentrations of metals, trace elements and key organic pollutants in the meat of different fish species from the Danube River. During 2011 and 2012, increased Hg concentrations were detected in the meat of predatory fish species. During the same period, concentrations of Pb and As were significantly below MAC (Table 1), while Cd concentrations were above MAC in 2012. While PCB and organochloride insecticide degradation products were detected in all tested fish species, concentrations were below MRL. Concentrations of PAH, organochloride insecticides and herbicides were below the level of detection of the analytical method (City Institute of Public Health 2011, 2012).

Janković et al. (2011) assessed PCB concentrations in the meat of various Danube fish species: wels catfish (*Silirus glanus*), northern pike (*Esox lucius*), freshwater bream (*Abramis brama*), crucian carp (*Carassius carassius*), pike-perch (*Sander lucioperca*), barbel (*Barbus barbus*), tench (*Tinca tinca*), sterlet (*Acipenser ruthenus*), common carp (*Cyprinus carpio*) and bighead carp (*Hypophthalmichthys nobilis*). PCB concentrations were below MRL in all meat samples (i.e. less than 3 mg/kg, according to the Official Gazette of FRY, No. 25/2010, 28/2011 and 20/2013). Such findings were also supported by the study of Djinović-Stojanović et al. (2013), who determined that the concentrations of organochlorine pesticides and PCB in the meat of white bream (*Blicca bjoerkna*) and barbel from the Danube River were below MRL. Conversely, Trbović et al. (2011) determined that the concentrations of DDT, DDE and DDD in asp (*Leuciscus aspius*) and barbel were slightly above MRL (Table 2).

Numerous studies were carried out in the area of the Danube basin regarding the metal and trace element concentrations in fish tissues. Research included species from different trophic levels, such as barbel, burbot (*Lota lota*), common carp, freshwater bream, pike-perch, Pontic shad (*Alosa immaculata*), silver carp (*Hypophthalmichthys molitrix*), sterlet, wels catfish, racer goby (*Babka gymnotrachelus*), and round goby (*Neogobius melanostomus*). In most of the analyzed species, metal and trace element concentrations in fish meat were below prescribed MAC (Jarić et al. 2011; Lenhardt et al. 2012a; Sunjog et al. 2012; Subotić et al. 2013a, b; Jovičić et al. 2015; Rašković et al. 2015). However, Trbović et al. (2011) found significantly higher Hg concentrations in the meat of the asp (1.255 mg/kg). Moreover, in a study focused on the metal and trace element accumulation in the tissues of the Pontic shad, As and Cd concentrations exceeded MAC in most of the analyzed muscle tissue samples (Višnjić-Jeftić et al. 2010). Possible reason for the higher concentrations of Cd in muscle tissue could be accumulation through food, given that Pontic shad feeds on contaminated anchovies, or through high Cd concentrations in sediments in the northwestern part of the Black Sea (Secrieru and Secrieru 2002).

Water quality in the Danube River Basin is substantially influenced by the inputs of pollutants. However, scientific studies and monitoring activities have not revealed concentrations of pollutants in the meat of fish species from the Danube River that would be considered alarming. Given that the Danube represents an international river, it is necessary to conduct regular monitoring activities (Hills et al. 1998).

3 Commercial and Recreational Fishery

Water ecosystems in Serbia are characterized by great diversity, which resulted in suitable conditions for the development of abundant and diverse fish stocks. Such conditions were the major reason for the continuous presence of fishing activity in this region since the Neolithic period (Hegediš et al. 2013). Inland fishery in Serbia represents common and traditional activity of local inhabitants, within the broader scope of widespread "living-by-the-rivers" lifestyle in the whole Panonian region. Given that this region is comprised of a largely rural population and that fishing plays an integral part of the livelihood, most households in the villages in the vicinity of the Danube River depend on fishing to a certain degree (Smederevac-Lalić et al. 2011a).

The Danube River, and two large tributaries, Sava and Tisza, are the only areas in Serbia where commercial fishing is allowed, and it is estimated that there are approximately 75–85 fish species inhabiting the river Danube (Smederevac-Lalić et al. 2011a). However, only one third of the species is considered attractive for fishing, while 39 species are protected by the fisheries legislation through permanent or temporary seasonal closures, as well as by restrictions such as minimal landing size and daily limits (Smederevac-Lalić et al. 2011a).

Fishing sector in Serbia comprises commercial, recreational and cropping fishing (to prevent the development or reproduction of non-native species). The current organization of the entire sector in Serbia is divided between four different ministries (Smederevac-Lalić 2013). Fishing regulations are generally well-developed through a number of laws and regulations. However, insufficient practical application of the legislation indicates that fishery sector has been developed without adequate harmonization with socio-economic characteristics of the area (Smederevac-Lalić 2013). Socio-economic status of fishermen represents an important factor that affects the sustainability of fishery resources and fishing activity. The number of active commercial fishermen in Serbia experienced a trend of a constant decline, as the sector failed to find its proper place in the transition process. Nowadays, commercial fishery represents a marginalized branch of the industry.

Recreational fishery catch was characterized by an increasing trend over the last decade (Table 3). However, as opposed to the majority of the European countries where recreational fishing has no more than a leisure activity character, associated with the standard of living, this kind of fishing activity in Serbia has a different character, and represents an additional source of income or supplement to the family nutrition (Smederevac et al. 2006). Due to a weakly organized fishing sector, which is also frequently subjected to political and management changes, there is a presence of significant level of illegal, unreported and unregulated fishing (IUU). Fishery governance institutions are still lacking adequate enforcement mechanisms to fight corruption and poaching.

Estimation of the actual fishing pressure from both commercial and recreational fishery is difficult. Recreational fishermen, as opposed to commercial fishermen, are mostly dispersed, which makes the monitoring of their activities much more difficult

Table 3 Annual number of active fishermen according to the issued licences, and their catch (in tonnes; Statistical office of the Republic of Serbia)

Year	2006	2007	2008	2009	2010	2011	2012	2013
Commercial fishermen	1051	611	520	667	502	493	488	511
Catch	1695	1447	1683	2112	2002	2260	1935	2235
Catch/fishermen	1.613	2.368	3.237	3.166	3.988	4.584	3.965	4.374
Recreational fishermen	94,896	103,045	85,524	106,559	84,875	78,945	80,919	77,589
Catch	936	1088	1468	1732	2805	3124	2863	2805
Catch/fishermen ($\times 10^{-3}$)	9.9	10.6	17.2	16.3	33.0	39.6	35.4	36.2
Commercial/recreational fishermen ratio	1.81	1.33	1.15	1.22	0.71	0.72	0.68	0.80

and is therefore likely to result in higher catch rates than those that are officially reported.

Fish catch statistics for the territory of Serbia was recorded by species since 1951. Catch was characterized by uniform oscillations until 2005, whereas a drastic increase in the total catch has been recorded afterwards. According to the official statistics, the total fish catch in Serbia was increasing as a result of a higher prevalence of lower-quality fish and non-native species in the total catch, the increase in the number of recreational fishermen, as well as due to the introduction of obligatory catch records keeping by local fishery managers, which resulted in improved catch reporting. The unreliability of statistics after the 1990 was the result of inadequate organization, the absence of catch redemption, and a lack of application of standardized methods for data collecting. Available freshwater fishery catch data in the Statistical Office of the Republic of Serbia is mostly based on the landing reports made by the public or private companies which were assigned to manage particular water resources. Unfortunately, there is a lack of data on the historic CPUE for the Danube River in Serbia (Jarić et al. 2015a).

Most frequently listed species in the landing books since 2006 were sterlet, common carp, wels catfish, pike-perch, northern pike, grass carp (*Ctenopharyngodon idella*), silver carp, bighead carp, freshwater bream, European perch (*Perca fluviatilis*), barbel, Prussian carp (*Carassius gibelio*), rudd (*Scardinius erythrophthalmus*), asp, chub (*Squalius cephalus*), common nase (*Chondrostoma nasus*), rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*), huchen (*Hucho hucho*), and tench (since 2009 placed under permanent closed season). Although Prussian carp, bighead carp, and silver carp were recorded in catch already in 1969, these three non-native fish species did not reach the status of economically important species until 1977 (Smederevac-Lalić et al. 2011a).

In general, fishery in the Danube in Serbia has been characterized over the past century by increasing fishing intensity, IUU fishing practices, and a lack of available information on the actual status of fish stocks. There are indices that the diversity of the fish species has changed spatially and temporally, with the major reduction in their diversity manifested since 1950. Fishery landings time-series can provide indications of changes in community composition. Combined use of catch time-series and different indices, such as those related to life history, resilience to fishing or mean trophic levels (i.e. those focused on the 'fishing down the food web' phenomenon) revealed negative trends in the exploited fish stocks in the Danube River in Serbia (Jarić et al. 2015a). Reported landings shifted towards smaller fish, situated at lower trophic levels, which also mature earlier, have a shorter lifespan, and are more resilient to fishing. It should be noted that the composition of landings is commonly influenced by a complex set of factors that are difficult to differentiate and understand and, besides overfishing, observed negative trends in life history traits of the exploited fish species might be also partly influenced by the changes in the environment, such as construction of dams, river regulation, climate change, pollution or eutrophication (Jarić et al. 2015a).

Fishery in Serbia was characterized by a constant increase in the fishing effort, primarily through increased prominence of recreational fishery. Fishery was targeting especially the most valuable fish species such as common carp, wels catfish and pikeperch (Smederevac-Lalić et al. 2011a; Smederevac-Lalić 2013). As a result of intensified fishery pressure, increased presence of illegal fishery, as well as other human impacts on freshwater ecosystems, there are indices of overfishing and of the decline of some native fish populations, followed by an increasing presence of non-native species.

4 River Regulation and Habitat Fragmentation

Rivers in Serbia shared the same fate as the other European rivers, with respect to the presence and magnitude of anthropogenic physical influences. Only a small number of streams, mostly in secluded, inaccessible mountainous areas, have escaped such adverse impacts, such as river fragmentation and loss of physical integrity. The oldest known man-made physical influence on rivers in Serbia was flow regulation of large lowland rivers (Danube, Sava and Tisza) by channel and embankment construction. Drainage ditches were constructed in the region as early as in the IV century, while the channelization of the future hydro-amelioration system Danube-Tisza-Danube (DTD) was initiated at the beginning of the XVIII century. However, first efforts towards organized flood prevention system were made around the middle of the XIX century. Most of the embankment and DTD system construction was completed after the Second World War, with the work being finalized near the end of the 1970s. Following the construction of the flood prevention system, swamplands, flood zones and the historic fish spawning areas were transformed to agricultural lands and uniform draining and irrigation channel systems. DTD system is 929 km long and comprises 24 weirs, 16 navigation locks, five safety gates, six pumping stations and 180 bridges, while 664 km of the system is open for navigation. During the construction, large sections or even whole natural rivers in Vojvodina province

Fig. 1 Satellite image of the Mrtva Tisza

were incorporated within this channel system. Such measures required substantial regulation of the river flow, which often resulted in the isolation of river meanders and their transformation into still waters, such as the Mrtva Tisza (Fig. 1). Due to the proximity of agricultural lands and settlements, large influx of nutrients will likely result in eutrophication, vegetation overgrowth and ultimately in the disappearance of all such water bodies in Vojvodina province.

Construction of dams and formation of water accumulations also has a long history in Serbia. The first such construction was made in the VI century on the Caričina River in southern Serbia, and it was used together with the aquaduct to supply water to the city Justiniana Prima. In recent history, dams were constructed mainly for energy production, such as the dam constructed in 1930 on the Djetinja River near the city of Užice, as well as for water supply, i.e. the dam constructed in 1937 on the Grošničko Lake near the city of Kragujevac. However, construction of larger dams and accumulations with the volume exceeding 10 million m^3 of water started only after the Second World War (Anonymous 2001). Such accumulations are Vlasina Lake, Međuvršje and Zvornik Lake, which were built between 1946 and 1957. Other larger dams and accumulations were constructed between the 1960s and 1990s (Fig. 2).

Beside their primary purposes, newly formed artificial lakes were commonly perceived as an opportunity to develop new resources for commercial and recreational fishery. Consequently, as well as due to the awareness of the expected negative impacts of dams on fish fauna, construction of some older dams was followed by the establishment of aquaculture facilities and hatcheries that were intended to compensate adverse impacts and facilitate development of newly established fish stocks (i.e. dams in the Perućac Lake, Iron Gates and the Vlasina Lake). However, those facilities were later on used only for commercial production, and the practice of the establishment of aquaculture facilities at the dams was later abandoned.

Interruption of migratory pathways of fish is recognized as one of the major negative impacts of dam construction. Adverse effects are especially manifested in anadromous species, such as sturgeons and shads. By preventing their upstream spawning migration, dams constructed in the Iron Gate gorge have contributed to the decline of their populations in the Danube, and represent one of the major threats to their survival (Lenhardt et al. 2006a). Such adverse impacts can be to an extent alleviated by fish passes, and there are ongoing initiatives to construct fishways at the two Iron Gate dams. Nevertheless, the dam on the Drina River at the Zvornik Lake is currently the only dam in Serbia that has a fish pass.

In addition to large dams, in Serbia there are also numerous other, smaller hydrotechnical objects. They mostly represent 2–10 m high dams with small water accumulations, or without them, such as anti-erosion dams or flood prevention weirs. During the period between 1961 and 1988, as much as 3200 such dams were constructed in Serbia on different rivers and streams, on average about 125 dams per year (Anonymous 2001). Although the potential negative impacts of these objects on biodiversity have received poor attention so far, it is likely that they might produce same effects as larger dams, such as habitat fragmentation, impairment of the physical integrity of water flow, and migration route obstruction.

In 2001, water engineering system in Serbia comprised in total 3550 km of embankments, 60 large dams and over 100 smaller accumulations, as well as 14,922 anti-erosion dams and flood prevention weirs. There was a plan to achieve the construction of further 242 km of embankments and 33 accumulations with the water volume over 10 million m^3 by 2021, as well as a large number of smaller dams and weirs. Although the difficult economic situation will apparently prevent full realization of this plan, it might be expected that severe floods, which occurred in Serbia during the spring 2014, will influence increased interest in sustainable irrigation measures and improved efforts towards construction of dams for water supply, industry, energy, irrigation and erosion and flood prevention.

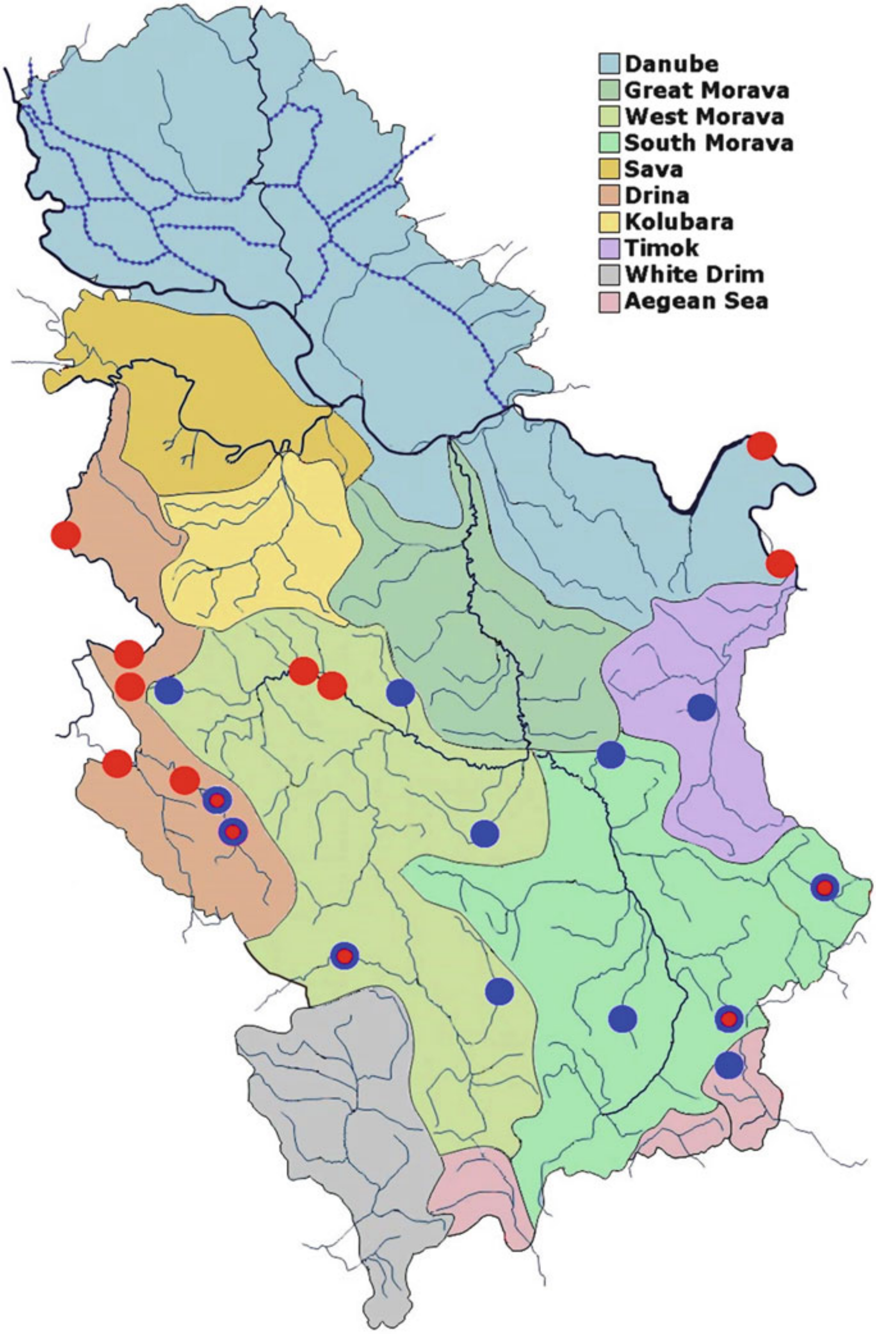

Fig. 2 Map of the Republic of Serbia with 22 large dams (red dots—energy production, blue dots—water supply, red/blue dots—both purposes) and the DTD system (blue dotted lines)

5 Invasive Species

The introduction of non-native fishes into drainages outside their natural range has occurred for centuries (Leonardos et al. 2008), and it may be traced back to the beginning of the first century A.D. (Holčik 1991). The principal pathways of introduction of non-native fish species include aquaculture, deliberate and accidental introductions, and ship ballast waters (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, which also includes the Main-Danube Channel (Panov et al. 2009).

In the Danube River basin in Serbia, non-native fish fauna comprises 25 recorded species (Table 4). The largest number of fish species originated from North America (10), Asia (6), Ponto-Caspian region (6), Europe (3) and South America (2). Four species (Prussian carp, brown bullhead *Ameiurus nebulosus*, black bullhead *A. melas* and pumpkinseed *Lepomis gibbosus*) now occupy more than 50% of the territory of Serbia, five species (bighead carp, silver carp, grass carp, stone moroko *Pseudorasbora parva* and rainbow trout) cover 20–50% of the territory and five species from the Gobiidae family (monkey goby *Neogobius fluviatilis*, racer goby, bighead goby *Ponticola kessleri*, round goby, and western tubenose goby *Proterorhinus semilunaris*) inhabit 10–20% of the territory (Lenhardt et al. 2011). Other invasive fish species registered in Serbia have a limited distribution or there are only records of individual specimens, without an indication of the existence or the area covered by established populations of these species.

Earlier introductions of non-native fish species into Serbian waters were made primarily in order to increase fish production, as well as for weed control and sport fishing (Lenhardt et al. 2011). During the 1960s, several Asian fish species were introduced in Serbia primarily for aquaculture and control of macrophyte vegetation in the newly formed channel network. Since the early seventies, the expansion of the Gobiidae family was recorded along the Danube River, mainly due to the construction of dams and channels which connect large rivers (Brandner 2014). In recent years, a significant expansion of the range of some species such as monkey goby was registered (Đikanović et al. 2013), while there were first records of five non-native fish species in the Danube in Serbia. Mississippi paddlefish (*Polyodon spatula*) and the hybrid striped bass (*Morone saxatilis* × *M. chrysops*) entered the Danube River by escaping from the aquaculture facilities in Romania and Hungary, with only a few specimens being observed (Lenhardt et al. 2006b; Skorić et al. 2013). The two South American fish species recorded in Serbia, Amazon sailfin catfish (*Pterygoplichthys pardalis*) and guppy (*Poecilia reticulata*), were most probably released by aquarists. Only a single individual of the Amazon sailfin catfish was registered in the Danube (Simonović et al. 2010), while a stable population of the guppy was recorded in a termal stream near the city of Niš (Milenković et al. 2013). Although the Amur sleeper (*Perccottus glenii*) invaded the Danube River only recently (Hegediš et al. 2007; Jarić et al. 2012), it is one of the most widespread non-native invasive fish species in Eurasia (Reshetnikov and Ficetola 2011). Together with stone moroko, it

Table 4 Non-native fish species in the Danube River basin in Serbia

Species	First record/introduction purpose	Native range
Hypophthalmichthys nobilis	1963/Aquaculture	Asia
Hypophthalmichthys molitrix	1963/Aquaculture	Asia
Ctenopharyngodon idella	1963/Aquaculture, weed control	Asia
Carassius gibelio	1960/Accidental	Asia
Pseudorasbora parva	1978/Accidental	Asia
Oncorhynchus mykiss	Between World War I and II/Aquaculture, sportfishing	North America
Salvelinus alpinus	Between World War I and II/Sportfishing, fill vacant niche	Europe, North America
Salvelinus fontinalis	Between World War I and II/Sportfishing	North America
Coregonus peled	1991/Sportfishing	Europe
Ameiurus nebulosus	1930/Aquaculture	North America
Ameiurus melas	2005/Aquaculture	North America
Lepomis gibbosus	1930/Ornamental fish	North America
Micropterus salmoides	1984/Sportfishing	North America
Syngnathus abaster	1998/Range expansion	Ponto—Caspian
Neogobius fluviatilis	1977/Range expansion	Ponto—Caspian
Babka gymnotrachelus	1991/Range expansion	Ponto—Caspian
Ponticola kessleri	1977/Range expansion	Ponto—Caspian
Neogobius melanostomus	1998/Range expansion	Ponto—Caspian
Proterorhinus semilunaris	XIX century/Range expansion	Ponto—Caspian
Gasterosteus aculeatus	1995/Ornamental fish	Europe, North America
Perccottus glenii	2004/Accidental, range expansion	Asia
Polyodon spathula	2006/Accidental	North America
Pterygoplichthys pardalis	2009/Accidental	South America
Morone saxatilis × *M. chrysops*	2012/Accidental	North America
Poecilia reticulata	2013/Accidental	South America

is often classified as one of the highest-risk fish invaders in Europe (Copp et al. 2009; Mastitsky et al. 2010; Puntila et al. 2013; Jarić et al. 2015b), so its further spread throughout the Danube basin seems likely. The presence of black bullhead in Serbian waterbodies probably dates from the period of introduction of the other bullhead species, but due to the difficulties in differentiating the two species it was identified for the first time in 2005 (Cvijanović et al. 2005).

Certain number of non-native fish species, primarily Prussian carp, pumpkinseed and both bullhead species, have substantial adverse impacts on native fish species. These species have become dominant in Vojvodina province due to suitable habitat for their establishment and spreading, such as slow lowland rivers and numerous channels, swamps and wetlands. Consequently, they are significantly threatening certain native species, such as tench and the crucian carp. These two native species are placed under permanently closed fishing season since 2009. Unfortunately, due to a lack of systematic monitoring of non-native fish species in Serbia, there are gaps in the understanding of their actual impact on native species. As a precautionary measure, there are eradication efforts implemented in some fishing waters, which are primarily focused on both bullhead species and bighead carp.

Proportion of non-native species is considerable, about 25% of the total number of recorded species. The current Law on the Protection and Sustainable Use of Fish Stocks defines non-native fish species as fish species that did not originally inhabit in certain fishing waters, and prohibits the introduction of non-native fish species from the remote geographic areas, as well as from the spatially closer, but mutually isolated basins.

6 Fish Genetic Diversity and Supportive Stocking

Lack of genetic data on fish species in Serbia is evident. Fish genetic research in the Serbian part of the Danube River was seldom conducted, and it was mostly focused on chromosome karyotyping in different fish species (Fontana et al. 1975; Vujošević et al. 1983). During the last two decades, research efforts were mostly directed on the genetic characteristics of the family Salmonidae (Marić et al. 2006, 2011, 2014; Tošić et al. 2014), as well as on sterlet (Cvijanović et al., unpublished data) and European mudminnow (*Umbra krameri*; Sekulić 2013). Assessments of the populations of both grayling (*Thymallus thymallus*) and huchen in the Danube in Serbia have shown that they are genetically distinct from the Slovenian and other European populations (Marić et al. 2011, 2014). Furthermore, according to Marić et al. (2006), indigenous brown trout still exists in the upper reaches of the main watercourses in Serbia. Sterlet mtDNA analysis in the Serbian section of the Danube (Cvijanović et al. unpublished data) showed new haplotypes when compared to the Hungarian and other European populations. Obtained information can contribute to the maintenance of autochthonous genetic diversity of these species, through the inclusion of genetic considerations within future management plans.

In order to help and boost fisheries, numerous attempts to stabilize populations by hatchery and release programs have been made in the Danube over the past few decades. As one of the Danube flagship species, sterlet is prime example of such efforts, with a number of countries carrying out stocking with larvae, fingerlings and juveniles (e.g. Guti 2006; Holčik et al. 2006; Smederevac-Lalić et al. 2011b; Lenhardt et al. 2012b). However, these stocking efforts have resulted in an overload with homogenous or even non-native genotypes in the recipient population, which might contribute to both inbreeding and outbreeding depression (Ludwig et al. 2009). In order to prevent the occurrence of such effects, genetic assessments of the suitability of specimens intended for stocking should be recognized as a priority, since the outbreeding is a major risk for wild populations with small effective population size and a limited range. The input of non-indigenous alleles to local gene pools can dilute or eliminate locally adapted alleles or allelic combinations (Ludwig et al. 2009). Furthermore, efficient genetic monitoring should be introduced by assessing natural populations both before and after the release of hatchery-reared juveniles (Ward 2006). According to Neff et al. (2011), current breeding programs are too focused on genetic diversity and thereby fail to acknowledge the complexities of the genetic architecture of fitness of wild populations. Research of population genetic structure prior to supportive stocking activities should be mandatory, since the identification of most suitable broodstock specimens is a prerequisite for successful stocking programs.

Lack of data and monitoring activities on the population genetic structure of the economically relevant fish species is a critical issue, which may ultimately result in inadequate management strategies. Negative effects of the non-documented stocking of grayling and huchen in Serbia during the 1980s were reported by Marić et al. (2011, 2014). Moreover, lack of detailed documentation for stocking activities regarding the genetic information can also obstruct future research activities focused on genetics, phylogeny and ecology of such populations, as it may result in misleading information about the diversity and inter-relatedness of wild populations (Cvijanović et al. unpublished data).

Potential and planned stocking programmes in Serbia are also faced with other logistic problems related to the suitability of stocking material. According to the Law on Protection and Sustainable Use of Fish Stocks (Official Gazette of RS, No. 128/2014), stocking of a fishing area may be conducted only with autochthonous specimens reared by the organization with special competences, as defined by special regulations, while the Public Procurement Law (Official Gazette of RS, No. 124/2012) established that all fishing area stakeholders are obliged to invite bids for public procurements. There are currently approximately five cyprinid hatcheries and eight salmonid hatcheries registered at the Ministry of Agriculture and Environmental Protection as organizations with special competences, which are therefore able to participate in tender procedures for stocking programmes. However, complicated public procurement biding procedures and the necessary time they require make such companies discouraged to produce specific stocking material. In addition, there are also no governmental subventions for these purposes, and when faced with the limited and unreliable market, hatcheries become reluctant to invest in certain species and specimens because there is no certainty that they will be able to sell produced specimens. On the other hand, inadequate procedures practiced at some hatcheries represent additional problem, such as inadequate knowledge of broodstock origin and the absence of broodfish tagging. This can lead to outbreeding errors and consequently to serious negative effects in wild populations.

If thorough genetic research becomes mandatory for stocking programmes in Serbia, it will help in the identification of the most suitable specimens for stocking.

In addition, stakeholders would be obliged to strictly define conditions of public procurement procedures and stocking material characteristics, while hatcheries would be able to evaluate costs of breeding and have more certainty in their bids. In the long-term, wild fish populations would benefit from these actions.

7 Diversity of Fish Parasite Fauna and Their Use for Monitoring Purposes

Parasites have a major importance in the ecosystems and in the biology of host species, as well as from an economic perspective as they represent common causes of fish diseases. Parasite infestation often leads to the deterioration of the general fish health condition, which consequently makes fish more sensitive to diseases or other negative factors. In specific conditions they can cause major losses in fishery resources or aquaculture production, especially of young fish. Parasite larval stages are also transmitted by fish from mollusks and crustaceans to birds and mammals. Their pathogenic activity is dependent upon a number of factors, such as the parasite species, degree of infestation, fish life history, age and condition of fish, as well as environmental factors (Britton and Pegg 2011). Parasites are increasingly recognized as important components of host biology, survival, population structure and, indeed, ecosystem functioning (Marcogliese 2004).

Studies of freshwater fish parasitofauna in open waters are of special importance for effective aquaculture rearing. The problem becomes more considerable by introduction of alien fish species, especially from Asian countries and USA, which also resulted in the introduction of virtually unknown parasite species. The success of introduced species may be facilitated by escapement from the effects of natural parasites (Torchin et al. 2003). According to the parasite/predator escape hypothesis, a host may profit from this favorable situation, attaining higher population densities and a greater individual body size in the colonized areas as compared to conspecifics in their native range (Torchin et al. 2001). The introduction of fish parasites into novel environments may represent serious threats to the health and survival of susceptible native fish populations (Bauer 1991). Specificity and complexity of the biological cycle largely determine potential parasite naturalization. The direct cycle confers parasites a capital advantage which, in general terms, counterbalances the specificity. The heteroxenous agents use a wide diversity of intermediate invertebrate hosts and therefore can become more easily established than those which have more specific intermediate hosts (Blanc 2001). Introduction of the Amur sleper in the Danube River also resulted in the introduction of the parasite Nematoda species *Philometriodes parasiluri*, for which we can not predict the impacts it is likely to produce will on autochthonous fish species (Nikolic et al. 2007; for the uncertainty regarding the identified species see Moravec 2008).

Over the last century, systematic research of parasitofauna in the Danube River basin in Serbia has been carried out on 54 freshwater fish species, with the total of

Table 5 The most frequently observed parasite species in fish from the Danube River in Serbia

Group	Parasitic species
Cestoda	*Caryophyllaeides fennica* (Schneider, 1902) *Caryophyllaeus laticeps* (Pallas, 1781)
Trematoda	*Allocreadium isoporum* (Looss, 1894) *Sphaerostomum bramae* (Müller, 1776)
Nematoda	*Philometra rischta* (Skrjabin, 1923)
Acanthocephala	*Pomphorhynchus laevis* (Müller, 1776) *Acanthocephalus lucii* (Müller, 1776)

170 fish parasite species recorded (Djikanović et al. 2012). Study of the endoparasites of 22 fish species in the Belgrade section of the Danube River indicated the presence of 54 parasite species, with 14 Cestoda, 19 Trematoda, 9 Nematoda and 12 Acantocephala species, and with approximately 55% of the examined fish specimens being infected (Djikanović 2011; Table 5). The most infested fish species was barbel. Acanthocephalan species *Pomphorhynchus laevis* (Müller, 1776) was recorded in each analyzed specimen.

Parasites are regarded as sensitive indicators of the environmental health, mainly based on their prevalence and infestation intensity, as well as on the knowledge of their biology (Britton and Pegg 2011). Parasitic species can be used as bioindicators of water quality, especially those that are dependent on a specific host (Sinderman 1958; Perić 1994). Pollutants may facilitate parasite infestation by increasing either host susceptibility or the abundance of intermediate hosts. Conversely, they can also decrease parasitism infestation if infected hosts suffer high mortality, if parasites are more susceptible to pollution than their hosts, or if pollutants negatively affect intermediate hosts (Sures 2004). Parasite population dynamics poses additional difficulties: they are mobile because of their fish hosts, and the effects of pollution on the parasite may be either direct or indirect through any of its hosts. As a result, presence or absence of a parasite species or changes in a community may have many causes (Kennedy 1997). The data on freshwater fish parasites is important for the evaluation of health condition and the general influence of the level of parasitism on the community structure.

8 Endangered Fish Species in the Danube River Basin in Serbia

Negative anthropogenic impacts have resulted in population declines and endangerment of numerous fish species in Serbian part of the Danube River Basin. Strictly protected fish species from the Danube River Basin in Serbia according to the national legislation are presented in Table 6. The list comprises 21 fish species which belong to seven families. Anthropogenic impact was mainly manifested through overfishing and poaching, river modification due to improvement of

Table 6 Strictly protected fish species in the Serbian part of the Danube River Basin, according to the national legislation (Official Gazette of RS, No. 5/2010)

Order	Family	Latin name	Common name
ACIPENSERIFORMES	**Acipenseridae**	*Acipenser gueldenstaedtii*	Russian sturgeon
		Acipenser nudiventris	Ship sturgeon
		Acipenser stellatus	Stellate sturgeon
		Acipenser sturio	European sturgeon
		Huso huso	Beluga sturgeon
ANGUILIFORMES	**Anguillidae**	*Anguilla anguilla*	European eel
CLUPEIFORMES	**Clupeidae**	*Alosa immaculata*	Pontic shad
CYPRINIFORMES	**Cobitidae**	*Cobitis elongata*	Balkan loach
		Misgurnus fossilis	Weatherfish
		Sabanejewia balcanica	Balkan loach
		Sabanejewia bulgarica	Bulgarian loach
	Cyprinidae	*Alburnus chalcoides*	Danube bleak
		Carassius carassius	Crucian carp
		Leucaspius delineatus	Sunbleak
		Rhodeus amarus	Bitterling
		Telestes souffia	Vairone
		Tinca tinca	Tench
ESOCIFORMES	**Umbridae**	*Umbra krameri*	European mudminnow
PERCIFORMES	**Percidae**	*Gymnocephalus baloni*	Danube ruffe
		Zingel streber	Danube streber
		Zingel zingel	Zingel

navigation corridors, habitat destruction, dam building, water and sediment pollution, inadequate fish stocking and spreading of non-native fish species.

Sturgeons are among the most endangered fish species and, according to the IUCN Red List, five sturgeon species listed in Table 6 are classified as critically endangered. Serbia prepared the Action plan for sturgeons in Serbia (Lenhardt et al. 2005) which was harmonized with the Action plan for the conservation of sturgeons in the Danube River Basin (Bloesch et al. 2006). However, while both Action plans defined appropriate measures for the protection of these valuable fish species, there are still ongoing poaching activities in the Lower Danube Region, and only limited investigation regarding this issue have been conducted so far. Improvement of sturgeon stocks represents a multi-decadal affair and requires common efforts of all countries along the Danube River, with the special attention directed on illegal sturgeon fishing in north-western part of the Black Sea (i.e. in Ukraine) which contains numerous wintering habitats for beluga, Russian and stellate sturgeon.

European eel (*Anguilla anguillae*) is listed as critically endangered within the IUCN Red List and as strictly protected by the national legislation. Data on European eel catch in the Serbian part of the Danube River Basin covers only the periods from 1954 to 1957 and from 1966 to 1968, when the annual catch ranged from 24 to 970 kg. Unfortunately, there are no data on European eel catch following these periods except for some sporadic records.

Pontic shad is classified as a vulnerable species according to the IUCN Red List, mainly due to the impoundment of rivers that reduced available spawning sites and migration routes, as well as due to overfishing during their migration runs. Although Pontic shad still represents a commercially important fish in the Danube Delta and within Lower Danube Region countries (Višnjić-Jeftić et al. 2013), it has been protected in Serbia since 1993 by the Decree on Protection of Natural Rarities (Official Gazette of RS, No. 50/1993).

Sturgeons and Pontic shad represent anadromous fish species that are greatly differentiated by their life characteristics, which resulted in a greater effect of adverse anthropogenic impacts, such as overfishing, poaching, dam construction and pollution, on sturgeons than on Pontic shad. Nevertheless, each of these species will require continual monitoring and implementation of effective management measures that would improve their protection and ensure population recovery.

European mudminnow (*Umbra krameri*) is classified as a vulnerable species in the IUCN Red List. In Serbia, it is listed as critically endangered, as its populations experienced a severe decline due to habitat desiccation and pollution (Sekulić et al. 2013). Habitat destruction and the spread of non-native fish species are the main reasons for population decrease of tench and crucian carp. Other fish species that are listed in Table 6 will require detailed investigation and continual monitoring in order to estimate more reliably the actual negative consequences of diverse anthropogenic impacts.

9 Future Perspectives

The Danube River in Serbia is characterized by a significant level of fish diversity, as well as by economically important fish resources. However, as discussed here, the Danube fish fauna is facing a number of adverse anthropogenic impacts, such as unsustainable fishery, habitat loss and fragmentation, water pollution and non-native species invasions. In order to ensure adequate protection and sustainable management of fish resources, it will be critical to introduce effective monitoring system that would include key environmental elements, such as water pollution levels and the population abundance, dynamics and genetic structure of selected umbrella and indicator species. Furthermore, it will be also necessary to introduce and enforce adequate management measures, such as improved fishing control, suppression of illegal fishery, improved reliability and standardization of fish catch statistics, fishway construction on both Iron Gate dams, restoration of key habitat such as spawning grounds and flood zones, improved control of critical non-native species introduction pathways and the development of suitable eradication measures, broodstock establishment for critically endangered populations and the standardized genetic screening of stocking material. In addition, further research efforts on the ecology and the status of fish species in the Danube will be necessary, as well as on their use as indicators of the state of the habitat (Lenhardt et al. 2015).

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Assessment of the Aquatic Ecosystem in the Slovak Stretch of the Danube River

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1 Introduction

1.1 Danube River Basin in Slovakia

1.1.1 General Characteristics

The catchment area of the Slovak Danube River Basin (DRB), representing the main river basin of Slovakia is 47,084 km^2. This area covers 96.0% of Slovak territory and creates 5.9% of the total DRB (Fig. 1; RBMPDD 2015). The rest of the Slovak territory belongs within the Vistula River Basin (4%). Agricultural land represents c. 50% of the DRB surface, forests and forest-related areas 45% and urbanised areas c. 5%. Average annual precipitation is 738 mm and average annual runoff reaches 228 mm. The territory of Slovakia is located in the temperate climate zone with regular changes of seasons, which is a typical feature of the middle latitudes.

Nine sub-basins belong to the DRB within the Slovak stretch of the Danube: Morava, Dunaj, Váh, Hron, Ipeľ, Slaná, Bodva, Hornád, Bodrog. They are situated in two ecoregions—the Carpathians and Pannonian lowlands. Tribute of the Slovak watershed to the Danube is represented by approximately 125 mil. m^3 s^{-1} runoff (Danube Basin Analysis—WFD Roof Report 2004).

Four main tributaries flow directly into the Danube river in the Slovak section: (1) Morava at Devín (r. km 1880; average discharge 106 m^3 s^{-1}); (2) Váh at Komárno (r. km 1766; average discharge 161 m^3 s^{-1}); (3) Hron near Štúrovo (r. km 1716; average discharge 55 m^3 s^{-1}); (4) Ipeľ near Szob (r. km 1708; average discharge 22 m^3 s^{-1}). The whole Slovak section of the Danube creates the following borders: the Slovak-Austrian border in the stretch of 1880–1872.7 r. km and

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Fig. 1 The Danube River Basin on the territory of the Slovak Republic (RBMPDD 2015)

Slovak-Hungarian border at 1852–1708.2 r. km. A Danube stretch of 20.7 km length is located on Slovak territory exclusively.

1.1.2 Socio-Economic Data

The territory of the Danube River Basin has 5.2 million inhabitants, comprising 6.42% of the entire River Basin population (DRBDMP 2009). Among the Danubian countries, Slovakia is characterised by a relatively high population density (111 inhabitants per km^2) with 56% of them urban population and with a majority of the inhabitants of productive age (71.7%). By comparison with most of the Danubian countries displaying negative population growth rates, Slovakia belongs (together with Austria, Bosnia and Herzegovina) among the countries with marginal population growth (0.129%). Basic socio-economic indicators based on the national data from 2013 show that the national GDP is 72.134 million euros. Which equals 13.330 € per capita, representing fifth place among all DRB countries (DRBDMP 2015).

1.1.3 Water Services

In the Slovak republic 83.6% of the population is connected to the public water supply, 60% to the public sewerage system and 58.7% to wastewater treatment plants. The percentage of human settlements in which wastewater is collected and treated reaches 96.2%. Concerning economic importance of water use, the share of industry in national GDP is significant (24.69%), while on the contrary the share of agriculture is very low (2.11%). Based on national data from 2012 the electricity generation reaches 3.59% and the share of hydro-power with electricity production 5125 GWh/year represents 18.4% (DRBDMP 2015). Slovakia has three major ports on its stretch of the Danube, and 8.24 million tons of cargo is transported annually within commercial inland navigation.

2 Slovak Stretch of the Danube River

2.1 Geomorphology

The Slovak stretch of the River Danube is situated in the Pannonian lowland and has a length of 172 km and width of *c.* 250–300 m. It belongs within two types: Danube section 4 (Lower Alpine Foothills Danube) and Danube section 5 (Hungarian Danube Bend). The border of these two types is at r. km 1791/1790 (Sommerhäuser et al. 2003).

The upper Slovak Danube Reach (Lower Alpine Foothills—Section type 4) is 73 km long and even if the bed slope is high here, the backwater effect is evident almost over the entire section. According DRBDMP (2015) the Gabčíkovo Water Structure in this section impounds for more than 17 km (about 1% of the entire length). The Čunovo reservoir is characterised by typical dammed river section features, both abiotic and biological characteristics of running waters turning into stagnant lake systems, especially in the side parts of the reservoir. Flow velocity is reduced, causing a sediment accumulation and deficits up and downstream of the dam. This increased sedimentation of fine suspended sediment results in higher transparency values. The described abiotic parameters affect and change the biological composition (e.g. macrozoobenthos, macrophytes, phytoplankton, zooplankton) as habitat structures within individual parts of the reservoir are limited. In terms of geo-morphology, the Danube here leaves its alpine character behind. The mean slope upstream of Bratislava is 0.43‰.

The lower Danube Reach (Hungarian Danube Bend—Section type 5) extends to the output point of the Slovak Danube—in Slovakia, farther continuing to Budapest. It belongs to the significant free-flowing stretches of the Danube. Within this reach the Danube starts to develop from an alpine (rhithron) to a lowland (potamon) river (JDS1 Technical Report 2002).

2.2 Hydromorphology

According to Brtek and Rotschein (1964) the River Danube changes its character from an epipotamal to a metapotamal river at approximately r. km 1810–1805, i.e. downstream of the Outlet Canal from the Gabčíkovo Water Scheme and the

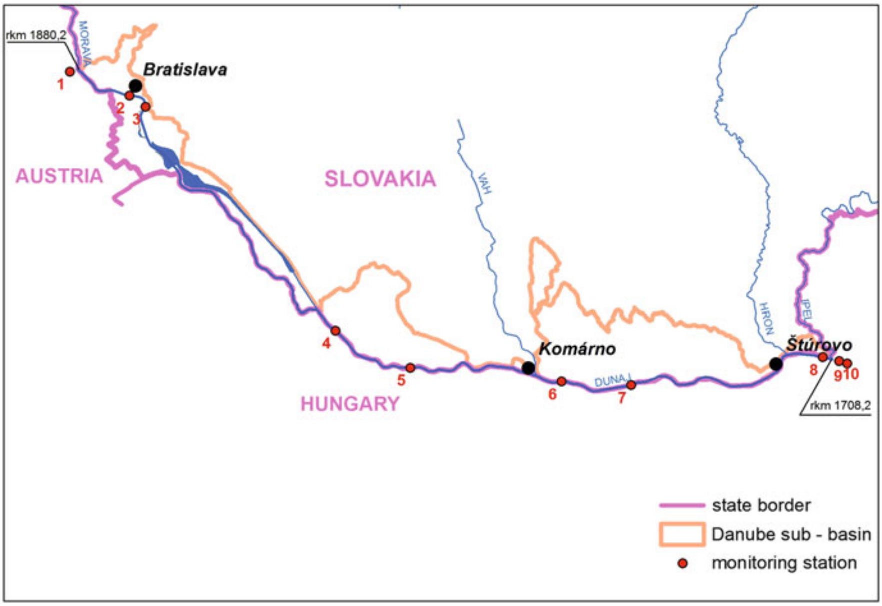

Fig. 2 Map of the investigated stretch of the River Danube: Grey lines and numbers indicate input and output of the River Danube to the Slovak territory. Sampling stations are identified in the following table

Danube River confluence (Fig. 2). This is demonstrated by the slope 0.27‰ between r. km 1880 and 1768 (upper reach) and only 0.064‰ between r. km 1768 and 1706 (lower reach). As the slope of the river determines the flow velocity (Sládečková and Sládeček 1998) and other abiotic, chemical and biological conditions, the bed sediments and benthic communities gradually change in this section (Elexová 2002).

The River Danube, which originally formed a rich system of side-arms on shared Slovak-Hungarian territory, was considerably regulated and channelized in the 1990s. Downstream of Bratislava the Gabčíkovo Water Scheme was built, consisting of the Čunovo dam, two parts of reservoir; hydropower plant, bypass navigation canal, locks chambers and outlet canal. The main exploitation is production of energy, flood protection, navigation, recreation and sport.

These structures ensure the flood water diversion between navigation canal and the River Danube. This means that this stretch of the River Danube is strongly regulated from the point of view of consistent flow. The structure allows protection of the inundation area against flood and in contrary the realization of artificial floods. However, the effect of flow regulation downstream of the outlet canal and River Danube confluence (Sap—r. km 1811) was identified as small (JDS 3 Technical Report 2015).

Concerning the hydromorphological assessment, eight indicators, which include several hydrological, morphological and hydraulic parameters were considered to estimate the final HYMO quality class (JDS 3 Technical Report 2015). Using the

No.	Station	r.km	Water body code	Water body section	Joint Danube Survey station
1	Upstream Bratislava	1882	SKD0016[a]	1880.2–1869	JDS1, JDS2, JDS3
2	Bratislava	1869	SKD0016	1880.2–1869	JDS1, JDS2, JDS3
3	Bratislava downstream	1865	SKD0019	1869–1851.6	
4	Medveďov	1806	SKD0017	1851.6–1806	JDS1, JDS2, JDS3
5	Kližská Nemá	1790	SKD0018	1806–1708.2	JDS3
6	Iža	1761	SKD0018	1806–1708.2	JDS1, JDS2, JDS3
7.	Radvaň	1748	SKD0018	1806–1708.2	
8	Chľaba	1710	SKD0018	1806–1708.2	
9	Szob	1707	(SKD0018)[b]	1806–1708.2	JDS1, JDS2, JDS3
10	Zebegény	1706			

[a]Station used as input to the Slovak stretch of the Danube due to the common Slovak-Austrian transboundary monitoring project
[b]Station used as output from the Slovak stretch of the Danube due to the common Slovak-Hungarian transboundary monitoring project

Slovak assessment method for large rivers, hydrology, sediment and fish continuity and river morphology were evaluated because of their close interdependence and synergic effect. As the river's shape and dimension are naturally adjusted according the discharge and sediment load, the habitats created are colonised by aquatic biota characteristic for particular river types. Any modifications of flow dynamics and sediment transport cause instability and consecutive hydromorphological alteration. After a short "slightly modified" stretch (original gravel substrate just upstream of the beginning of Slovak stretch and Morava confluence/Hainburg in Austria) continues the "extensively modified" section with riprap fortification of banks and backwater effect of the Čunovo dam, reaching downstream of Bratislava. Further section of Gabčíkovo hydropower plant region is classified as "severally modified". The remaining free-flowing Slovak section is gradually improving from "extensively" to "slightly modified".

3 Investigation of the Slovak Stretch of the Danube River

The River Danube has been monitored on its Slovak stretch since the mid-1990s. The first period of investigation focused on the Slovak-Austrian and Slovak-Hungarian transboundary stations, mainly of physical-chemical, microbiological and hydrobiological factors. Since 1989 the detailed monitoring has been carried out due to the Gabčíkovo Water Scheme construction and the number of factors measured has been expanded as well as the number of stations. In 2007 Slovakia started to monitor the River Danube according to the requirements of the Water

Framework Directive (WFD; Directive 2000/60/EC) focused mainly to the ecological status/potential and chemical status assessment.

3.1 Benthic Invertebrates

Benthic invertebrates (representing macro-invertebrate assemblages) are commonly used to assess the quality of rivers because of the good knowledge of their environmental needs and responses to different environmental factors, caused by pollution, hydromorphological alterations and also by other impacts. Under the WFD, they must be considered as one of the "biological quality elements" for "ecological status" assessment.

Within the Slovak stretch of the River Danube, monitoring and assessment of the influence of naturally occurring and anthropogenically induced flow reduction on the benthic invertebrate assemblages was performed from January 1997 to November 1998. The main objective was to evaluate the effect of significant change of the Danube river character on the macroinvertebrate community in Slovak territory. It was sampled in the Danube main stream's longitudinal profile from morphologically intact banks with original substrates (avoiding banks fortified by riprap material) (Table 1 and Fig. 2).

The highest flow velocity at site 1—Upstream Bratislava (Table 1) is caused by the upland character of the Danube. The bottom substrate mostly consists of coarse gravel and pebbles. On the Slovak territory, just downstream of site 1, the Danube changes to a lowland character. Additionally, site 3, with extremely low flow velocities, is influenced by the backwater effect caused by the damming in the Gabčíkovo Water Scheme region, and by waste water from Bratislava and the Slovnaft oil refinery. Hence the original gravel substrate is covered here by about 30 cm of sand-mud layer due to this lenitic character. The detailed abiotic characteristics of the five sampling sites are given in Elexová and Némethová (2003). At sites 7–10, with low slope (downstream of the Gabčíkovo Water Scheme; Fig. 2), the flow velocity is gradually reduced. The Danube has already a lowland character in this region, with stabilised slope of 0.06‰. The prevailing gravel is mixed with

Table 1 Characteristics of sampling sites including mean values with standard deviation of chosen parameters from 12 samplings

	1-Upstream Bratislava	3-Bratislava downstream	7-Radvaň	8-Chľaba	10-Zebegény
R. km	1882	1865	1748	1710	1706
Bottom sediment	Gravel, pebbles	Sand, mud	Gravel	Gravel	Sand, mud
Flow velocity (m s^{-1})	0.57 ± 0.17	0.09 ± 0.07	0.41 ± 0.09	0.19 ± 0.03	0.33 ± 0.13
Discharge (m^3 s^{-1})	1556 ± 407	1612 ± 446	1867 ± 496	1898 ± 503	1905 ± 505

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sandy particles and the finer gravel with a great quantity of sand is present in the last investigated locality.

Twelve quantitative samplings were carried out in the riparian zones during 1997 and 1998 at all five localities with measurement of additional abiotic parameters. The taxa determined were classified according to the corresponding functional feeding groups (FFG). Changes in the feeding groups' distribution along the Slovak Danube longitudinal profile were monitored in relation to the selected hydrological parameters.

Under the leadership of the International Commission for the Protection of the Danube River (ICPDR) three Danubian research expeditions—Joint Danube Survey—JDS 1, 2, 3, held in 2001, 2007 and 2013, respectively (JDS1, 2, 3 Technical Reports 2002, 2008, 2015) were devoted to the monitoring of the Danube river quality. Benthic faunal composition of the entire Danube Slovak stretch was studied within this activity as well (Fig. 2), where several sampling methods and their combination were applied (deep-water—dredge, polyp grab, air-lift, multicorer; multi-habitat, kick and sweep, light) during the late summer season.

Since 2003 a long-term monitoring of the benthic fauna community in Slovak water bodies has been carried out, fulfilling the WFD requirements (Mišíková Elexová et al. 2010). Among numerous streams also the Danube River is regularly monitored at several sampling sites during the spring or autumn, using AQEM (2002) method of sampling and sample processing modified for large river conditions—restricted to the riparian substrates.

In total, 160 benthic invertebrates taxa belonging to 18 systematic groups were recorded in the monitored section of the Danube riparian zone during the investigation in 1997 and 1998 (Elexová and Némethová 2003). For comparison, during the long-term monitoring 180 taxa were registered in corresponding section within the period 2003–2008. The related checklist of benthic macroinvertebrates comprises the taxa lists of 11 sampling sites located on the Slovak Danube river main stream (Mišíková Elexová et al. 2010).

The number of taxa in the monitored localities ranged between 70 and 95. Representatives of crustaceans, molluscs, oligochaetes and larvae of chironomids predominated. Many typical Danubian and Ponto-Caspian species consisting mainly of molluscs (*Fagotia/Microcolpia daudebartii acicularis, Lithoglyphus naticoides, Theodoxus danubialis, Th. transversalis, Dreissena polymorpha),* of crustaceans *(Chelicorophium curvispinum, Dikerogammarus bispinosus, D. haemobaphes, Obesogammarus obesus, Jaera istri,* and *Limnomysis benedeni),* oligochaeta *(Limnodrilus profundicola, Potamothrix moldaviensis)* and polychaeta *(Hypania invalida)* were found. As a consequence of the changes in flow and substrate, the benthic community shifts from rheophilous to potamophilous in the longitudinal profile.

Almost 50% of the taxa were rheophilous in 1- Upstream Bratislava which had the highest flow velocity and the lowest mean temperature (11.2 °C). The rheophilous oligochaetes and snails were represented by the mass occurrence of *Stylodrilus heringianus* and the less abundant *Ancylus fluviatilis.* The occurrence of other rheophilous species such as stonefly larvae *Leuctra fusca, L. hippopus,* mayfly

Heptagenia sulphurea, diptera *Atherix ibis, Dicranota* sp., midges representative of Diamesinae, Tanypodinae, Orthocladiinae, rheophilous caddisflies of Leptoceridae, Limnephilidae, Glossosomatidae, *Brachycentrus subnubilus* and the non-native New Zealand snail *Potamopyrgus antipodarum* was interesting from the faunistic point of view. FFG of shredders formed the most numerous group here and scrapers were found frequently as well.

The prevalence of indifferent or potamophilous taxa was recorded in slow-flowing condition with backwater effect of 3-Bratislava downstream locality: oligochaetes, midge larvae, mayfly larvae of the Caenidae family and *Potamanthus luteus*, Ponto-Caspian *Limnomysis benedeni,* Ceratopogonidae, and Hydracarina g. sp. They represent mostly the FFG of collectors of fine organic mater and FFG of predators. The decrease of rheophilous taxa led to the absence of *Stylodrilus heringianus, Limnodrilus profundicola,* Baetidae and Heptagenidae, stoneflies of Leuctridae, beetles of Elmidae and many rheophilous caddisflies, midges and other Diptera species. Also based on the analyses of multihabitat sampling during JDS3 the macrozoobenthic community indicates two typological sections for Slovak stretch, where the first section reaches to downstream Bratislava and the latter begins in Gabčíkovo reservoir (JDS3 Technical Report 2015).

The Danubian fauna in 7-Radvaň additionally comprised here also snails *Theodoxus danubialis, Fagotia (Microcolpia) daudebartii acicularis,* potamophilous big shells of the genus *Unio*, a dragonfly *Gomphus vulgatissimus* and water bugs that were all found further downstream. This locality was mainly colonized by shredders and scrapers FFGs. Brtek (1953) considered it as a boundary region between Danubian and Pontocaspian fauna. Monitoring and JDS localities Komárno and Iža can be considered as faunistically comparable, where *Esperiana esperi* and *Theodoxus fluviatilis* were found additionally.

The larvae of limnophilous mayflies *Potamanthus luteus, Ephemera lineata, Caenis luctuosa,* the eudominant snail *Lithoglyphus naticoides,* and *Viviparus acerosus* preferred the sand-gravel substrate in 8-Chľaba, with higher temperatures and discharges, but lower flow velocities. Midge larvae and representatives of the Ceratopogonidae family also occurred frequently. Chľaba was the only sampling site where the leech *Erpobdella nigricollis* and rheophilous *Ecdyonurus dispar* mayfly larva was recorded. Many additional potamophilous species were recorded such as the rare Danubian *Theodoxus transversalis,* big shells *Anodonta anatina* and *Pseudanodonta complanata,* the mayflies *Ephemera vulgata, E. lineata* and *Ephoron virgo*, and dragonfly *Calopteryx splendens.* Similar findings were recorded in monitoring and JDS close localities, such as mass occurrence of *Lithoglyphus naticoides* that was examined in Štúrovo/upstream of the Hron tributary mouth, sporadic or rare presence of *Viviparus acerosus, Pseudanodonta complanata,* mayflies of *Ephemera* genus, and the dragonfly *Calopteryx splendens* only in Szob/downstream of the Hron and Ipeľ mouth (Fig. 2). Despite the slow current the total number of taxa (95) was the highest and the rheophilous taxa were still abundant here (e.g. of Baetidae, Heptagenidae, Leptoceridae, Brachycentridae, Hydropsychidae, Cricotopus). Similarly to 3-Bratislava downstream species composition here was represented mainly by collectors of fine organic mater and predators.

The number of rheophilous taxa decreased considerably in 10-Zebegény, as the flow velocity fluctuated only around 0.3 m s^{-1}. It was demonstrated during all investigations by the replacement of rheophilous Ephemeroptera by the potamophilous genera *Caenis, Ephemera, Potamanthus* and the scarce *Ephoron virgo*. The percentage of the filterers FFG increased particularly in this locality. (Elexová and Némethová 2003).

Considerably fewer larvae of Ephemeroptera (as well as of some other insect taxa) were examined during the JDS samplings, because of the summer season. On the contrary, the presence of the mayfly *Electrogena affinis* in the lower section of the Slovak stretch was faunistically interesting. JDS data confirmed the presence of massed caddis fly species *Hydropsyche bulgaromanorum* and *H. contubernalis* as well as the rare occurrence of mayfly *Ephoron virgo,* typical in slope-reduction region of the Danube river—in 7-Radvaň downstream Kližská Nemá (R. km 1790). Regarding aquatic insects, both JDS and monitoring results as well as the results of previous investigation show a major role of Chironomidae and the highest abundances of Trichoptera taxa within the sensitive EPT (Ephemeroptera/Plecoptera/Trichoptera) group.

3.2 Phytobenthos

Benthic algae (periphyton or phytobenthos) are the most successful primary producers in aquatic habitats. They are widely considered to be the main source of energy for higher trophic levels in many, if not most, unshaded temperate region streams (e.g., Minshall 1978; Lamberti 1996; Mulholland 1996). In addition to primary production, they are important chemical modulators transforming inorganic chemicals into organic forms (Lamberti 1996; Mulholland 1996); participate in purification processes (Vymazal 1988); function as stabilizers of substrata and serve as an important habitat for many other organisms. All these features make them an essential component of aquatic ecosystems. In the Danube, where nutrients have been identified as an important anthropogenic pressure threatening the quality of the river water (DRBDMP 2009), benthic algae are an essential component of all bio-assessment studies.

Phytobenthos together with macrophytes are identified as Biological Quality Element under the Water Framework Directive (2000/60/EC), and as such need to be monitored to identify anthropogenic influences on aquatic ecosystems. Especially in rivers, phytobenthos is considered among the most suitable indicators determining the impact of nutrient pollution. The methods for phytobenthos use in water quality monitoring and assessment have been evolving in two main streams using the whole phototrophic community on one hand and diatoms only on the other hand. Slovak national method for phytobenthos is based on diatom module together with filamentous bacteria module. However, during Joint Danube Surveys (JDS1, JDS2, JDS3) the non-diatom community has also been investigated as well as the phytobenthos biomass in the last two JDS (JDS1 Technical Report 2002; JDS2 Technical Report 2008; JDS3 Technical Report 2015).

3.3 Diatoms

Based on the monitoring results of the period of 2003–2009, altogether 57 taxa of benthic diatoms have been recorded at seven sampling stations of the Slovak stretch of the Danube. The most frequent were *Achnanthidium minutissimum* (Kützing) Czarnecki, *Amphora copulata* (Kützing) Schoeman and Archibald, *Amphora pediculus* (Kützing) Grunow, *Cocconeis euglypta* Ehrenberg, *Cymbella compacta* Ostrup, *Diatoma ehrenbergii* Kützing, *Diatoma vulgaris* Bory, *Encyonema silesiacum* (Bleisch in Rabenhorst) D.G. Mann, *Gomphonema olivaceum* (Hornemann) Brébisson var. *olivaceum*, *Gomphonema tergestinum* Fricke, *Melosira varians* Agardh, *Navicula capitatoradiata* Germain, *Navicula cryptotenella* Lange-Bertalot, *Navicula gregaria* Donkin, *Navicula lanceolata* (Agardh) Ehrenberg, *Navicula recens* (Lange-Bertalot) Lange-Bertalot, *Navicula tripunctata* (O. F. Müller) Bory, *Nitzschia dissipata* (Kützing) Grunow sensu lato, *Nitzschia inconspicua* Grunow, *Nitzschia sociabilis* Hustedt, and *Rhoicosphenia abbr*eviata (Agardh) Lange-Bertalot (Hlúbiková et al. 2010).

Monitoring results of the period 2010–2014 show that the number of taxa varies between 206 (2011) and 154 (2013). Diatom taxa that occurred in relative abundance above 5% were as follows: Amphora *pediculus* (Kützing) Grunow, *Diatoma ehrenbergii* Kützing, *Diatoma vulgaris* Bory, *Luticola goeppertiana* (Bleisch in Rabenhorst) D.G. Mann, *Melosira varians* Agardh, *Navicula antonii* Lange-Bertalot, *Navicula cryptotenella* Lange-Bertalot, *Nitzschia dissipata* (Kützing) Grunow var. *dissipata*, *Navicula gregaria* Donkin, *Navicula lanceolata* (Agardh) Ehrenberg, *Navicula recens* (Lange-Bertalot) Lange-Bertalot, *Nitzschia sociabilis* Hustedt, *Navicula splendicula* Van Landingham, *Navicula tripunctata* (O. F. Müller) Bory, and *Surirella brébissonii* Krammer & Lange-Bertalot var. *brébissonii* (WPH WG SKHUTC 2010, 2011, 2012, 2013, 2014).

3.4 Non-diatom Community

About 20 taxa were identified of the non-diatom community. Non-diatom species diversity was mainly created by species of cyanobacteria (Cyanophyta) and green algae (Chlorophyta). Red algae (Rhodophyta) have occurred rarely on this stretch of the Danube. Together nine taxa of cyanobacteria were found in the samples from the Slovak stretch of the Danube, represented by mainly filamentous genera such as *Heteroleibleinia* (Geitler) L. Hoffmann, *Homeothrix* (Thuret ex Bornet et Flahault) Kirchner, *Leptolyngbya* Anagnostidis et Komárek, *Lyngbya* C. Agardh ex Gomont, *Oscillatori*a Vaucher ex Gomont, and *Phormidium* Kützing ex Gomont. Coccal cyanobacteria were present in a minority. Among green algae, a total of ten taxa occurred at individual sampling stations. The most abundant filamentous species was *Cladophora glomerata* (Linnaeus) Kützing, which was usually accompanying water macrophytes. Two taxa of red algae (Rhodophyta) were found, *Bangia artropurpurea* (Roth) Aghard and *Hildebrandia rivularis* (Liebmann) Aghard (JDS2 Technical Report 2008; JDS3 Technical Report 2015).

3.5 Phytobenthos Biomass

Quantification of phytobenthos biomass has been carried out *in situ* on the natural substrate by fluorescence fingerprint measurements using the BenthoTorch® (bbeMoldaenke) in the frame of both Joint Danube surveys (JDS2 2008; JDS3 2015). On each of five or more stones (cobbles) five sub-areas were measured to obtain sufficient database of chlorophyll-*a*. Three main algal groups were distinguished: diatoms, green algae and cyanobacteria. For each of these groups and for total benthic algal biomass, the chlorophyll-*a* level was determined in μg/cm^2.

Values of the of the total benthic algal biomass ranged on the Slovak stretch of the Danube in 2007 between 0.358 and 1.337 μg/cm^2 (JDS2 2008) while in 2013 values were almost double (1.27–2.68 μg/cm^2) (JDS3 2015). The phytobenthos structure evaluated via chlorophyll-*a* content was mainly formed by cyanobacteria and green algae in 2007 (JDS2 2008). In the year 2013 biofilm had been created mainly by diatoms (JDS3 2015).

3.6 Phytoplankton

An essential quality element in all lakes and larger rivers is the autotrophic phytoplankton. Photosynthetic processes by primary producers are important in the cycling of carbon and in the oxygen budget. The accumulated biomass can serve as food for other trophic levels. The composition of the phytoplankton assemblage and the biomass produced primarily indicates the trophic status of the water body. Species composition of phytoplankton may also be used to evaluate impacts from certain chemicals or to evaluate changes in hydromorphology which affect phytoplankton assemblages (JDS3 2015). In the Slovak stretch of the Danube the phytoplankton has been investigated for more than 27 years (Makovinská and László 1997; Makovinská and Hindák 1998; Makovinská 1998; Makovinská et al. 2003; Makovinská and Velická 2007).

The total number of identified taxonomic groups comprised Chlorophyta at 41.7%, Chromophyta 38.2%, Euglenophyta 12.1% and Cyanophyta 7.5% (Makovinská and László 1997; Makovinská et al. 2003; Makovinská and Velická 2007). Ratios of the above-mentioned groups of algae and cyanobacteria/

cyanophytes have been selected as one of the measures entering the national ecological status assessment method based on phytoplankton for large rivers.

Based on the results of routine monitoring in the period 2010–2014 the number of taxa of the Slovak stretch of the Danube (from Bratislava to Szob) ranged between 142 (2014) and 278 (2013). In the whole period the dominant groups were diatoms and coccal green algae (e.g. diatom genera *Achnanthidium, Amphora, Asterionella, Aulacoseira, Calone*is, *Campylodiscus*, *Cocconeis, Craticula, Cyclostephanos, Cyclotella, Cymatopleura, Cymbella, Cymbellopsis, Cymbopleura, Delicata, Diadesmis, Diatoma, Didymosphenia, Diploneis, Encyonema, Encyonopsis, Eolimna, Epithemia, Eucocconeis, Eunotia, Fallacia, Fragilaria, Frustrulia, Gomphonema, Gyrosigma, Hannaea, Hippodonta, Karayevia, Melosira, Navicula, Nitzschia, Pinnularia, Reimeria, Rhoicosphenia, Sellaphora, Skeletonema, Stephanodiscus, Surirella, Tabellaria, Tryblionella, Ulnaria)* and genera of Chlorococcales (*Acanthosphaera, Actinastrum, Ankyra, Closteriopsis, Coelastrum, Crucigeniella, Dicellula, Dictyosphaerium, Didymocystis, Didymogenes, Elakatothrix, Franceia, Golenkinia, Keratococcus, Koliella, Lagerheimia, Micractinium, Monoraphidium, Nephrocytium, Oocystella, Pediastrum, Planktosphaeria, Pseudodidymocystis, Pseudokirchneriella, Pseudotetrastrum, Radiococcus, Scenedesmus, Selenastrum, Schroederia, Siderocelis, Sphaerellopsis, Stichococcus, Tetraedron, Tetrastrum,* and *Treubaria* (WPH WG SKHUTC 2010, 2011, 2012, 2013, 2014).

Phytoplankton biomass expressed by the concentration of chlorophyll-*a* has been measured together with species diversity and abundance. In the period 2010–2014 the values of chlorophyll-*a* were observed in the range 0.2 (Szob 2014)—68.4 (Szob 2010) μg l^{-1}. Mean values varied between 8.0 (Bratislava 2012) and 25.7 (Szob 2011) μg l^{-1}. Generally average values of phytoplankton biomass in the years 2010–2011 increased between Bratislava and Szob to double, while this trend was not evident in the years 2012–2014 (WPH WG SKHUTC 2010, 2011, 2012, 2013, 2014).

3.7 Macrophytes

Macropyhtes are aquatic plants that live in the littoral zone of rivers and lakes (Haslam 2006). Taxonomically, they comprise non-vascular plants (bryophytes—mosses and liverworts), vascular plants (angiosperms) and macroalgae (charophytes, filamentous green algae, etc.). From a life-form point of view macrophytes can be divided to emergent (helophytes) as well as free floating and submerged macrophytes (hydrophytes). Through their connection with the aquatic habitat macrophytes are a very important biological element for the assessment of the ecological status of rivers. Therefore they are chosen as one of five biological elements for assessment of the ecological status of water bodies in the Water Framework Directive (WFD 2000). The Slovak national method for ecological status assessment for macrophytes is based mainly on hydrophytes while helophytes and amphiphytes have lower weight in the classification system.

Macrophytes of the Slovak stretch of the Danube were studied from 2003 within the frame of the national monitoring. The results of the period of 2003–2008 have been summarized by Baláži et al. (2011). The upper part of the Slovak stretch (1880.2–1806 r. km) was characterized by macroscopic algae (*Cladophora* Kütz., *Melosira* C. Agardh), Bryophytae (*Brachythecium rivulare* Schimp., *Cinclidotus riparius* (Host ex Brid.) Arnott) and Tracheophyta *(Alisma plantago-aquatica* agg., *Butomus umbellatus* L., *Ceratophyllum demersum* L., *Iris pseudacorus* L., *Elodea nuttallii* (Planch.) H. St. John, *Lemna gibba* L., *Lemna minor* L., *Lycopus europaeus* L., *Lythrum salicaria* L., *Myriophyllum spicatum* L., *Persicaria amphibia* (L.) Delarbre, *Persicaria maculosa* Gray, *Phalaroides arundinacea* (L.) Rauschert, *Phragmites australis* (Cav.) Trin., *Potamogeton pectinatus* L., *Potomogeton perfoliatus* L., *Veronica beccabunga* L., *Potamogeton crispus* L., *Typha latifolia* L., and *Spirodela polyrhiza* (L.) Schleid.). In the lower part of the Danube (1806–1708.2 r.km) only taxa of Tracheophyta were recorded (*Butomus umbellatus* L., *Ceratophyllum demersum* L., *Elodea nuttallii* (Planch.) H. St. John, *Lemna gibba* L., *Lemna minor* L., *Myriophyllum spicatum* L., *Persicaria maculosa* Gray, *Potamogeton pectinatus* L., *Potamogeton perfoliatus* L., *Rorippa amphibia* (L.) Besser, *Salvinia natans* (L.) All., *Spirodela polyrhiza* (L.) Schleid., and *Sparganium erectum* L.) (Baláži et al. 2011).

Monitoring results of the period of 2010–2013 showed that number of taxa varied between 12 (2010) and 25 (2013) in the whole Slovak stretch of the Danube. However hydrophytes that are the most important from the point of view of ecological status assessment were of less frequent occurrence (*Amblystegium fluviatile* (Hedw.) Loeske, *Ceratophyllum demersum* L., *Cinclidotus riparius* (Brid.) Arnott, *Cladophora* sp., *Enteromorpha intestinalis* (L.) Link, *Oscillatoria* sp., *Potamogeton crispus* L. *P. nodosus* Poiret, *P. pectinatus* L. and *P. perfoliatus* L., and *Spirogyra* sp.) (WPH WG SKHUTC 2010, 2011, 2012, 2013).

3.8 Other Aquatic Communities

3.8.1 Zooplankton

Investigation of the Rotatoria and Crustacean fauna of the River Danube in the river section of Bratislava—Budapest was provided in the period 1993–2000 systematically only. Altogether 195 taxa were identified, of which 128 taxa were Rotatoria, 44 Cladocera and 23 Copepoda. Dominant and most abundant species were Rotatoria taxa, such as *Brachionus angularis*, *B. calyciflorus*, *Keratella cochlearis*, *K. cochlearis* var. *tecta*, *K. quadrata*, *Polyarthra dolichoptera* and *P. vulgaris*. Of the Cladocera community, *Bosmina longirostris*, while of the Copepoda, taxa such as *Acanthocyclops robustus* species were present in almost all samples. The latter group was represented mostly by its copepodite larvae. On the basis of quantitative investigations values ranged in the interval of 5–4992 individuals per 100 l, and the mean values between 136 and 531 individuals per 100 l. In general values showed significant increasing zooplankton abundance each year in the longitudinal section of the investigated stretch of the Danube. Rotatoria always occurred in the highest individual numbers in each sampling points while number of Crustacea was significantly lower (Makovinská et al. 2003).

3.8.2 Fish

In Slovakia the fish community was not a part of systematic monitoring until the year 2011, when more than 270 sections of the Slovak rivers has been investigated using method harmonized on the European level. However the very large rivers such as River Danube were excluded due to the sampling method. In the frame of JDS2 and JDS3 the fish community was sampled at selected stretches (JDS2 Technical Report 2008; JDS3 Technical Report 2015). Based on the results of the JDS3 the Slovak Fish Index has been calculated for ecological status assessment. The results shows moderate status for the whole Slovak stretch of the Danube, excluding the Čunovo reservoir where bad status was identified based on the fish community (JDS3 Technical Report 2015).

3.8.3 Invasive Alien Species

Results of the JDS2 and JDS3 (JDS2 Technical Report 2008; JDS3 Technical Report 2015) showed that the Danube river is exposed to the intensive colonisation of non-indigeneous (non-native, alien or exotic) species and further spreading in both north-west and south-east directions throughout the basin. Level of biocontamination was derived from data on number and abundance of non-indigenous species of macroinvertebrates and fish. Both used communities showed this level of biocontamination from moderate to high (SBC index 2–3; Arbačiauskas et al. 2008) in the Middle section.

During JDS3, out of 25 recorded neophytes, four were aquatic macrophytes (*Azolla filiculo*ides Lam., *Elodea nuttallii* (Planch.) H. St. John, *Lemna turionifera* Landolt and *Vallisneria spiralis* L.). Only *Vallisneria spiralis* L. was found in Szob.

In total 12 non-native fish species were recorded during JDS3 (JDS3 Technical Report 2015). In the Slovak stretch, the following alien taxa were examined: *Carassius gibelio* Bloch, *Gasterosteus aculeatus* Linnaeus, *Lepomis gibbosus* Linnaeus, *Neogobius fluviatilis* Pallas, *Neogobius (Babka) gymnotrachelus* Kessler, *N. kessleri* Günther, *N. melanostomus* Pallas, and *Pseudorasbora parva* Temminck and Schlaegel.

A considerable number of alien macro-invertebrate species were recorded in this section comprising the Slovak stretch (20) and the majority of them are Ponto-Caspian (JDS3 Technical Report 2015). Besides *Hypania invalida, Potamothrix moldaviensis, Potamopyrgus antipodarum* of New Zealand origin, *Lithoglyphus* *naticoides, Dreissena polymorpha, Chelicorophium curvispinum, Dikerogammarus bispinosus, D. haemobaphes, Obesogammarus obesus, Jaera istri*, and *Limnomysis benedeni*, were commonly found during the investigation in 1997–1998, the monitoring and JDS expeditions, both carried out after 2000, revealed the presence of other important alien species such as commonly occurring *Theodoxus fluviatilis, Dikerogammarus villosus, Echinogammarus ischnus, Chelicorophium robustus, C. sowinskyi, and Esperiana esperi*. The gradual spread of the East Asian *Corbicula fluminea* from lower stretches of the Danube was registered. It was frequently observed, first in the lower section of the Slovak stretch, later in the entire monitored section. Other non-native species such as *Echinogammarus trichiatus, Katamysis warpachowsky, Niphargus hrabei, Dendrocoelum romanodanubiale,* and the Pontic *Dreissena bugensis* were rare or less frequent.

3.8.4 Ecological Status Assessment

The Water Framework Directive (WFD 2000) has brought a new approach to the assessment of aquatic ecosystem. The ecological status of surface waters is based on national evaluation systems. And the harmonization of the biological assessment systems within the European Union provides the intercalibration process. The main focus is on aquatic biological communities—biological quality elements (benthic invertebrates, phytoplankton, phytobenthos, macrophytes and fish). Physical-chemical quality elements (and hydromorphological quality elements are supportive for aquatic organisms. Ecological status assessment includes also specific synthetic and non-synthetic substances relevant for Slovakia. Biological classification schemes are type specific, stressor specific, they fulfil the normative definition of the requirements of WFD and European Union guidance's, measured values are compared with reference conditions, species diversity and invasive species are included as well. Most of the Slovak biological classification schemes have been already intercalibrated. Physical-chemical determinants consist of thermal and oxygen conditions, salinity and nutrients. Among specific synthetic and non-synthetic substances relevant for Slovakia are including 26 matters. Generally the principle of "one out all out" was used. For the water bodies SKD0016 and SKD0018 ecological status is evaluated. Water bodies SKD0019 and SKD0017 are heavily modified and therefore the ecological potential is identified.

Based on the monitoring results of the period of 2009–2013 the ecological status has been calculated for the second River Basin Management Plan (DRBDMP 2015). The partial results are given in the following table (Table 2). Fish are excluded from the ecological status assessment because there is no harmonized sampling method for very large rivers.

Based on the results the overall ecological status/potential was evaluated as moderate for the major part of the Slovak stretch of the Danube (SKD0018, SKD0019, SKD0017) except the upper part (SKD0016) that has good status. The moderate status has been identified based on the benthic invertebrates (3) in the

Table 2 Ecological status assessment of partial quality elements of the period 2009–2013

Water body code	Water body section	PH	PB	MF	MZB	CH	HYMO	RS	ES total
SKD0016	1880.2–1869	1	2	1	2	2	2	S	Good
SKD0019	1869–1851.6	1	2	2	3	2	4 (HMWB)	S	Moderate
SKD0017	1851.6–1806	1	2	2	3	2	4 (HMWB)	S	Moderate
SKD0018	1806–1708.2	1	3	3	3	2	2	S	Moderate

PH phytoplankton, *PB* phytobenthos, *MF* macrophytes, *MZB* benthic invertebrates (macrozoobenthos), *CH* physical-chemical parameters, *HYMO* hydromorphological parameters, *RS* specific organic and inorganic relevant substances, *ES TOTAL* overall ecological status/potential, *HMWB* heavily modified water body, *S*—the statistical results are below environmental quality standards

section of the r.km 1869–1708.2 while in downstream water body (SKD0018) showed moderate status phytobenthos and macrophytes as well. Based on individual metrics and quality elements the moderate status is caused by nutrient pollution and hydromorphology. Any of the 26 relevant synthetic and non-synthetic substances exceeded their environmental quality standards.

4 Conclusions

The Slovak stretch of the River Danube has been monitored since the mid-1990s. Since 1989 detailed monitoring has been carried out due to the Gabčíkovo Water Scheme construction, and in 2007 Slovakia started to monitor the River Danube according to the requirements of the Water Framework Directive focused mainly to the ecological status/potential and chemical status assessment.

Decreasing slope and flow velocity, with the consecutive changes in substrate composition on the Slovak stretch of the Danube River, induce the gradual benthic community shifts from rheophilous to potamophilous in longitudinal profile. Macrozoobenthos, with many typical Danubian taxa, indicates two typological sections for the Slovak stretch, separated by the Gabčíkovo Dam. The rheophilous species of shredders and scrapers functional feeding groups, adjusted to coarse organic matter prevail in upper section with higher flow velocity. The increasing fine organic matter and water temperature, with high plankton abundance in longitudinal profile—starting from the Gabčíkovo reservoir area—favours filterers and potamophilous taxa in the lower slow-flowing section. Farther downstream, in free-flowing lower section with natural change in character from an alpine to a lowland, a lot of Pontocaspian species occur and many of them represent alien species (mainly snails and crustaceans).

In the Slovak national method for phytobenthos is based on diatom module together with filamentous bacteria module. However during Joint Danube Surveys (JDS1, JDS2, JDS3) the non-diatom community has also been investigated as well as the phytobenthos biomass in the last two JDS. Non-diatom species diversity was mainly created by species of cyanobacteria and green algae. Red algae had been occurred rarely on this stretch of the Danube.

In the Slovak stretch of the Danube the phytoplankton has been investigated for more than 27 years. In the whole period the dominating groups were diatoms and coccal green algae. Average values of phytoplankton biomass, expressed by the concentration of chlorophyll-a, in the years 2010–2011 doubled between Bratislava and Szob, while this trend was not evident in the years 2012–2014.

Macrophytes of the Slovak stretch of the Danube were studied from 2003 within the frame of national monitoring. The upper part of the Slovak stretch was characterized by macroscopic algae, Bryophytae and Tracheophyta. In the lower part of the Danube only Tracheophyta were recorded. Hydrophytes that are the most important from the point of view of ecological status assessment were in general of lower occurrence.

Among other aquatic communities the zooplankton and fish were not investigated systematically. Investigation of the Rotatoria and Crustacean fauna of the River Danube in the Bratislava—Budapest section was performed in 1993–2000. In the frame of JDS2 and JDS3 the fish community were sampled at selected stretches. Based on the results of the JDS3 the Slovak Fish Index shows moderate ecological status in the whole Slovak stretch of the Danube excluding Čunovo reservoir where poor status was identified based on the fish community.

Results of the JDS3 showed that the Danube River is exposed to the intensive colonisation of non-indigeneous (non-native, alien or exotic) species. Four of 25 recorded neophytes belonged to aquatic macrophytes and only *Vallisneria spiralis* was found at the end of the Slovak section. In total 12 non-native fish species were recorded during JDS3 and 8 taxa were examined in the Slovak stretch of the River Danube. A considerable number (20) of alien species of macroinvertebrates were recorded in this surveyed section.

Based on the results the overall ecological status/potential was evaluated as moderated for the major part of the Slovak stretch of the Danube (SKD0018, SKD0019, SKD0017) except upper part (SKD0016) that is in good status. The moderate status has been identified based on the benthic invertebrates in the section of the r.km 1869–1708.2 while in downstream water body showed moderate status phytobenthos and macrophytes as well.

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State and Changes of Natural Environment in Polish Part of the Danube River Basin Poland

Weronika Maślanko, Beata Ferencz, and Jarosław Dawidek

1 Introduction

Within Poland, the Danube River basin includes three water regions:

- the Black Orava,
- the Czadeczka,
- the Moravian (Fig. 1).

2 Location

2.1 Administrative

The Black Orava water region is situated in the southern part of Poland, including a fragment of the Orava-Nowy Targ valley. In the administrative division it is the south-western part of Małopolska province, Nowy Targ county. The area includes four communes: Jabłonka (58.98% of the catchment), Lipnica Wielka (18.68% of

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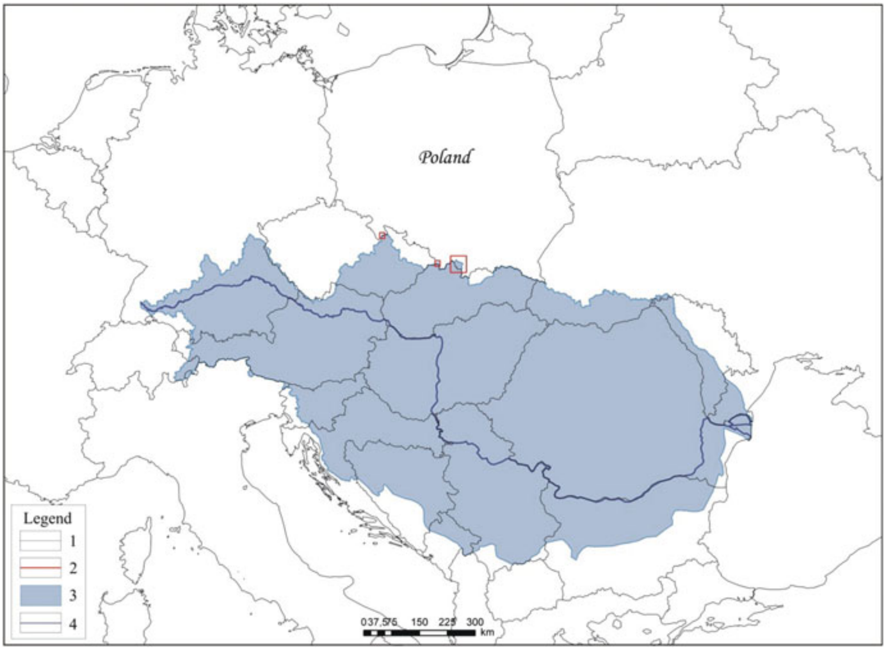

Fig. 1 Localization of the Danube's water regions in Poland in the context of the Danube river basin in Europe. Legend: 1—national borders, 2—water regions (from the left: Moravian, Czadeczka, Black Orava), 3—Danube basin, 4—Danube river

the catchment), Czarny Dunajec (16.68% of the Black Orava River catchment) and Raba Wyżna (5.66% of the catchment) (Synowiec, Główka 2013). The Black Orava water region covers an area of 359.7 km^2, while the Czadeczka 24.6 km^2. Administratively, the Czadeczka River water region is located in Silesia province, Cieszyn county, only in one commune—Istebna, whereas the third water region of Danube River basin in Poland called Moravian covers only an area of 0.72 km^2 as a part of the Lower Silesia province, Kłodzko county (Szczegółowe wymagania . . . 2010).

2.2 Physical and Geographical

The Black Orava River catchment is located within two physical-geographical macro-regions. Its northern part it is located in the West Beskids, which includes the Beskid Żywiecki mesoregion. The remaining part of the catchment includes the Orava-Podhale Depression with the mesoregion of the Orava-Nowy Targ valley. Within the borders of the Beskid Żywiecki the following sub-regions may be distinguished: the Babiogóra Mountain range, Orava Sections and the Orava-Podhale Beskid. The Żywiec Beskid is fragmented by wide river valleys of the Lipnica, Syhlec and Zubrzyca, and their tributaries. Such formed partial catchments

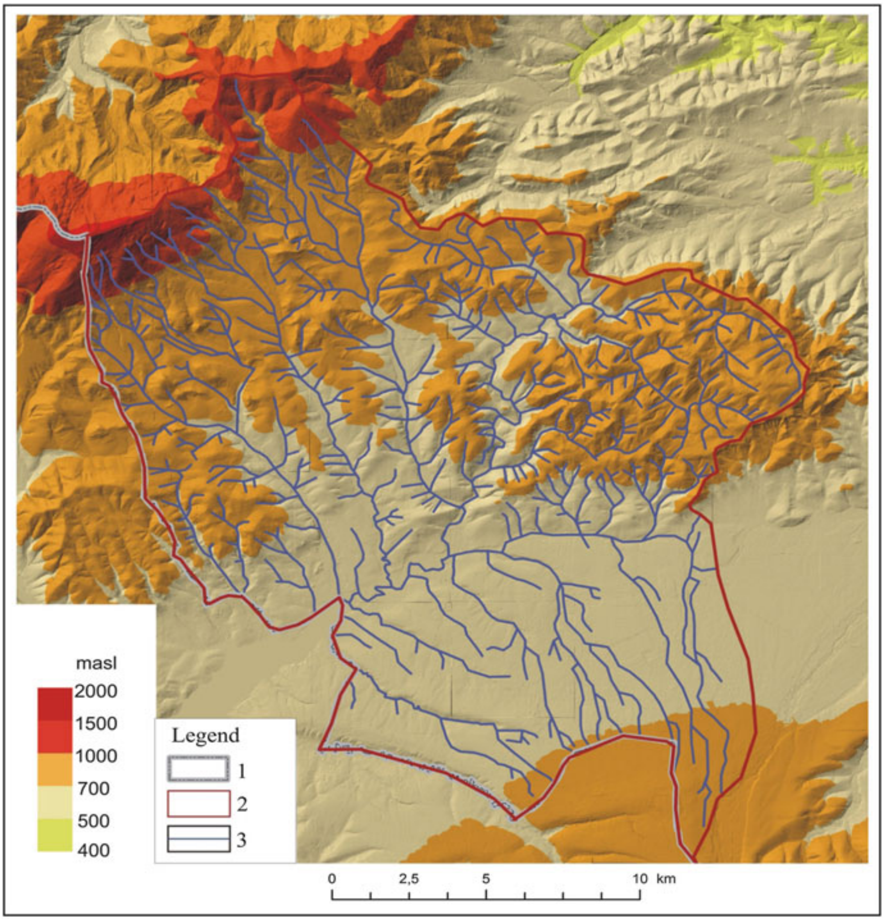

Fig. 2 Relief of the Black Orava water region. Legend: 1—national border, 2—water region borders, 3—rivers (Source: Documentation Centre of Geodesy and Cartography (CODGiK), Poland)

are separated by ridges, of which Bucznik is the highest. The course of ridges and valleys in the Beskid Żywiecki is along the meridian, and the streams flowing from Babia Góra and Polica mountain contribute flow to the Black Orava River (Warunki zarządzania. . . .). Elevation of the Black Orava water region ranges from 598 to 1724 m a.s.l (Fig. 2).

According to physical-geographical division (Kondracki 2002), the Czadeczka River catchment is located in the Carpathian megaregion, the Outer Western Carpathians province, Western Carpathians sub-province, in the Western Beskids macroregion. The Western Beskids' landscape is characterized by a medium-sized mountain range, with altitudes ranging from 600 to 1400 m above sea level. The height of these two massifs, Pilsko and Babia Góra, exceeds 1500 m above sea level.

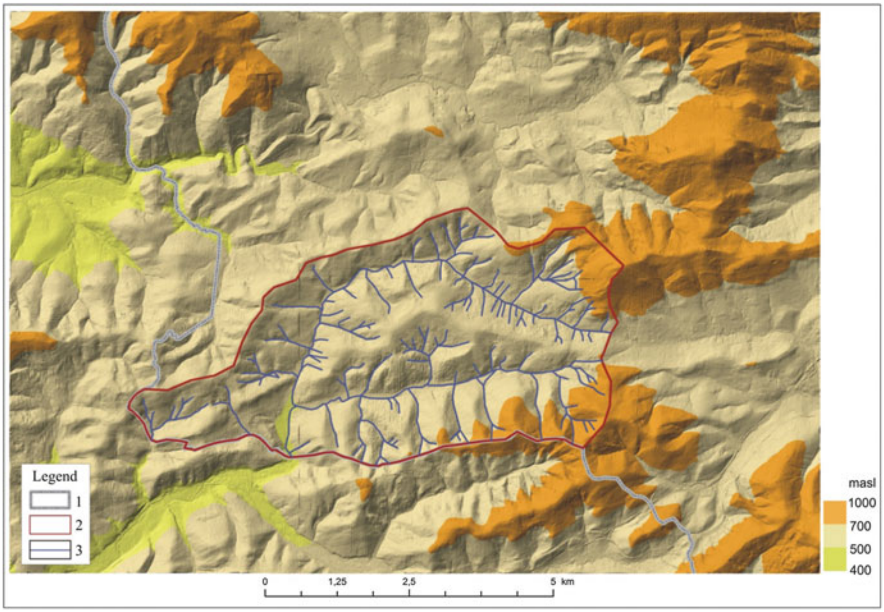

Fig. 3 Relief of the Czadeczka water region. Legend: 1—national border, 2—water region borders, 3—rivers (Source: Documentation Centre of Geodesy and Cartography (CODGiK), Poland)

The southern border of Olza catchment is determined by the hogsback (starting with the Ochodzita culmination—895.0 m above sea level) extending to the Łupienie on the border with the Czech Republic. It is a fragment of the European watershed separating the Baltic Sea basin from the Black Sea basin. The southern Polish border with Slovakia is marked by a lower ridge extending from Solowy Peak and descending to the Czadeczka River valley. The elevation of the Czadeczka water region ranges from 400 to 1000 m above sea level (Fig. 3).

According to physical-geographical division (Kondracki 2002), the Moravian water region lies in the Eastern Sudetes macroregion, in the Śnieżnik mountain range. Its northern border is formed by a ridge extending between the mountains Small Śnieżnik and Śnieżnik—the highest peak of this mountain range. This ridge descends towards the south-east, crossing the Polish state border. In that range Śnieżnik has the greatest height—1425 m above sea level, Small Śnieżnik—1318 m above sea level and Trójmorski Peak—1145 m above sea level (Fig. 4). Springs of the Moravian water region are situated on southern slopes of Śnieżnik.

2.3 Climate

The wide variation in climatic conditions of mountain regions favours its regionalization. The Black Orava' catchment belongs to the 13th climate zone—the

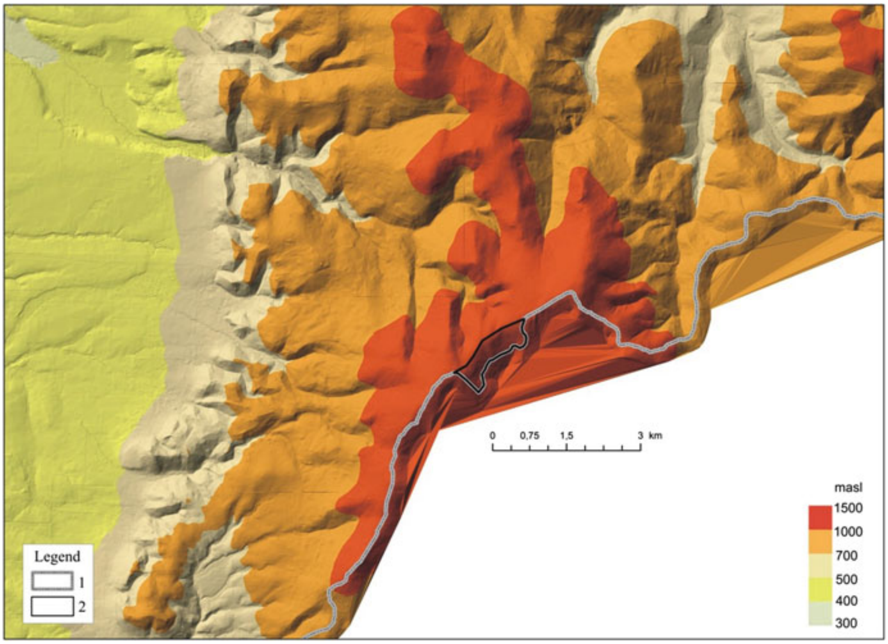

Fig. 4 Relief of the Moravian water region. Legend: 1—national border, 2—water region borders (Source: Documentation Centre of Geodesy and Cartography (CODGiK), Poland)

Carpathian region (Wiszniewski and Chełchowski 1975), which also corresponds to the climate- agricultural district (Gumiński 1948). According to the division of Kondracki (2002), the area belongs to the 21st district, called Carpathian. The Czadeczka River catchment belongs to the Carpathian climate region (Romer 1962), whereas the Moravian water region belongs to the Kłodzki climate region (Woś 1999). Generally, climatic conditions of separated water regions are varied and depend mainly on the elevation above sea level, terrain and location in relation to the dominant direction of flow of air masses.

2.4 Hydrographic

The basic units of water management resulting directly from the European Union Water Framework Directive, 2000/60/EC are so-called Uniform Parts of Waters. The term includes both surface water, e.g. stagnant water reservoirs, streams, coastal marine waters, as well as underground waters. 10 uniform parts of surface waters had been designated in the Black Orava water region (Table 1).

Underground waters in the Black Orava River catchment belong just to one uniform part of underground waters—PLGW2200161. The Czadeczka's water region consists of one spring combined part of surface waters—CZ0101, and one

Table 1 Uniform parts of surface waters in the Black Orava river catchment

Code	Name	Length of watercourse (km)
PLRW120012822219	The Black Orava to the Zubrzyca	25.1
PLRW120012822229	The Zubrzyca	14.6
PLRW120012822249	The Piekielnik	13.4
PLRW120012822269	The Syhlec	18.8
PLRW120014822279	The Black Orava from the Zubrzyca (without Zubrzyca) to estuary	9.1
PLRW1200128222729	The Lipnica	18.9
PLRW1200128222923	Chyżny to state border	8.1
PLRW1200128222929	Chyżny on border	1.3
PLRW1200128222949	Krzywań	8.5
PLRW1200128222989	Jeleśnia within Poland	12.7

uniform part of surface water—PLRW120012824229 (named as Czadeczka). In Czadeczka's water region there is also one of uniform part of underground water—no. 145 with area of 24.6 km^2. There is a small piece of the main ground water reservoir no. 348 within its borders (Pistelok 2014). The Moravian water region does not comprise permanent surface watercourses, whereas the pattern of land use is 98.9% forests and grasslands, and only 1.1% agricultural land. According to the division into uniform parts of underground waters, in the Moravian water region there is a uniform part of underground water part no. 125. In addition, within the water region of Moravian one water-economic district—called Łaba was distinguished (W-XII F).

3 The Characteristics of the Natural Environment

3.1 Abiotic

3.1.1 Geological Structure

The Black Orava catchment lies within the landslide of the Orava Valley, where sedimentation of terrestrial sediments of the Neogene and Quaternary occurred. In the oldest sediments the following layers can recognized: the Czarny Dunajec, the Orava, the Koniówka, the Podczerwienny and Mizerniański (Watycha 1977). These are lacustrine sediments of Badeńsko-Sarmatian, Pannonian and Pontian ages (Oszast and Stuchlik 1977). They had been developed as clay and sandy sediments with insertion of lignite and shingle, and reveal the Lipnica Wielka, the Lipnica Mała and the Jabłonka (Nagy 1993). The Neogene's sedimentation in the Orava Valley was subject to tectonic modifications, as confirmed by:

- uneven distribution of sediments thickness of the century (from 930 m in the Czarny Dunajec to 228 m in Domański Peak),
- existence of sedimentary and slip faults (Pomianowski 2003) and seismic (Baugmart-Kotarba 2001),
- cracks of the Neogene gravels showing horizontal stress direction (Tokarski, Zuchiewicz 1998).

The Neogene sediments cover the Quaternary fluvial and fluvioglacial deposits, originating, inter alia, from the Tatra Mountains, the Podhale and the Beskids. They form an alluvial terraces of the Czarny Dunajec River, as well as the Black and White Orava. Ongoing in the Neogene a subsidence gave a place to quaternary uplift that caused cut-off erosion of older deposits filling the valley (Baugmart-Kotarba 2001). A geological structure of the Orava Valley shows a distinct three-sectional character. It expresses as the difference in shape between the eastern, western and south-western part.

The Czadeczka water region is built with flysch deposits—sandstones, shales and conglomerates of the Eocene-Oligocene age and Cretaceous-Eocene marls and spotted shales. Deposits of the Magura nappe in the Czadeczka catchment build lithologically varied biotite layers of the Jaworzynka (Upper Cretaceous-Senon) with streaks built from shale of the same age spotted with marls. In this area also occur sandstones, shales and marls of Maastrichtian layers and the Paleocene dark (black) shales with discoveries of fossil fauna of Wawrzaczów Groń. Large areas are occupied by sandstones from Łyska (Paleocene-Eocene), but the largest area of the sedimentary series in the municipality constitute Oligocene shales and sandstones of under Magura layers with small inliers of zoogenic sandstones. The series is complemented by narrow Eocene patches of spotted shales. The youngest link of the geological structure are Quaternary sediments, primarily limited to the river valleys and lower parts of mountain slopes.

3.1.2 Soil

In the southern part of the Black Orava' River catchment area and in small parts of the northern part, loess soils have developed over clastic sedimentary rocks. Loess soils cover about 30% of the area studied (Warunki zarządzania....). Loam and clay soils developed on flysch sedimentary rocks occur in the remaining area. Loamy soils extend between the Black Orava River, the Zubrzyca stream (Black Orava's right tributary), and the Piekielnik stream (left tributary). In the western part of the Black Orava' River catchment, adjacent to the state border, loamy soils occur in the west wing of the sub-catchment of the Lipnica stream, while the eastern wing is covered by clayey soils. The surface of the loam soils represents about 20% of the area under study, while that of clay soils is about 15%. Rocky soils and skeletal soils developed on flysch sedimentary rocks have a small share. The largest, compact complex of skeletal soils occurs on the slopes of mountain ranges of Babia Góra and Polica. Rocky soils occur in the upper parts of Babia Góra and Polica. The total percentage of skeletal and rocky soils does not exceed 2%. Boggy soils, developed on a variety of peats, are also present in the studied catchment, and the main area of their occurrence is region of the Piekielnik village, as well as a small part in the area of the mouth of the Syhlec watercourse. Peat soils occupy about 4% of the catchment. Light, medium and heavy alluvial soils (11%) dominate in the remaining part. Alluvial soils formed from contemporary alluvial deposits or alluvial-deluvial, due to their agricultural usefulness are used as meadows and pastures, but rarely are afforested (IUNG 1961).

Acid brown soils formed on waste-mantle of the Carpathian flysch rocks predominate in the soil cover of the Czadeczka water region. Their granulometry is dominated by medium and heavy clay, in some parts dusty and light clays. Basement rocks arrear shallow, at a depth of less than 50 cm. These soils are characterized by low levels of nutrients for plants and acidity. Alluvial mountain soils are formed in watercourse valley bottoms. Terrain and climatic conditions favour soil erosion, whereas forest cover and heavy granulometric composition of soils greatly reduce the intensity and extent of this process (Aktualizacja Gminnego Programu…).

In the Moravian water region soils are typical of mountain areas and can be classified into several groups of origin:

- lithogenic—initial rocky (litosoles) and loose (regosoles), which were formed on the mountain slopes and rocky areas,
- autogenous—represented by acid brown and proper soils, podzolic and podzol soils, formed under the influence of soil-forming factors, parent rock, vegetation and terrain,
- semihydrogenic-marshy and gley soils, where the impact of groundwaters or heavy gleying is marked in the lower and middle parts of the soil profile. Wetting of upper levels is mainly conditioned by rainwaters,
- hydrogenic-boggy and moorland soils (peat and half-bog soils),
- alluvial—represented by alluvial soils.

Rocky and skeletal soils are the most common in the analyzed area. They are formed from rocks of metamorphic origin. Mostly they are covered with forests and occupied by areas with slopes >20°. Usage value of such mountain soils is low due to difficult climatic conditions and high water erosion. At an altitude of about 500 m a.s.l., fields and meadows are transformed into pastures, while above 600 m a.s.l. they have completely disappeared. In valleys podzolic soils dominate in mountainous areas. They occur together with brown subtype mountain soils, often as podzolic-brown soils. In the waterlogged valleys narrow strips of a sand-gravel alluvium occur, while river muds occur less frequently.

3.1.3 Climate

The climate of the Black Orava water region is characterized by low winter precipitation compared to that of summer. The average annual precipitation is *c.* 900 mm (Kondracki 2002). The catchment of the Black Orava River, located below 700 m a.

s.l., is characterized by the moderately warm climate, with an average air temperature more than 6 °C. Above 700 m a.s.l. are located areas having a moderately cold climate. The average values of temperatures range between 4 °C and 6 °C (PIG 2004). The most common air masses coming over the catchment area are humid masses of maritime polar air. Snow covers the area for about 100 days annually, which produces a very short plant growing season (200–210 days). Annual precipitation amounts to 750 mm, but increases with altitude even up to 1800 mm (e.g. peak areas of the Tatra Mountains). The highest precipitation occurs in July, with an average of *c.* 105 mm, while the lowest in January, with an average of 35 mm. The hottest month is July, whereas the coldest is January (PROFIT 2004).

The most common air masses coming over the Czadeczka River catchment area are humid maritime polar air masses from the west and northwest, which bring about increase in annual precipitation, particularly on the northern slopes. In spring and autumn temperature inversions are commonly observed in the valleys. Temperature drops are accompanied by persistent fog. The effect of the Czadeczka water region' elevation above sea level is the climate zonation (Prognoza oddziaływania... Czadeczki). There are two climate levels:

- moderate warm, to 550 m a.s.l. The average annual temperature in these regions ranges from 6 °C to 8 °C, while the annual precipitation is between 950–1350 mm. Snow remains on that heights for about 90–140 days a year.
- moderate cold, above 550 m a.s.l. The average annual temperature ranges from 4 °C to 6 °C, while the annual precipitation is 1200–1800 mm. This level is characterized by a long snow cover—125–175 days a year.

Over the year, the lowest precipitation was recorded in March (Istebna-Młoda Góra, Istebna village and Istebna-Zaolzie) and in October (Kubalonka and Stecówka), with the highest in June (all stations except Młoda Góra, where the maximum falls in July).

In the Moravian water region a typical mountain climate dominates, which is typical for the whole Sudety Mountains. It is characterized by lower monthly average and annual average temperatures and higher temperature amplitudes than in the surrounding water regions. The winter period lasts a bit longer than in the valleys, resulting in shortening of the plant growing season, which lasts about 180 days. The annual average temperatures range from 6 °C to 7 °C. The monthly average temperature in January ranges from −2 °C to −3 °C. The snow deposition range is 50–60 days a year, and in elevated parts up to 160 days. Total precipitation during the year reaches 1150 mm (Kondracki 2002).

3.1.4 Waters

Surface Waters

The Black Orava River' catchment, with an area of 358.4 km^2, is the largest area of the Danube River basin in Poland. The Black Orava springs are at 915 m a.s.l. in the

Orava-Podhale Beskids, on the slopes of Żeleźnica. The spring section with a length of 12.9 km and a slope of 15.1 m km^{-1} is called the Orawka stream. In Podwilk village a right bank tributary of the Bębeński stream passes into the stream. Its length is 8.5 km and slope is 7.6 m/km^{-1}. *c.* 800 m below, the left-bank tributary's Bukowiński stream, with a length of 9.25 km and a slope of 21.6 m/km^{-1} is observed. Part of the river from the Bukowiński stream mouth is called the Black Orava and it flows into the Orava-Nowy Targ Valley (Augustyn and Nowak 2014). The main tributaries of the Black Orava are the Bębeński stream, Pietrzakowski stream, Bukowiński stream, Zubrzyca, Syhlec, Piekielnik, Chyżnik and Lipnica. The river is fairly deeply indented into the ground in the upper part and flows in a wooded gorge with steep slopes, up to several metres deep. The bottom is rocky, with some small rapids.

In the river bends, gravels of varying granulation and fine-grained mud are deposited. In the lower river course banks are mostly flat, there are only fragments with higher banks, when the river deepens. Banks are eroded in those parts and voided by water. Gravel-banks which form in meanders are covered with shrubby willow. The river bottom in that section is covered with pebbles. Small patches of riparian willow and alder scrub locally extend as bands along the river. The Black Orava River flows through several small towns: Podwilk, Orawka, Jabłonka and Chyżne, and flows into the Orava reservoir in Slovakia. Ten uniform parts of water rivers, which catchments form integrated parts of waters GW1001 (the Black Orava from the spring to the state border) were distinguished in the Black Orava River catchment area. The total length of uniform parts of surface water within Poland is 201.4 km, among which the length of the natural watercourses is 131.1 km (approx. 65.1%), whereas strongly modified parts–70.3 km (approx. 34.9%). River regime of the region is called as nival-pluvial (snow-rain). The monthly average outflow of the summer period is slightly higher or nearly equal to the monthly average outflow of spring. There is a significant predominance of surface water supplying in that water region, amounting to over 65% of the total outflow (Kukulak 2007).

As regards area, the Czadeczka River catchment is the second (24.6 km^2) area in Poland belonging to the Danube basin. The Czadeczka originates in the spring at about 700 m a.s.l, on the south-western slopes of Ochodzita Hill, under the Rupienka mountain pass. The Czadeczka stream from the spring staggered an arc to the west and south, taking up water of the largest left bank tributary of the Krężelka, below the settlements, which is localized out of the Jaworzynka and crosses the Polish—Slovak state border. In Čierne village it flows into the Czernianka. The first right tributary of the Czadeczka (with significant discharge) is an unnamed stream draining the western slopes of Ochodzita. This watercourse begins its course at an altitude of 725 m a.s.l. Another, larger tributary of the Czadeczka is another stream without a name. A right-bank tributary flows from the spring at an altitude of about 650 m a.s.l. The other two right tributaries of the Czadeczka have significantly lower discharges and the Biłkowski brook is only periodic. The Czadeczka's first left-bank tributary, the Gorzołków stream, originates at an altitude of about 620 m a.s.l in the Zapasiek area. The largest left-bank tributary of the Czadeczka is the Krężelka River with its spring situated at an altitude of about 725 m a.s.l in the area called the

Silesian Kiczorki. The Krężelka has two tributaries, the left-bank one the Sołowy stream (flowing at about 825 m above sea level) that drains the massif of Salt Peak and Trojak Mountain. The second tributary of the Krężelka is a Huge Stream with the spring at an altitude of about 635 m a.s.l.

Underground Waters

Two aquifers of the active exchange zone may be distinguished in the Black Orava River catchment. The Quaternary aquifer is in loam sediments and, deeper, residual in fissure rocks forming the Carpathian flysch. The Quaternary aquifer level comprises watered coarse materials—sands and gravels. A flysch aquifer is mainly observed in flysch sandstones, conglomerates, fragmented limestones, claystones and marls. The Quaternary aquifer that fills mainly mountainous valleys, is characterized by favourable hydrogeological parameters. The thickness of this productive aquifer ranges from 5 to 15 m. The abundance of the water aquifer floor determines the degree of cracking of the flysch sediments. The water at flysch level is characterized by total dissolved solids (TDS) 200–500 mg dm^{-3}. They are of a simple, two-ion hydrochemical calcium bicarbonate type. These are waters of infiltration origin and along the depth of water TDS value increases (Małecka et al. 2007).

There are fragments of three undocumented main ground water reservoirs in the Black Orava River catchment area:

- no. 439—the reservoir of the Magura (Gorce) layers, including Paleogeneo-Cretaceous sections of Carpathian flysch. The area of the reservoir within the catchment area is approximately 102 km^2, which accounts for 28% of its surface. It is situated in the central part of the catchment.
- no. 440—the Nowy Targ fossil valley. This reservoir is formed in the Quaternary sediments, occupies the southern part of the catchment and provides 32% (approximately 114 km^2) of the surface. Disposable resources are estimated at about 86,000 m^3 day^{-1}. The reservoir is poorly insulated above, resulting in high susceptibility to contamination.
- no. 445—the reservoir of the Magura (Babia Góra) layers. It includes Paleogeneo-Cretaceous segments of Carpathian flysch. It occupies the northern part of the catchment area of about 37 km^2 (10% of the catchment area).

Underground waters of the Czadeczka water region are associated with the fissure- porous medium (the Carpathian flysch). A flysch aquifer is represented by sandstones, conglomerates, fragmented limestones, claystones and marls, occurring in different proportions.

One aquifer was identified in the catchment, which included the Paleocene-Cretaceous flysch groundwater reservoir. In the southern part occur the Neogene Krosno sandstones and Upper Cretaceous biotite layers (the Magura unit), while in the north mainly sandstones of Istebna lower layers of sandstone and Godula with Malinowski conglomerate (the Silesian unit). The Paleogeneo-Cretaceous layers remain hydraulically connected and form one common aquifer. Utility level occurs on average at a depth of about 15 m below the ground surface. The depth of the water rises in the upper parts to about 30 m below the ground surface, while in the western part of the uniform part of underground waters even up to 50 m below the ground surface. The thickness of the aquifer generally ranges from 6.7 to 47.5 m. It is supplied due to infiltration of rainfall. Natural zones of groundwater drainage are the numerous springs and the Czadeczka River with its tributaries. Individual water intake (wells drilled and dug) represent anthropogenic drainage, mainly for tourist and recreational purposes.

There are two aquifer levels in the Moravian water region: the Quaternary and the Palaeozoic-Proterozoic. Fissure waters in crystalline formations of the Palaeozoic-Proterozoic occur at a depth from several metres to more than 100 m. Yields are from several to 30 $m^3 h^{-1}$, mostly reaching a value of 10 $m^3 h^{-1}$. Waters in the Quaternary sediments are associated with the rock mantle with small thickness. The water table is freely or under a slight pressure. Yield of drilled wells is up to a few $m^3 h^{-1}$ (Michniewicz et al. 1989). Infiltration as a discontinuous process has a pulse character with the highest value of supply in the spring and summer. Drainage, as a continuous process, has a low annual variability. Natural drainage constitutes a linear flow into the deposits of river bed which are local base of drainage (Staśko and Tarka 2002; Staśko and Michniewicz 2007). There is a small part of undocumented main ground water reservoirs with the number 339—Śnieżnik—the Bialskie Mountains in the Moravian water region. It is a fissure reservoir with available resources (for the whole reservoir) that are estimated at about 37,000 $m^3 day^{-1}$ (Ocena stanu.... 2005).

3.1.5 Land Use Forms

The predominant land use pattern in the Black Orava' River catchment is agricultural land (Fig. 5), which account for over 55% of its surface (Table 2). A large area is also occupied by forests and semi-natural ecosystems (39% of the catchment). Anthropogenically transformed areas occupy less than 2% of the catchment area.

In the Czadeczka' water region two forms of land use dominate: agricultural areas (47% of the catchment area) and forest and natural green areas (45% of the catchment area). Areas transformed by human pressure constitute 8% of the catchment area. In the Moravian water region only one form of land use occurs—forests.

3.2 Biotic

3.2.1 Types of Nature Protection

There are many areas of significant natural value in the area of the Black Orava water region (Fig. 6). The most important are under different form of legal conservation:

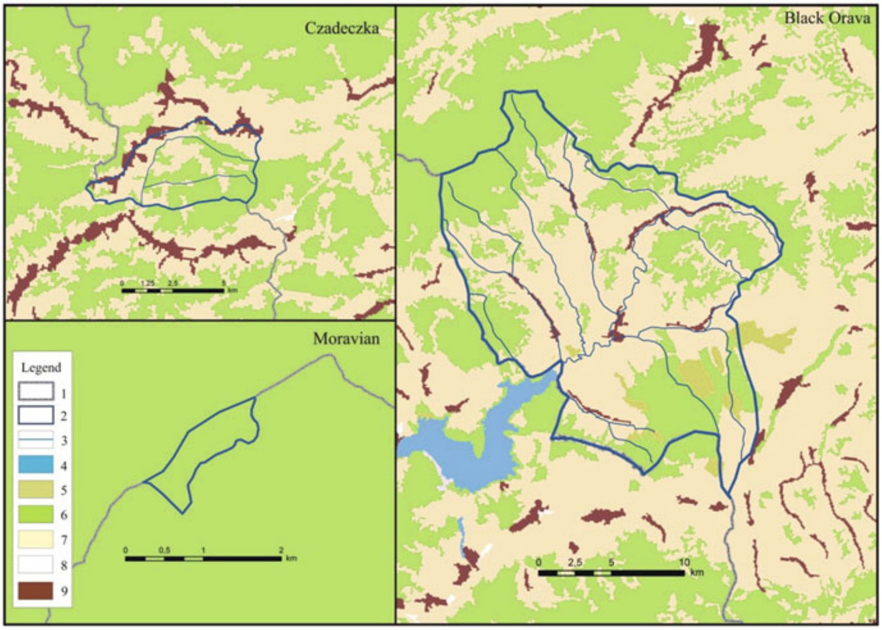

Fig. 5 Land use forms in the Danube's three water regions in Poland (Source: Corine Land Cover). Legend: 1—national border, 2—water region, 3—rivers, 4—water bodies, 5—wetlands, 6—forests and semi-natural areas, 7—agriculture areas, 8—artificial surfaces, 9—built-up areas

Table 2 Land use forms in the Black Orava River catchment

Forms of land use (Corine Land Cover—1 level)	Forms of land use (Corine Land Cover—3 level)	Area (km^2)	Percentage (%)
Forests and semi-natural ecosystems	Coniferous forests	128.09	35.61
	Deciduous forests	0.02	0.01
	Mixed forests	5.46	1.52
	Forests in changing status	6.87	1.91
	Grasslands and natural pastures	0.23	0.06
	Heaths and shrubs	0.25	0.07
Wetlands	Inland marshes	1.50	0.42
	Peatbogs	9.75	2.71
Agriculture lands	Agriculture land out of irrigation systems	98.98	27.52
	Meadows	73.24	20.36
	Agriculture land with high share of natural vegetation	9.88	2.75
	Complex systems of crops and plots	17.97	5.00
Anthropogenic areas	Dispersed development	7.43	2.07

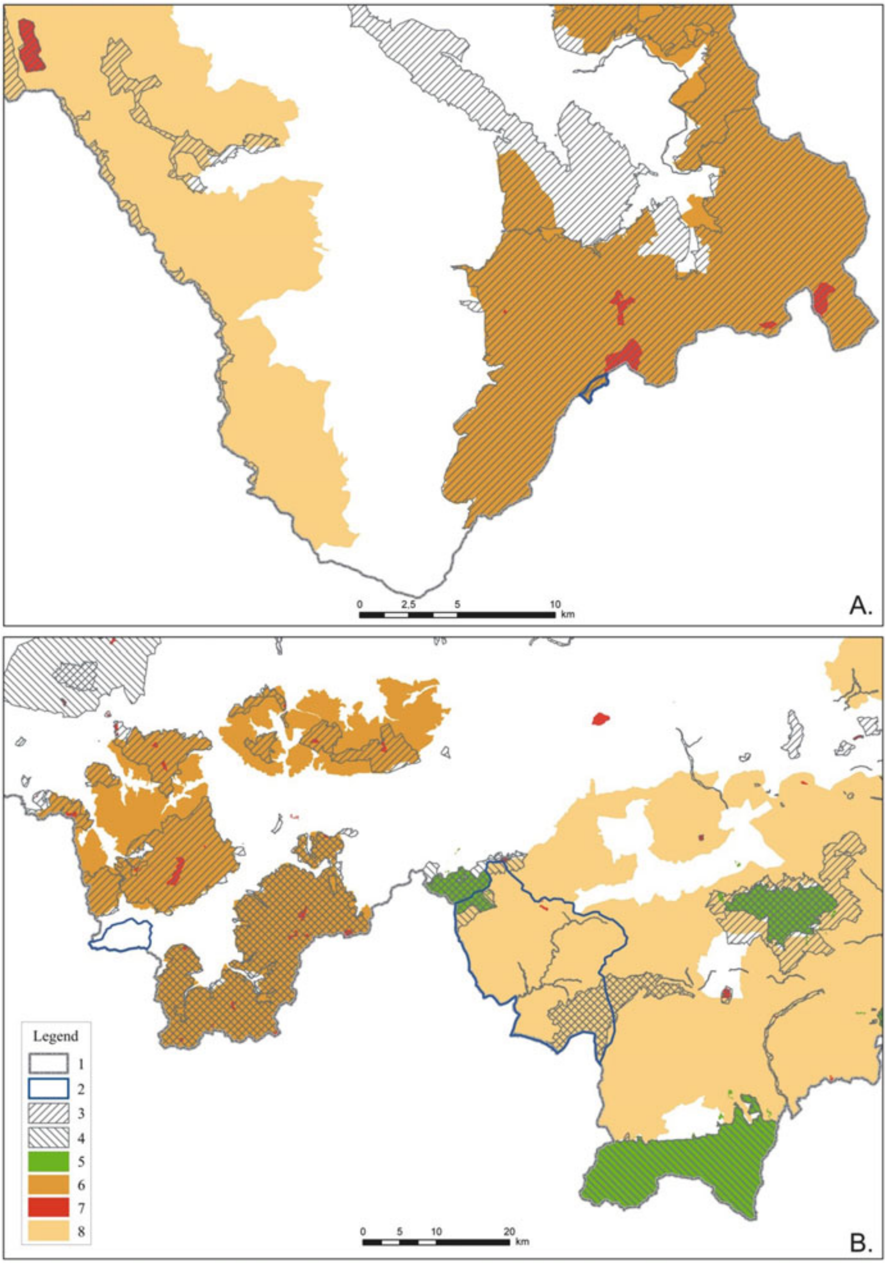

Fig. 6 Network of protected areas in surroundings of Danube water regions in Poland: (**a**) Moravian water region, (**b**) Czadeczka and Black Orava water regions. Legend: 1—national border, 2—water region, 3—NATURA 2000 Special Area of Conservation, 4—NATURA 2000 Special Protection Area, 5—national park, 6—landscape park, 7—nature reserve, 8—area of protected landscape

1. The Babiogóra National Park and its buffer zone. The Black Orava water region comprises 2.6% of the Babiogóra National Park (about 9.5 km^2). Protection includes watershed mountain areas. The ecosystems are autonomous, and they are mainly supplied by precipitation. Simultaneously the most valuable ecosystems of the Babiogóra National Park are covered by other forms of environmental protection, for example Natura 2000 sites. Babia Góra is the highest peak in the Western Beskid Mountains with height of 1725 m a.s.l. and high landscape values. This characteristic feature of the Black Orava catchment's landscape dominates in the north-western part as an attractive viewpoint of the valley and Lipnica Wielka and Lipnica Mała villages.
2. The "Bembeńskie" nature reserve protects the peatland valley of a small forest stream. It is a hydrophilic ecosystem, strongly depended on the groundwater level. There is a protected site of marshy spruce woodland with alder and rare subalpine species of tall herb communities in an area of approximately 0.2 km^2 of the reserve.
3. Three Special Protection Areas (approx. 19.3% of the whole water region):
   (a) a Special Protection Area "Orava—Nowy Targ Peats"—PLB 12007
   (b) a Special Protection Area "Babia Góra"—PLB 120011
   (c) a Special Protection Area "Polica Mountain Range"—PLB 12006.
4. Four Special Areas of Conservation (together represent approx. 16.7% of the whole water region):
   (a) a Special Area of Conservation "Black Orava"—PLH 120002
   (b) a Special Area of Conservation "Orava—Nowy Targ Peats"—PLH 120016
   (c) a Special Area of Conservation "Babia Góra"—PLH 120001
   (d) a Special Area of Conservation "Polica Mountain Range"—PLH 120012
5. Two Special Areas of Conservation listed on the Shadow List 2013,
6. The South Małopolska Area of Protected Landscape. Outside the entire area of the national park, the water region is covered by the area of protected landscape (97% of the catchment area). Its most important function is to maintain the permeability of ecological corridors. These corridors not only include river bed, but also its floodplain with associated plant vegetation. The entire catchment area of the Black Orava River has outstanding landscape values, particularly because of the Borcok pine-spruce forest near Jabłonka village, growing on former peat bog, where valuable species of plants and animals still occur.
7. Ecological corridors essential to maintain the coherence of the Natura 2000 network, protected under Art. 10 of Directive 92/43/EEC.

Particularly valuable habitats are high moors with surrounding ecotones, bog-springs, coniferous and swamp forests and meadows (e.g. "Orava-Nowy Targ Peats"). To protect 12 habitat types (including four priority) of Annex I of the Habitats Directive, a Special Area of Conservation (PLH120016) was designated. In addition, in the moors the following species can be found: Ornate Bluet dragonfly (*Coenagrion ornatum* S.), thick-shelled river mussel (*Unio crassus* P.) and migrating large predators, i.e. wolf or bear (Annex II of the Habitats Directive). A Special Protection Area (PLB120007) due to the presence of black grouse (*Lyrurus tetrix* L.), corncrake (*Crex crex* L.), black stork (*Ciconia nigra* L.), wood grouse (*Tetrao urogallus* L.), hazel grouse (Tetrastes banasia L.), Eurasian crane (Grus grus L.), kingfisher (*Alcedo atthis* L.), boreal owl (*Aegolius funereus* L.), black woodpecker (*Dryocopus martius* L.), tawny pipit (*Anthus campestris* L.), red-breasted flycatcher (*Ficedula parva* B.) and red-backed shrike (*Lanius collurio* L.) was also designated (Warunki zarządzania…).

The northern part of the Puścizna Wielka is the best preserved part of the clump-valley structure bogs. There are also other locations of peatlands, except of Natura 2000 site, e.g. alkaline peatlands in the area of the upper course of the Bębeński Stream and in the region of Chyżny in the Black Orava River catchment area. Within the area of "Babia Góra" Natura 2000 site occur at least 16 species of Annex I of the Birds Directive, 18 habitat types in Annex I and 13 species listed in Annex II of the Habitats Directives. Moreover, there are eight species of the Polish Red Book of Animals and many rare, endangered and legally protected species. The Black Orava River catchment area includes 24% of the Special Area of Conservation entitled "Babia Góra" PLH120001 Natura 2000 site and 33% of the Special Protection Area entitled "Babia Góra" PLB120011.

A part of the Black Orava river from Harkabuz village to the Lipnica river's mouth constitutes a Special Area of Conservation called "Black Orava". The width of the river bed ranges from 3 to 20 m with a depth of 10–120 cm. The banks of the Black Orava are generally mild, steep only in parts with increased lateral erosion. In the vicinity of the river mostly pastures and cultivated fields occur, locally banks are covered with willow and patches of riparian forests. In the area 5 species in Annex II and 3 species of Annex I of the Habitats Directive are present (Warunki zarządzania…).

As important natural values associated with water, following can be distinguished:

- the only natural habitat of Danube salmon (*Hucho hucho* L.) (extinct in Polish natural range)
- population of golden loach (*Sabanejewia aurata balcanica K.*) (on the verge of extinction)
- population of Ukrainian brook lamprey, a subspecies *Eudontomyzon mariae vladykowi* (on the verge of extinction)
- the Black Sea form of brown trout *Salmo trutta m. Fario* L.
- frequently occurring mountainous spruce on peats
- riverside and gravel-banks on the Black Orava river and Bembeńskie nature reserve.

The Black Orava catchment area includes the following nature monuments: 11 lime-trees (*Tilia*), two ash trees, elm, oak and maple. Lynx (1361) is under protection in this water region, as well as 14 species dependent on an aquatic habitat:

- Carpathian Tozzia—*Tozzia carpathica* L.—4116

- Ornate Bluet—*Coenagrion ornatum* S.—4045
- Barbus—*Barbus peloponnesius* V.—2503
- Carpathian newt—*Triturus montandoni* B.- 2001
- Yellow-bellied toad—*Bombina variegata* L.—1193
- European fire-bellied toad—*Bombina bombina* L.—1188
- Northern crested newt—*Triturus cristatus* L.—1166
- Bullhead—*Cottus gobio* L.—1163
- Spined loach—*Cobitis taenia* L.—1149
- Brook lamprey—*Lampetra planeri* B.—1096
- Thick-shelled river mussel—*Unio crassus* P.—1032
- Narrow-mouthed whorl snail—*Vertigo angustior* J.—1014
- Vertigo Geyera—*Vertigo geyeri* L.—1013
- Carpathian newt—*Triturus montandoni* B.—2001.

There are also several types of protected areas in the surroundings of the Czadeczka water region:

1. A buffer zone of the Silesian Beskid Landscape Park. The Czadeczka water region belongs to the buffer zone of the Silesian Beskid Landscape Park. This landscape park is under protection because of its natural, historical and cultural heritage. The purpose of its creation was to preserve, popularize and disseminate these values in terms of sustainable development (art. 26, paragraph 1 of Polish Nature Conservation Act). It covers an area of 38.620 hectares, while the dominant form of land use is forests (Fig. 6).
2. A Special Area of Conservation "Silesian Beskid"—PLH 240005.
3. Protective forests. These are areas where there is specific care of proper state of health and sanitary protection of forest stands, preferring natural regeneration and species, and spatial structure is formed in accordance with the habitat conditions (Aktualizacja Gminnego…).
4. Promotional Forest Complex of Silesian Beskids. This was created by a directive of the Director General of State Forests (no. 30 from 19 December 1994). It is composed of forests with a total area of approximately 39.780 ha. The main task of this form of protection is permanent conservation and restoration of the forests' natural values with rational methods of forest management on an ecological basis, as well as integration of objectives of forest management and active nature conservation (Prognoza oddziaływania…Czadeczki).

There are the following forms of protection in the Moravian water region:

1. The Śnieżnik Landscape Park. It includes three mountain groups of the Eastern Sudetes: Śnieżnik Massif, Golden Mountains and Bialskie Mountains, with outstanding natural values. The park is characterized by the occurrence of different types of landscape: from the lowland inner-mountain valleys, through landscapes of old mountain range, old river valleys, to an erosion landscape of tectonic edges and peak zones of Śnieżnik with a sub-alpine character. Rocks, boulder fields and vast caves with unique stalactite and stalagmite formations are quite an attraction for tourists (Prognoza oddziaływania… Czarnej Orawy).

2. Nature reserves. The 'Bear Cave' is a geological reserve protecting the largest cave of the Sudety, of which the dripstone display is one of the most beautiful in Poland. The 'New Morava' forest reserve was created in the south-western part of the Bialskie Mountains. Primeval area of the Śnieżna Białka includes part of a large forest, known as the Jawor Forest, including mixed mature forest of lower wooded zone, beech-sycamore forest additional fir, spruce and rowan.
3. A Special Area of Conservation "Bialskie Mountains and Śnieżnik Group"—PLH 020016.

3.2.2 Fauna

1. In two Natura 2000 sites of the Black Orava catchment, Babia Góra and Polica, among species that are associated with aquatic habitats and water-dependent (bogs and marshy forests), grouse (*Tetrao tetrix* L.) (A409) and capercaillie (*Tetrao urogallus* L.) (A108) are protected species (Kowalczak et al. 2009). Apart from the aforementioned, corncrake (*Crex crex* L.) (A122) is under protection in the area of Orava-Nowy Targ Natura 2000 site. In areas PLB12011 and PLB12006, both located in the upper parts of the mountains, a dominant form of water supply is atmospheric precipitation—not directly threatened by changes in water management. In addition, the area analyzed is protected by large-scale protected areas, such as national park, nature reserve, SPA—Special Protection Areas and SAC—Special Areas of Conservation.
2. The Czadeczka catchment's mammal fauna consists of about 40 species. Half of these are small mammals of the genus of *Sorex*, *Neomys*, *Apodemus* and *Microtus*. The rarest are carnivores—lynx (*Lynx lynx* L.), wolf (*Canis lupus* L.) and brown bear (*Ursus arctos* L.), a periodical migrant. Among ungulates the most common are roe deer (*Capreolus capreolus* L.) and red deer (*Cervus elaphus* L.). Breeding avifauna is represented by 80 species (it constitute approximately 33% of the breeding avifauna of Poland). The rarest species include: corncrake (*Crex crex L.*), black woodpecker (*Dryocopus martius L.*), green woodpecker (*Picus viridis L.*), ring ouzel (*Turdus torquatus L.*), spotted flycatcher (*Muscicapa striata* P.), common raven (*Corvus corax* L.) and nutcracker (*Nucifraga caryocatactes* L.).
3. As a result of forestry intensification and tourism penetration, western capercaillie (*Tetrao urogallus* L.), which was still observed until after the Second World War, has disappeared from the Istebna forest. The majority of bird species is subjected to strict legal protection. Among reptiles, the occurrence of five protected species was confirmed: sand lizard (*Lacerta agilis* L.), viviparous lizard (*Zootoca vivipara* J.), slow worm (*Anguis fragilis* L.), grass snake (*Natrix natrix* L.) and European adder (*Vipera berus L.*). All species of reptiles are protected by law. The amphibian fauna consists of about ten species, the rarest including fire salamander (*Salamandra salamandra* L.), Carpathian newt (*Lissotriton montandoni* B.) and alpine newt (*Ichthyosaura alpestris* L.). All species of amphibians are also subject to legal protection (Aktualizacja programu. . . .).

3.2.3 Flora

Within the borders of the Black Orava water region eight water-dependent habitat types are under protection:

- a pioneering herbaceous vegetation on gravel-banks along mountain streams—3220
- *Myricaria* scrub on gravel banks and heaps along mountain streams—3230
- mountainous and riverside herb communities—6430
- degraded high moors, capable of natural and stimulated regeneration—7120
- transitional moors and hag peats—7140
- mountainous and lowland alkaline bogs of a bog-spring, sedge and moss character—7230
- bog woodland—91D0
- riparian alluvial forests of poplar, alder and ash—91E0.

Moreover, the Black Orava Natura 2000 site protects pioneer herbaceous vegetation along mountain streams, mountainous and riverine herb communities and riparian forests. Among all water-dependent habitats, the mountainous and riverside herbs are also protected in the area of Polica.

Forest habitats of the Czadeczka catchment represent four habitat types in terms of typology: mixed mountain forest (3718 ha; 96.3%), mixed coniferous mountain forest (119 ha; 3.1%), mountain forest (24 ha; 0.6%) and mountain alder (1 ha, 0.0%) (Barszcz and Mach 1984). Forest species composition is dominated by spruce, whereas insignificant land surface is occupied by beech, fir, maple, Scots pine, grey alder, black alder, ash, birch and oak (Strategia zarządzania dla...).

4 Changes of Natural Environment

4.1 Changes of Water Quality Parameters

Water quality expressed e.g. by a group of physical and chemical parameters, is one of the most important factors determining trend and rate of environmental changes. Share of Uniform Parts of Surface Waters in the structure of their use (Table 3) is a good indicator of state and degree of environment transformation.

In 2008 the Black Orava, Lipnica and Syhlec watercourses did not comply with the requirements for fish occurrence in natural habitat due to exceeding limit values of biogenic and oxygen indicators, mainly: N-NO_2, TP, N-NH_4 non-ionized ammonia, dissolved oxygen. Simultaneously studies have shown lack of polluted water and threatened by pollution with nitrogen compounds from agricultural sources. Three strongly modified Uniform Parts of Surface Waters were designated in the Black Orava catchment area according to the Water directive:

Table 3 Intended use of uniform parts of surface waters in the Black Orava catchment

Code of uniform parts of surface waters	Water intended to fish existence		Water for public supply purpose	Water for recreational purpose
	Salmonidae	*Cyprinidae*		
PLRW120012822219	+	–	–	–
PLRW120014822279	+	–	–	–
PLRW1200128222729	+	–	–	–
PLRW120012822249	+	–	+	–
PLRW120012822269	+	–	+	–
PLRW120012822229	+	–	–	–
PLRW1200128222949	+	–	–	–

Source: Informacja o stanie środowiska . . .

- PLRW120012822229—Zubrzyca,
- PLRW120012822269—Syhlec,
- PLRW1200128222729—Lipnica.

Conducted classification of ecological status of Uniform Parts of Surface Waters (based on the Regulation of the Minister of Environment of the Republic of Poland from 20 August 2008) showed the following variation in water catchment areas of the Black Orava (Table 4).

Underground waters of the Black Orava water region are characterized by a good state according to the classification of the chemical status of Uniform Parts of Underground Waters (according to the directive of the Minister of the Environment from 23 July 2008 on the criteria and method of groundwater state evaluation).

The biggest threat to the quality of surface water in the Czadeczka River catchment is human pressure that includes:

- water intake for municipal and industrial purposes,
- municipal and industrial sewage discharge,
- pollution area associated with run-off of rainwater, especially in rural areas,
- morphological and hydrological changes of watercourses (river regulation, flood protection).

State and resources of underground water in the Czadeczka water region (Uniform Parts of Underground Waters) are as follows:

- chemical state—good (study year: 2010),
- quantitative state—good (study year: 2010).

The underground water resources of the Czadeczka water region do not differ from areas with similar hydrogeological structure. Economic yield of underground water aquifer amounts 158.1 m^3/day/km^2 (3887.679 m^3/day), while area of the whole water region is 24.59 km^2.

Table 4 Ecological state of the Black Orava catchment' waters

Codes of uniform parts of surface waters	Name	Status	Identification of morphological changes	Status evaluation
PLRW120012822219	The Black Orava to Zubrzyca	Natural	Lack	Moderate
PLRW120012822229	The Zubrzyca	Strongly modified	Numerous thresholds (36 levels and 31 thresholds) and regulations changing environmental conditions of fish and invertebrates, debris dam	Good
PLRW120012822249	The Piekielnik	Natural	Lack	Moderate
PLRW120012822269	The Syhlec	Strongly modified	Debris dam preventing fish migration, longitudinal dam modifying environmental conditions of fish and invertebrates	Good
PLRW120014822279	The Black Orava to the estuary	Natural	Lack	Moderate
PLRW200062138789	The Lipnica	Strongly modified	Debris dam and levels without fish ladder changing environmental conditions of fish and invertebrates	Good
PLRW1200128222923	The Chyżny to state border	Natural	Lack	Moderate
PLRW1200128222929	The Chyżny state	Natural	Lack	Moderate
PLRW1200128222949	The Krzywań	Natural	Lack	Moderate
PLRW1200128222989	The Jeleśnia in Polish border	Natural	Lack	Moderate

Source: Ocena stanu wód …

4.2 *Changes in the Biosphere*

The most intense change in the biosphere as a result of human impact on the Polish side of the Danube basin was observed in ichthyofauna. Increasingly in the twentieth century an interactive segregation, understood as the ability to interaction of communicating with each other different kinds of organisms, occupying different space within a given habitat, isolating individuals in this area was mainly caused by changes in water and organic matter flow, as well as physical-chemical parameters, granulometry of sediments and thermal conditions (Poff and Allan 1995).

In a study of ichthyofauna of the Black Orava River basin, conducted in the 1960s Eurasian minnow *Phoxinus phoxinus* L. was the dominant species. It accounted for 41.2% of all caught fish. It clearly dominated in the Oravka, the Zubrzyca and the Lipnica rivers, respectively 45.9, 45.3, and 44% (Holčik et al. 1965). Gudgeon *Gobio gobio L.* (25.6%) and roach—*Rutilus rutilus* L. (25, 4%) dominated in the Black Orava River.

Roach dominated also in the Piekielnik Stream (25.8%). Brown trout *Salmo trutta m. fario* (36.3%) dominated in the Zubrzyca Stream, whereas in the Lipnica and Piekielnik additionally chub—*Squalius cephalus* L., respectively 26.2 and 25.5% (Augustyn and Nowak 2014). In a study conducted in the years 1979–1982 leading dominance of any ichthyofauna species did not occur in the Black Orava catchment (Skóra and Włodek 1989), whereas significant share of the Eurasian minnow (21.2%), chub (17.3%), brown trout (16.7%), alpine bullhead—*Cottus poecilopus* H.(12.1%) and roach (11.6%) were marked. In the Black Orava's tributaries leading dominance was formed by following species: Eurasian minnow in the Oravka (30.2%) and the Lipnica (31.5%), brown trout in the Zubrzyca and the Syhlec (respectively 45.7 and 33.6%), alpine bullhead in the Lipnica (30.3%) and chub and gudgeon in the Piekielnik (respectively 28.8 and 27.4%) (Augustyn and Nowak 2014).

In the studies from the beginning of the present century, Przybylski et al. (2002) observed the leading dominance of the European minnow, both in the Black Orava waters of (46.17%) and Oravka (38.8%), Syhlec (40.12%) and Lipnica (47.74%). Simple domination was formed in the Black Orava by perch *Perca fluviatilis* L. (17.49%) and roach (12.7%), alpine bullhead—in the Zubrzyca (46.63%), Syhlec (33.33%) and Lipnica (35.54%), whereas brown trout—in the Oravka (29.18%) and the Piekielnik (25.14%),

In the period 2010–2011, in the whole Black Orava basin leading dominance was formed by minnow (44.82%), dominating also in the Oravka (39.84%), the Zubrzyca (65.85%), the Syhlec (62.69%) and Lipnica (50.94%). Moreover, a leading species dominance was formed by perch (45.73%) and chub (26.63%) in the Black Orava and perch in the Piekielnik (32.64%) (Augustyn and Nowak 2014).

Changes in ichthyofauna that occurred in the 1950s were related to the creation and filling of the Orava reservoir, which in the period 1952–1964 was accompanied by species introduction. In the 1970s large-scale irrigation works were carried out. Hydro-engineering structures in the river beds modified the flow dynamics and natural fish life cycle, particularly rheophile species looking for reproductive lotic sites (Anderson et al. 1995). In the more recent period, pollutants are an essential factor causing structural changes in ichthyofauna in the Black Orava river basin. Stenotopic species can not stand the load of pollutants transported by the river and they are being replaced by more resistant eurytopic species (Augustyn and Epler 2006a, b).

In the Czadeczka waters the disappearance of *Hucho hucho* L., the largest salmonid representative, was the result of changes in ichthyofauna. By the late

1940s, this species was frequently observed in waters of the Polish part of the Danube river (Witkowski and Kowalewski 1988). Poaching had contributed to the fact that already in the mid-1950s this species was occasionally caught in the Czadeczka waters (Witkowski and Kowalewski 1994; Witkowski et al. 2009). Currently, the Danube salmon is recognized as extinct in the wild in natural sites (Witkowski et al. 2009). Among the most important reasons for its disappearance, hydrotechnical development of rivers, water and aggregate intake, water pollution, deforestation of mountain and submountain areas, as well as poaching have been mentioned.

The current state of the Czadeczka ichthyofauna is defined as poor. River waters are inhabited by only four fish species: brown trout (*Salmo trutta m. Fario*), minnow (*Phoxinus phoxinus*), stone loach (*Barbatula barbatula* L.) and alpine bullhead (*Cottus poecilopus* H.). It results from water pollution, manifested e.g. as high temperature conditions and conductivity (Kotusz et al. 2010).

4.3 Potential Threats

On the basis of conducted measurements, in the Black Orava River catchment area a natural content of investigated metals (cadmium, copper, nickel, lead, zinc) in the soil was found. This means no possibility of soil contamination and possibility of cultivation of all agricultural and horticultural plants. Soil has not been contaminated with polycyclic aromatic hydrocarbons (PAHs). In terms of sulphate sulphur content, only tested soil profile within the catchment (in the Jabłonka village) showed second degree of contamination (in the IV° scale). It was an average content, both in 2000 and 2005 year (WIOŚ 2008).

In the case of Orava-Nowy Targ Peats (PLH120016, PLB12007), the biggest threat is an anthropogenic modification of water conditions. Fundamental issues include: drainage, increasing of underground water levels as a result of gravel exploitation, as well as peat exploitation for heating and industrial applications. Moreover, the area of the Orava-Nowy Targ Peats is an area of high-risk for birds, habitats and species. Among special areas of habitat conservation also highly exposed is the Black Orava area (PLH120002) exposed to water pollution from household sewage (Warunki zarządzania...). Disordered water and sewage disposal constitute an important problem in following municipalities: Raba Wyżna and Czarny Dunajec. In the Lipnica Great village more than 70% of inhabitants use a sewage plant. While the degree of sewerage in the Jabłonka municipality is diverse and different in villages as follows: Jabłonka—65.3%, Lower Zubrzyca and Upper Zubrzyca—83.8%, Lipnica Mała—50.2%, Podwilk—13%, Oravka and Chyżne—0%.

Potential risks for riverside habitats include: drainage, cleaning and hydroelectric interference in riverbeds, regulations conducting to lower water levels in streams, drainage of rivers, water intake leading to a distortion direction, flow rate and reduce their level, tree cutting resulting from a variety of conditions (in the case of riparian

Table 5 Status of uniform parts of surface rivers waters in the Danube basin in Poland

State	Length (km)
Natural	174.8
Modified	51.5
Sum	226.3

On the basis of results of SZCW and SCW and MPHP delimitation

forests). Important factors impinging on the existence of riparian forests and willow scrub in the valleys of the rivers and streams are the frequency of flooding and the quantity and quality of water that floods the vegetation.

Domestic sewage delivered into streams and disposal of waste has negatively affected Ukrainian lamprey populations in the Black Orava catchment. In 2009, in the upper course of the Black Orava and the Piekielnik rivers, an increased values of biochemical oxygen demand (BOD) (1.8–2.9 mg L^{-1}) was found, what indicated the load of the river by completely purified wastewater (Amirowicz, unpublished data). Water pollution weakens condition of individuals, affecting the viability and fertility, reducing the possibility of species survival (Strategia zarządzania. . .).

Incorrect modification of riverbeds can be also a threat. These activities change the structure of the bottom substrate and reduce the diversity of microhabitats in the riverbeds. It can result in limited number of suitable sites for spawning and larval development sites. Creation of migration barriers for ichthyofauna is another threat. For the Ukrainian lamprey even low threshold water lifting, lead to fragmentation of its range. This increases the probability of extinction of such a fragmented population. The significance of this problem consists in the fact that the Black Orava catchment was isolated from the rest of the Wag basin by the Orava reservoir and recolonisation cannot occur.

The main threat to water quality in the Czadeczka water region are wastewater loads. In the catchment area there are three municipal sewage treatment plants: (a) treatment in Koniaków Pustka, from which treated wastewaters are discharged into the “Pod Pustkami” stream; (b) treatment in Jaworzynka, from which treated wastewaters are discharged into the Czadeczka river; (c) the treatment of the hotel-tourism complex in Jaworzynka.

Terrain and climatic conditions of the Istebna commune favour the occurrence of soil erosion. However, a large forest cover of the area, as well as usually heavy granulometry composition of soil, reduce the intensity and extent of this process.

Waters of rivers of the Polish part of the Danube basin should be mainly considered as natural (Table 5).

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Pressures and Impacts on Ecological Status of Surface Water Bodies in Ukrainian Part of the Danube River Basin

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1 Introduction

In 2002 Ukraine ratified the Convention on Protection of the Danube River (signed 29 June 1994) and is one of the Parties (14 countries and European Commission) of the Convention. In 1999 Ukraine supported the establishment of the International Commission of Protection of Danube River (ICPDR), which is the co-ordination and implementation body of the Convention and EU Water Framework Directive.

For Ukraine cooperation in the Danube river basin is important in the following sectors:

- As implementation of Ukraine's international obligation as a Party to the Danube River Protection Convention, as well as to the Article 414 of Chap. 19 (Danube River) of the EU-Ukraine Association Agreement *«Bearing in mind the transboundary nature of the Danube river basin and its historical importance for riparian communities, the Parties shall implement more rigorously the international commitments made by the EU Member states and Ukraine in the spheres of navigation, fisheries, protection of the environment, in particular of aquatic ecosystems, including conservation of living aquatic resources, to archive good ecological status as well as in other relevant spheres of human activity*»;
- As a platform to obtain practical experience in the implementation of the EU Water Framework Directive and EU Flood Directive by means of the national experts' participation in the development of the Danube River Basin Management Plan (2009 and 2015) and its sub-basin—the Tisza river basin (2010).

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Three Danube sub-basins are located within Ukraine: Tisza, Upper Siret and Prut and part of Danube Delta—the most upstream and downstream stretches of the river basin.

This chapter focuses on the ecological status assessment of the two Ukrainian Danube sub-basins: Upper Tisza and Danube delta.

1.1 Tisza Basin Analysis

1.1.1 Classification

The Ukrainian part of the Tisza basin is represented by the Upper Tisza (from the source at Chorna Tisza to Badalovo village, 7 km downstream from the mouth of the Borzhava river), as well as the Middle Tisza (Latorica, Uzh and Tisza river basins from Solovka village to Solomonovo). The total length of the Tisza River within Ukraine is 265 km. From the source at Chorna Tisza until Dilove village of Rakhiv region, the Tisza flows in the territory of Ukraine (the total length of the stretch is 76 km, of which the Chorna Tisza stretch is 50 km). For a further 61 km, the Tisza forms the border between Ukraine and Romania. Downstream of Tyachiv, the river flows in Ukrainian territory to Vilok village (mouth of the Batar river). Downstream, the river forms the border between Ukraine and Hungary for 25 km, and downstream of Badalovo the Tisza flows in Hungarian territory for 77 km. From Solovka village, the right bank of the Tisza is again Ukrainian, and the left is Hungarian up to Solomonovo/Zahon village (river stretch of 19 km).

The Ukrainian part of the Tisza basin is located within two ecoregions: Hungarian lowland (ecoregion 11)—35% of the basin, and Carpathians (ecoregion 10)—the remainder. The border between these ecoregions is the 200 m a.s.l. contour.

The following categories of water body are present in the Ukrainian part of the Tisza basin: rivers, lakes, heavily modified and artificial water bodies.

Classification of the rivers of the Ukrainian part of the Tisza basin was made following system A (Annex II of EU Water Framework Directive) using the four descriptors out of four that are obligatory: ecoregion, altitude, catchment area and geology. In so far as no biological description was used, the classification is abiotic. The thresholds between classes proposed by the EU WFD were used for all descriptions, except altitude (four types instead of three).

By catchment area, small rivers have a catchment from 10 to 100 km^2, medium: 100–1000 km^2, large: 1000–10,000 km^2, very large: >10,000 km^2. The very large rivers category includes only the Tisza, downstream from the confluence with the Tur River at 724 km (from the mouth).

There are six large rivers in the basin: Tisza from the place of confluence of the Chorna and Bila Tisza until confluence with the Tur (stretch 916–727 km), right side tributaries Teresva, Rika and Borzhava, which enter it directly, as well as the Uzh and Latorica, tributaries of the Bodrog sub-basin.

By *geology*, most of the identified water bodies (10 out 12 types) belong to the calcareous type. The other two belong to the siliceous type; they are located within the volcanic Carpathians and Marmaros mountains. There is no water body with organic geology.

By altitude, all water bodies were split into four types (according to EU WFD, there should be minimum of three types: lowland <200 m, mid-altitude 200–800 m, and >800 m).

- First type—lowland <200 m (the lowest mark in Tisza basin is 101 m a.s.l.). These water bodies belong to the “Hungarian lowland” ecoregion.
- Second type includes river basins with average altitude 200–500 m a.s.l. This type, “rivers, located at foothill belt”, belongs to “the Carpathians” ecoregion.
- Third type includes the rivers with average altitude 500–800 m a.s.l., termed “rivers located in low mountains”.
- Fourth type termed “rivers located in middle-size mountains”; their altitude is >800 m a.s.l.

In total, 12 types of river water bodies were identified (Fig. 1).

Taking into account the small surface area of the lakes, their identification and classification were not carried out.

1.1.2 Hydromorphological Assessment/Status

Hydromorphological assessment was carried out for the river water bodies of Uzh, Latorica, Borzhava, Chorna and Bila Tisza, Tisza from Rakhiv city to Tyachiv city, Tereblya and party Teresva. It was done following BS EN 15843:2010 “Water quality. Guidance standard on determining the degree of modification of river hydromorphology”. Candidates for heavily modified water bodies were not assessed.

Results: almost half (47%) of 30 identified water bodies have good status and only 7%—«moderate». 23% of water bodies, mainly those located in upper reaches of the rivers have high status. Around a quarter of water bodies (23%) were not assessed (Figs. 2 and 3).

1.2 Aquatic Biodiversity

1.2.1 Phytoplankton

Phytoplankton in the rivers is represented by 117 species (127 taxa of rank below genus) of algae out of 5 divisions. The most widespread include *Bacillariophyta*—64 species, *Chlorophyta*—27, *Euglenophyta*—19. There are much fewer taxa of *Cyanophyta* and *Dinophyta*—5 and 2 species respectively. The number of species in the genus *Scenedesmus* is 10, Diatoma—4 species, 9 taxa of rank below genus,

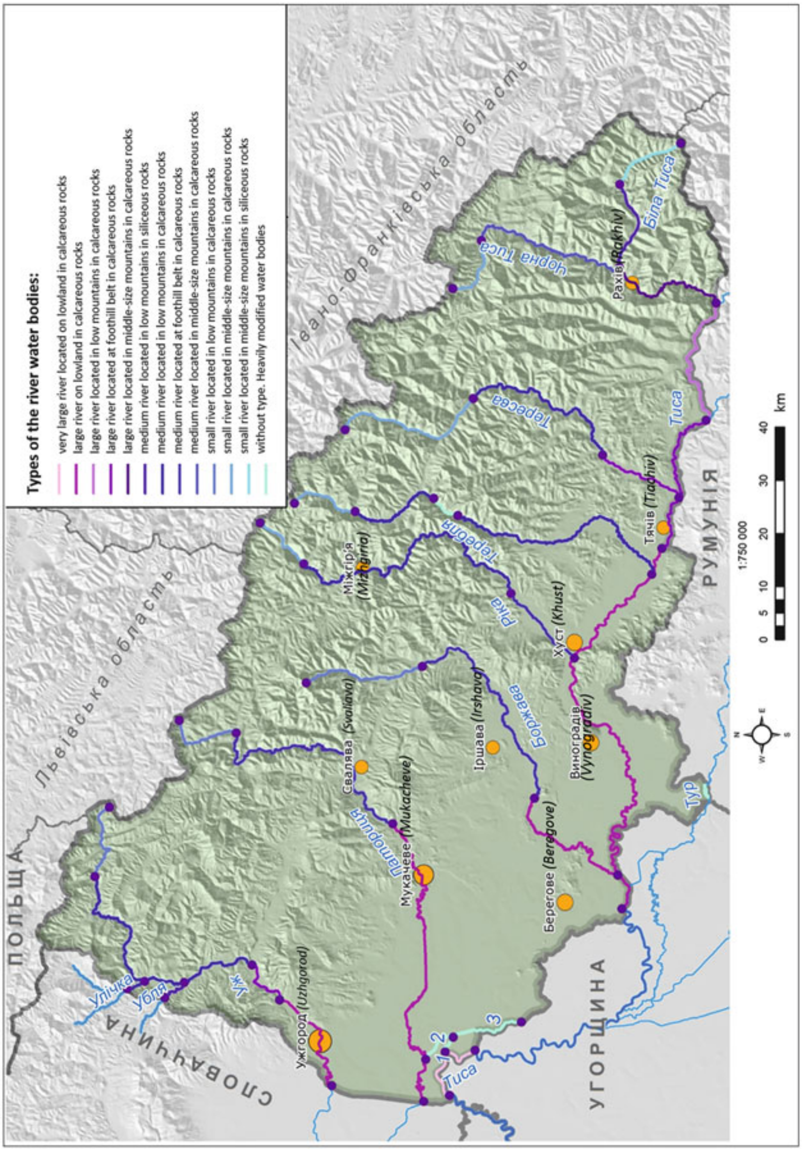

Fig. 1 Typology of surface water bodies in Ukrainian part of the Tisza basin

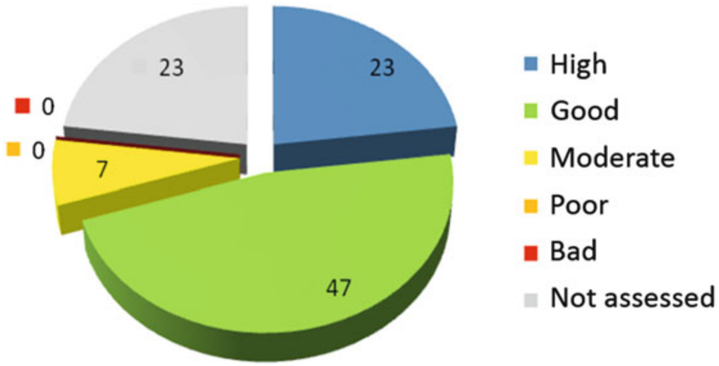

Fig. 2 Hydromorphological status of river water bodies (% from total number)

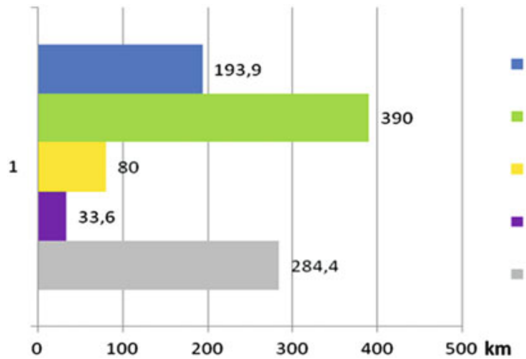

Fig. 3 Length of water bodies with different hydromorphological status (in % from the total length of the surface water bodies)

Navicula—9 species, 12 taxa of rank below genus, Nitzschia—8 species, *Cymbella* and *Gomphonema*—6 species. A peculiarity of the floristic range of the researched rivers is the high number of periphyton algae—species of the genera *Ceratoneis*, *Cocconeis*, *Cymbella*, *Gomphonema*, etc. The lowest algal species diversity is observed in upper (mountainous) reaches of the rivers (12–19 species). The highest number of species is in the foothills and lowland river reaches: in the Tisza near Vynogradiv—34 species, at the border of Ukraine—39, in the Latorica at the border—43 species.

1.2.2 Water Plants

There is no real higher water plant flora in the Tisza basin. Macrophyte development in montane rivers is limited by a number of factors: low water temperature, high flow velocity, catastrophic phenomena in the form of rainy floods and mud flows, high water turbidity, irregular river discharge, etc. In the reaches serving as the zone of sediments transition, macrophyte development is almost fully limited not only in the riverbed, where aquatic mosses can develop (e.g. *Fontinalis*), but also along the river bank, where sometimes one sees the sedges *Carex riparia, C. gracilis,* and *C. inflata* (Huds).

Floristic composition, coverage and structure of coenoses vary significantly and depend upon riverbed profile, depth and sediments structure. Mosses, mainly green (*Drepanocladus revolvens* (Lindb.) Cheney ex Wils., *Aulacomnium palustre* (Hedw.) Schwägr., *Calliergon cordifolium* (Hedw.) Kindb.), typical for upper montane landscapes, play a significant role here. The community *Doroniceta carpaticae* is endemic to the Ukrainian Carpathians. These communities are established in low and medium-altitude parts of the sub-Alpine belt on the banks of the riverbeds in shallows with running water. Moss coenoses (*Cratoneuron commutatum* (Brid.) G. Roth., *Philonotis fontana* (Hedw., Brid.), *Mnium punctatum* (Hedw.) are highly developed in shallow running waters in peatlands. Besides the dominant *Cardamine amara* L. (40–90%) coenoses include *Caltha palustris* L., *Poa deylii* (Chrtek and V. Jirásek), *Epilobium montanum* L. and *Parnassia palustris* L. as well as *Cratoneuron commutatum* (Brid., G. Roth.), *Philonotis Fontana* and *Dicranoweisia crispula* (Hedw., Lindb. ex Milde). In the sub-Alpine and upper forest belt on river banks and in shallow running water there are rarely species of vascular plants, *Juncus squarrosus* L., *Valeriana simplicifolia* (Rchb.) Kabath., and *Veronica beccabunga* L. Below the mountains within the Khust-Solotvino depression, covering the low mountains of the upper part of the basin, more favourable conditions exist for the growth of vegetation. But directly in the riverbed, water plants do not develop due to the number of negative hydrological factors, mainly significant fluctuations of water levels because of periodic floods. The hydrophyte flora (sub-aquatic plants and plants with floating leaves) remains poor—17 species, including some rare species such as *Trapa natans* L., *Limosella aquatica* L., *Eleocharis ovata* (Roth) Roem. et Schult., *E. multicaulis* (Sm.) Desv., *Caulinia minor* (All.) Coss. et Germ. and *Lindernia procumbens* (Krock.) Philcox.

1.2.3 Invertebrates

Zooplankton of mountainous rivers is poor and represented by few plankton species and forms. There are 31 species of invertebrates determined in total. The zooplankton of the Tisza river basin, besides plankton species, includes typical bottom-dwelling and periphyton communities. On average such plankton communities are characterized by an abundance of 2200–2700 species/m^3 and biomass 7.7–9.2 g/m^3. In the riverbed part of the rivers in zooplankton samples, species associated with substrate and drifting invertebrates typical for the river bottom, *Chydorus sphaericus* (O.F. Müller), *Paracyclops fimbriatus* (Fischer), *Harpacticoida* gen. sp. were dominant.

The fauna of bottom-dwelling macroinvertebrates included 861 animal species from 28 taxonomic groups of higher rank. The richest species groups were *Insecta:*

mosquitos—247, *Trichoptera*—119, *Ephemerioptera*—99, water bugs—65, mayflies—54, other *Diptera*—50, *Heteroptera*—26, dragonflies—23 species respectively. There were numerous mollusc species: *Gastropoda*—54 species and *Bivalva*—9 species respectively. Worms were also present: *Oligochaeta*—29 and leeches—21 species respectively. There were 24 species of Crustacea identified. Other groups were not numerous. From the general results of quantitative and qualitative samples, the largest species diversity was determined in the riverbed part of the Tisza river—310 species, as well as for the Borzhava river—276 species respectively. The lowest species diversity was found in the small rivers: Kisva—58 species, Shopurka—57 species.

Among the bottom-dwelling fauna, the most species-rich communities are in rivers at an altitude of 400–600 m: quantitative samples revealed more than 40 species, with a maximum of 67—in the Teresva, despite of the size of the river. The lowest species diversity is typical for communities established in large rivers in the foothills—no more than 10 species.

During surveys, rare and endangered species were identified:

- a flat worm (*Crenobia alpine)* in the Ozirtse stream;
- molluscs: *Theodoxus transversalis* found in hard substrates in lower part of Tisza; *Unio crassus crassus*—in lower part of Latorica and Botar polder system;
- leeches: *Cystobranchus respirans*—in upper part of Tisza, *Erpobdella monostriata*—in polder systems, *Trocheta bykowskii*—in upper reaches of Latorica; medicinal leech (*Hirudo medicinalis*)—in montane lakes;
- *Crustacea*: Cave shrimp (*Nyphargus stygius*) in Botar river; European crayfish (*Astacus astacus*)—in Botar, Mlynovystya and Holt rivers; *Acentrella sinaica* (is this not in *Insecta*, related to *Baetis*?)—in Chorna Tisza, Shopurka, Kisva, Teresva and upper part of Tisza up to Tyachiv;
- *Insecta*: *Baetis alpinus*—in almost all mountainous parts of Tisza basin, except Kisva and Borzhava; *Baetis beskidensis*—in Tisza at mouth of Sapintse, *Baetis gracilis*—in the rivers Chorna Tisza, Shopurka and Teresva; typical of rocky substrate—*Baetis muticus*, present almost in all rivers of the basin; *Baetis scambus*—in main riverbed of Tisza until Tyachiv and also Chorna and Bila Tisza, Teresva and Borzhava; *Baetis tracheatus*—only in upper part of Botar; *Baetis tricolor*—a few specimens in Borzhava; *Choroterpes picteti*—in many small rivers of Tisza basin; *Electrogena affinis*—in Borzhava; *Ephemera lineata*—in mouth section of Teresva river; *Ephemerella mucronata*—in the Tisza riverbed and in the Borzhava basin; *Heptagenia coerulans*—in main riverbed of Tisza as well as rivers Skorodniy and Botar; *Heptagenia fuscogrisea*—only in the main course of Tisza; *Oligoneuriella polonica*—in Tisza river upstream of the border with Hungary; *Oligoneuriella rhenana*—in the Tisza riverbed as well as rivers Shopurka, Teresva, Borzhava, Larotica and Botar; *Torleya major*—in Tisza and Latorica; *Caenis beskidensis* is registered in Tisza and Teresva rivers; *Agrion splendens splendens*—in Botar and Borzhava; *Calopteryx virgo*—in water bodies of Botar amelioration system; *Gomphus vulgatissimus vulgatissimus*—in mouth section of Borzhava; *Onychogomphus*

forcipatus forcipatus—in Teresva; *Onychogomphus cecilia*—in low part of Tisza and water bodies of Botar system; *Isogenus nubecula*—in Tisza and Teresva rivers; *Perla abdominalis*—in upper parts of Teresva and Borzhava; *Perla bipunctata*—in Teresva river; *Perla burmeisteriana* in rivers of Teresva, Borzhava, Latorica and small tributaries of Tisza; *Perla grandis*—only in Botar; *Perla marginata* was found in Tisza, Shopurka, Teresva, Borzhava, Botar; *Taeniopteryx auberti* and *Taeniopteryx schoenemundi*—only in upper reach of Tisza; *Mystacides azureus* are found in Borzhava, *Oxyethira flavicornis*—only in Botar system.

Notonecta: *Aphelocheirus aestivalis* (taxonomic confusion or something missing?)—few specimens in lower reach of Ukrainian part of Tisza.

The following species were registered for the first time for the region: *Theodoxus transversalis, Cystobranchus respirans, Erpobdella monostriata, Niphargus puteanus; Acentrella sinaica, Baetis tracheatus; Heptagenia fuscogrisea; Oligoneuriella polonica; Agrion splendens splendens; Gomphus vulgatissimus vulgatissimus; Onychogomphus forcipatus forcipatus; Onychogomphus cecilia; Aphelocheirus aestivalis; Perla bipunctata; Perla grandis, Taeniopteryx auberti, Mystacides azureus* and *Oxyethira flavicornis.*

1.2.4 Fish Fauna

At present, 63 species and sub-species of lamprey and fish from 16 families have been confirmed in the Ukrainian part of Tisza basin.

By taxonomic composition, the most widespread species include *Cyprinidae*, including 33 species and sub-species (52.4%), *Percidae*—8 species (12.7%) and salmonids—6 species and forms (9.5%); there are fewer *Cobitidae*—3 species and subspecies (4.8%) and *Cottidae*—2 species (3.2%). Another 11 families include one genus and one species.

The ichthyological value of the upper part of the Tisza river basin is confirmed by the high number of species included in the "Red Book of Ukraine" (1994). In total there are 10 species or sub-species of lamprey and fish, including *Eudontomyzon danfordi, Acipenser ruthenus, Leuciscus souffia agassizi, Gobio uranoscopus frici, Umbra krameri, Hucho hucho, Thymallus thymallus, Zingel zingel, Z. streber, Gymnocephalus schraetser*. Tisza basin endemics include *E. danfordi, H. hucho, G. schraetser, Z. streber, G. uranoscopus, R. albipinnatus vladykovi*; and endemics in common also for Dniester river basin—*Romanogobio kesslerii, U. krameri* and *Z. zingel*.

The new fish species for Ukraine, cactus roach [*Rutilus pigus virgo* (Heckel 1852)], was caught in the amelioration channels of the Tur-Batar in summer 2010. For the first time in the region, the following species were confirmed: Balon's ruffe [*Gymnocephalus baloni* (Holcik et Hensel)] and black sea chub (*Petroleuciscus borysthenicus* Kessler 1859) in the Botar system.

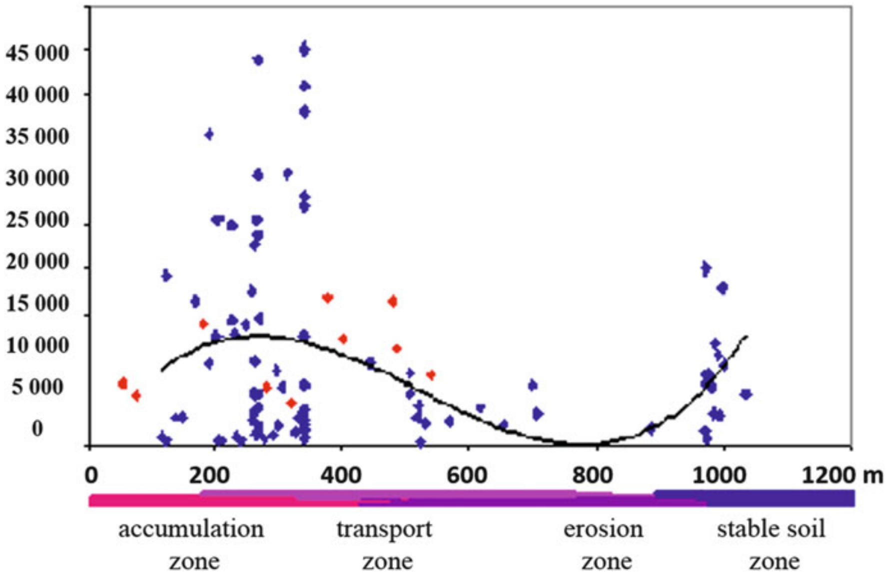

Fig. 4 Number of bottom invertebrates depending on the altitude

General analysis of biota showed that aquatic diversity inhabiting the Tisza basin represents not a single continuum, but separate communities living in different altitude-related habitats. With altitude, species, associated with substrate, are replaced by plankton forms, while at the same time their abundance, biomass and species diversity grow linearly. The same tendency in changes in fish species composition with altitude was described by many researchers and confirmed in the Tisza river basin. The only exception is the altitudinal limit of grayling (*Thymallus thymallus*), which is preserved only in some of the rivers within the western hydrological sub-region of the Tisza in Tereblya, Rika and rivers of the "Sinevir" national park. Because of the absence of grayling in all other rivers, this niche is occupied by trout: its lower limit is sometimes decreased until 250 m a.s.l., overlapping for some 50–80 m the upper distribution limit of maraena (Baltic species?).

For bottom-dwelling invertebrates, other regularities apply, which are first of all related to movement of bottom sediments. As a rule, one can identify a zone of stable soils in upper reaches, a zone of intensive erosion, a zone of transport and a zone of deposition of movable and suspended solids (Fig. 4). In mountain rivers, zones of intensive erosion and transport dominate. Starting from the upper zone of stable soils, located 1000 m a.s.l., the number of species, their abundance and biomass decreases rapidly. The minimum is fixed at 800 m a.s.l., which is defined as a border between mid-altitude and high altitude. Below this, all parameters start to grow. Abundance and species diversity of bottom-dwelling invertebrates reach their maximum at 300 m a.s.l., below which there is quite rapid (especially with regard to a number of species) and slow (with regard to abundance) reduction of the values of these parameters. Biomass of bottom-dwelling invertebrates reaches its second maximum at 200 m a.s.l. (limit between lowland and mid-altitude) and further remains at the same level until the river reaches the lowlands, where processes of sediment accumulation dominate.

In conditions of changes on granulometric composition and movement of bottom sediments in different altitudes, qualitative composition of invertebrates changes. Nymphs of ephemerons (mayflies) and amphipods dominate in river water bodies above 800 m a.s.l. At water reaches 300–800 m a.s.l., the number of *Trichoptera* and especially of mosquitos increased (in the case of mosquitos by three times); *Gastropoda* molluscs appear. For the reaches with almost no bottom sediment deposition, the species composition of mosquitos, *Oligochaeta* and bivalve molluscs increases. Riverbed processes are the main factors, limiting the quantitative values of invertebrates at 600–800 m a.s.l., where the erosion of bottom sediments is the most intensive.

Change in the structure 'dominance—biodiversity' in the communities go with the changes in substrate and changes in the river water body type. Average data for all types of substrate demonstrate that the form of this curve remains unchanged within one river water body type. The following peculiarities were defined:

- Stable soil zone (1000 m a.s.l.): communities with high number of species, represented quite evenly;
- Intensive erosion zone: it is impossible to establish stable communities here; the number of species have been reduced, their combinations are occasional; the share of some species (such as highly mobile mayflies), adapted to conditions of permanent erosion increases;
- Transport zone: here the erosion processes go together with partial sediment accumulation, leading to increase of habitat diversity; the number of species increases, and dominance reduces because of more equal opportunities to live for different forms of invertebrates;

Accumulation zone: here there is a wider range of values in conditions of increase of general trend of dominance.

Significant Water Management Issues

For the Ukrainian part of the Tisza, as well as for the Danube river basin as a whole the following main significant water management issues (SWMIs) for surface and ground waters include:

- Organic pollution;
- Nutrient pollution;
- Hazardous substances pollution;
- Hydromorphological alterations.

Two additional SWMIs specific for Ukrainian part of the Tisza river basin include:

- Littering of the riverbeds and floodplains by communal waste;
- Expansion of invasive species.

1.2.5 Organic and Nutrient Pollution

The main sources of organic and nutrient pollution of the Tisza River are communal wastewaters, industry and agriculture.

In the Ukrainian part of the Tisza basin are 19 settlements with population equivalent (p.e.) >2000 [(Fig. 5)]. Among them, Uzhgorod has p.e. > 100,000. Mukachevo also belongs to a large conurbation (p.e. > 84,000). In total there are seven towns with p.e. EH 10–100,000. The remaining 11 settlements have p.e. 2000–10,000 (Fig. 5).

The two biggest towns, Uzhgorod and Mukacheve, are responsible for the main share of pollution by organic substances and nutrients (84% of organic matter (by BOD_5) and 88% of organic matter (by COD)), 91% of total nitrogen and 93% of total phosphorus. Nitrogen is present normally in the form of nitrates, phosphorus in the form of phosphates.

Pollution by organic substances with industrial wastewaters is not significant. In total in 2010, 0.01 thousand tonnes of organic matter (by BOD_{full}), 0.017 thousand tonnes (by COD_{Cr}) were discharged. The main sources of pollution here are resort areas.

1.2.6 Hazardous Substances Pollution

Priority substances (including other pollutants, for which environmental quality standards (EQS) are established by the Directive 2008/105/EC) enter water bodies

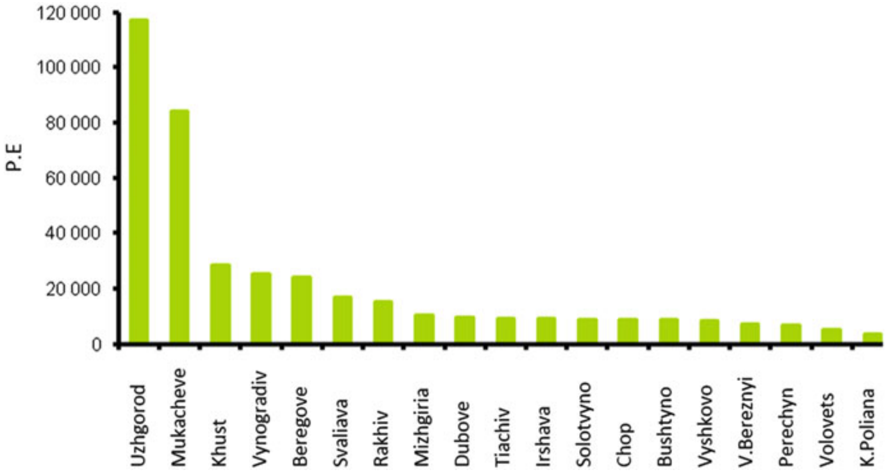

Fig. 5 Settlements in Ukrainian part of Tisza with p.e. >2000

with industrial waste water from car construction, forestry-chemical production and mining, as well as from animal husbandry, food production and communal wastewaters. Monitoring of priority substances in the surface waters and bottom sediments of the Tisza basin showed exceedance of the EQS for the concentrations of di (2-ethylhexyl)-phthalate (DEHP), naphthalene, cadmium and lead in the Tisza as well as in its tributaries. Besides, there were increased concentrations of polyaromatic carbons (PACs) in the samples, which indicate pollution by oil products.

1.2.7 Hydromorphological Alterations

The following types of hydromorphological alterations occur in the Tisza basin:

- Breaking of continuity of rivers and barriers to free migration of aquatic fauna, including fish (only two constructions breaking the continuity were fixed: dam of Tereblya-Rikska HPP and dam at Uzh river created to ensure backwater for drinking water of Uzhgorod);
- Hydrological changes (significant transfers of water from one river basin to another—this is the case only for Tereblya- Rikska HPP);
- Loss of hydraulic connection between riverbed and floodplain (reduction of the floodplain area);

  River morphology modification.

1.2.8 Littering of the Riverbeds and Floodplains by Communal Waste

This SWMI is specific for the Ukrainian part of the Tisza basin. The main reason for this is the absence of proper communal waste collection and management. Only 60% of the population is covered by services to collect and recycle waste. The low percentage of service provision can be explained by underdeveloped infrastructure (absence of containers, specialized trucks, etc.) as well as the low density of rural population and poor access to some settlements. Moreover, the higher up in the mountains, the smaller the percentage of the population to receive waste management services. As a result, illegal dump-sites are creating, mainly in the river floodplains, producing floating river litter.

1.2.9 Expansion of Invasive Species

By contrast with most pollutants of man-made origin, the majority of which are decomposed in the process of natural self-purification and can be controlled by man, invasive species can reproduce themselves and spread in the environment, creating biological barriers, destroying native species and ruining the structure of biotic communities with unexpected and irreversible consequences. The unique biodiversity of the Tisza basin with many endemic and rare species, so sensitive to external impacts, should be protected from invasive species from other basins. Taking into account the direct connection between the Tisza and Danube, where already many invasive species live, the Tisza and its tributaries are vulnerable to biological pollution. The results of surveys for the Tisza basin during 2001–2015 show the presence of many invasive aquatic species, some of which have extended significantly in some water bodies.

The list of invasive invertebrates includes the following:

- *Branchiura sowerbyi* (Beddard 1892)—found in Beregovo polder system;
- *Hypania invalida* (Grube 1860)—a few specimens found in Balzatul river at 1010 m a.s.l. on watershed border between Tisza and Prut basin.
- *Lithoglyphus naticoides* (Pfeiffer 1828)—found in Latorica, where in the river stretch between Mali Geevtsi village to the state border it plays a subdominant role in the riparian zone, and in Uzh near Uzhgorod.

Dikerogammarus haemobaphes (Eichwald 1841)—a few specimens found in Uzh downstream of Uzhgorod.

The list of invasive fish species includes:

- *Oncorhynchus mykiss* (Walbaum 1792) (syn. *Salmo gairdneri; Salmo irideus*) is widely farmed in riverbed and artificial ponds and, in times of extreme flooding, it enters the rivers in large numbers. There is evidence regarding its natural spawning in some rivers and in Tereblya water reservoir, but there is so far no confirmation regarding its capacity for self-restoration.
- *Salmo ischchan gegarkuni* (Kessler 1958) was introduced into the rivers Rika and Chorna Tisza. Its spawning conditions correspond to those of native brown trout, which leads, according to I.D. Shnarevych, to interchange of populations and gradual assimilation of the species.
- *Salvelinus fontinalis* (Mitchill 1814) and *Salvelinus* sp. have been farmed in some rivers and lakes of the Carpathians, from where it has periodically entered the rivers. No cases of natural spawning have been confirmed.
- *Pseudorasbora parva* (Temminck and Schlegel 1846) is found in some lowland rivers, which it entered together with other pond fish.
- *Carassius auratus gibelio* (Bloch 1782) is confirmed in almost all water bodies below 250 m a.s.l. and rivers with slow velocity, oxbow arms, and ponds. It has become widespread.
- *Ctenopharyngodon idella* (Valenciennes 1844), *Hypophthalmichthys molitrix* (Valenciennes 1844), and *Aristichthys nobilis* (Richardson 1845) are farmed in many ponds in the Zakarpattya lowland. Sometimes they can be seen in the rivers because of illegal release. No cases of natural spawning in Tisza basin are confirmed.

Perccottus glenii (Dybowski 1877), *Lepomis gibbosus* (Linnaeus 1758) and *Ictalurus nebulosus* (Le Sueur 1919) have been found in large numbers in polder systems and sometimes are seen in the downstream reaches and oxbow arms of the Borzhava and Latorica.

Among aquatic macrophytes, only one invasive species, Canadian pondweed (*Elodea canadensis*), is confirmed. It develops significantly in polder systems, where it can fully suppress native plant species.

1.3 Ecological Status Assessment

Values of reference conditions for ecological status assessment were identified using one of three methodologies: establishment of the existing reference conditions, analysis of historic data, and modelling based on established trends in dynamics of some descriptors present in the basin.

1. Identification of values of descriptors at reference sites. In total, there were nine reference stations (three of them are located in the rivers with catchment of >500 km^2), representing only three types of water courses.
2. Analysis of historical data. In order to define what is typical for the Tisza basin aquatic diversity communities, the following type-specific communities were defined: «Upper Tisza local species combination» for the Chorna and Bila Tisza, Tisza (upstream Vynogradiv), Rika, Tereblya, Teresva, Kisva (Kosivska) and its tributaries and "Danube local species combination" for the Tisza (downstream of confluence with the Borzhava), Borzhava (as far as confluence with the Irshava), Latorica, Uzh and their tributaries (Afanasyev 2015).

Modelling of reference values of biological descriptors was done of the basis of the study of dependence of the composition and quantitative features of aquatic biodiversity communities (bottom-dwelling invertebrates, fish) on altitude a.s.l., composition and character of bottom sediments dynamics, level of organic pollution and heavy metals, etc.

It was found out that biological features depend more on the temperature, level of erosion/accumulation/transit of sediments compared to altitude a.s.l., geology and catchment area. Reference values of biological descriptors were identified for rivers' groups, to which the relevant types were assigned taking into account structure of aquatic diversity communities (Afanasyev et al. 2013). Reference biological quality elements (BQE) for Tisza basin rivers are provided in Table 1.

Ecological status and potential assessment for surface water bodies was carried out using River Quality & Biodiversity Assessment (RQBA) (Afanasiyev 2002). It was done for all groups of BQE, stated in V WFD (macrophytes are included for assessment only in lowland reaches of the rivers, where their abundance is sufficient for high confidence data), as well as some hydromorphological features of habitats. At the same time, selected biological descriptors included all types of pressures on the water bodies. In total, ecological status assessment was carried out for 30 river water bodies. Water quality assessment by general physical-chemical parameters was done on the basis of monitoring data for 2010–2014. Assessment of biological parameters was done during 2003–2015. Results of the assessment are set out in Table 2 and Fig. 6.

Table 1 Reference biological quality elements for Tisza river basin

	Rivers of the western hydrological subdistrict		
	Tisza tributaries, which flows generally to the west		
	Danube local combination of species		
	Zone of erosion and transport of sediments	Zone of sediment accumulation	
		Riverbed	Oxbow
Block 1—Water quality (bioindication of water quality)			
Trend biotic index	*7*	*6*	*6*
P&B fpl	*1.0*	*1.5*	*1.8*
Trophicity	*Oligomesotrophic*	*Oligomesotrophic*	*Eutrophic*
Block 2—Structure of bottom invertebrates groups (number of bottom invertebrates species for reference conditions groups)			
Number of species	*Plecoptera—9* *Ephemeroptera—15* *Trichoptera—12* *Odonata—5*	*Plecoptera—6* *Ephemeroptera—10* *Trichoptera—10* *Odonata—5* *Bivalvia—3*	*Plecoptera1* *Ephemeroptera—4* *Trichoptera—3* *Odonata—3* *Bivalvia—1* *Gastropodae—7*
Block 3—Biodiversity (number of indicative for reference conditions species, endemics and protected species)			
Macroalgae	*1*	*x*	*x*
Embryophytes	*x*	*x*	*5*
Invertebrates	*12*	*10*	*6*
Fishes	*4*	*9*	*2*
Amphibian	*4*	*1*	*1*
Invasive species	*0*	*0*	*0*
Block 4—Biotopes (Ecotopes, which provide biodiversity indicative for reference conditions ratio of the main types of biotopes)			
Composition of bottom soil	*Rock ledge 10%*	*Cobble 30%*	*Silted sand 20%*
	Boulders 20%	*Sand 10%*	*Silt 30%*
	Cobble 20%	*Silted sand 20%*	*Clay 10%*
	Gravel 20%	*Clay 30%*	*Plant debris 30%*
	Other 30%	*Other 10%*	*Other 10%*
Belt of aquatic vegetation	*x*	*x*	*2*

	Rivers of the eastern hydrological subdistrict			
	Tisza and tributaries, which flows generally to the east			
	Upper Tisza local combination of species			
	Zone of stable soil and erosion	Zone of erosion and transport of sediments	Zone of sediment accumulation	
			River bed	Oxbow
Block 1—Water quality (bioindication of water quality)				
Trend biotic index	*8*	*7*	*6*	*6*

(continued)

Table 1 (continued)

	Rivers of the eastern hydrological subdistrict			
	Tisza and tributaries, which flows generally to the east			
	Upper Tisza local combination of species			
	Zone of stable soil and erosion	Zone of erosion and transport of sediments	Zone of sediment accumulation	
			River bed	Oxbow
P&B fpl	*1.0*	*1.0*	*1.5*	*1.8*
Trophicity	*Oligotrophic*	*Oligomesotrophic*	*Oligomesotrophic*	*Eutrophic*
Block 2—Structure of bottom invertebrates groups (number of bottom invertebrates species for reference conditions groups)				
Number of species	*Plecoptera—12 Ephemeroptera—15 Trichoptera—12 Odonata—3*	*Plecoptera—10 Ephemeroptera—15 Trichoptera—12 Odonata—5*	*Plecoptera—7 Ephemeroptera—10 Trichoptera—10 Odonata—5 Bivalvia—3*	*Ephemeroptera—3 Trichoptera—5 Odonata—5; Gastropodae—5*
Block 3—Biodiversity (number of indicative for reference conditions species, endemics and protected species)				
Macroalgae	*1*	*1*	*x*	*x*
Embryophytes	*1*	*x*	*x*	*5*
Invertebrates	*10*	*11*	*7*	*6*
Fishes	*2*	*12*	*10*	*3*
Amphibian	*1*	*4*	*1*	*1*
Invasive species	*0*	*0*	*0*	*0*
Block 4—Biotopes (Ecotopes, which provide biodiversity indicative for reference conditions ratio of the main types of biotopes)				
Composition of bottom soil	*Rock ledge 30%*	*Rock ledge 20%*	*Cobble 40%*	*Silted sand 20%*
	Boulders 20%	*Boulders 10%*	*Sand 20%*	*Silt 40%*
	Cobble 20%	*Cobble 30%,*	*Silted sand 10%*	*Plant debris 40%*
	Plant debris 5%	*Gravel 20%*	*Clay 10%*	
	Other 25%	*Other 20%*	*Other 20%*	*Other 0%*
Belt of aquatic vegetation	*x*	*x*	*x*	*3*

Table 2 Ecological status assessment

Ecological status	High	Good	Moderate	Poor	Very poor
Number of water bodies	3	11	12	4	0
Length (km)	73.9	286.6	439.5	148.1	0
Length (%)	7.5	29.2	44.8	9.5	0

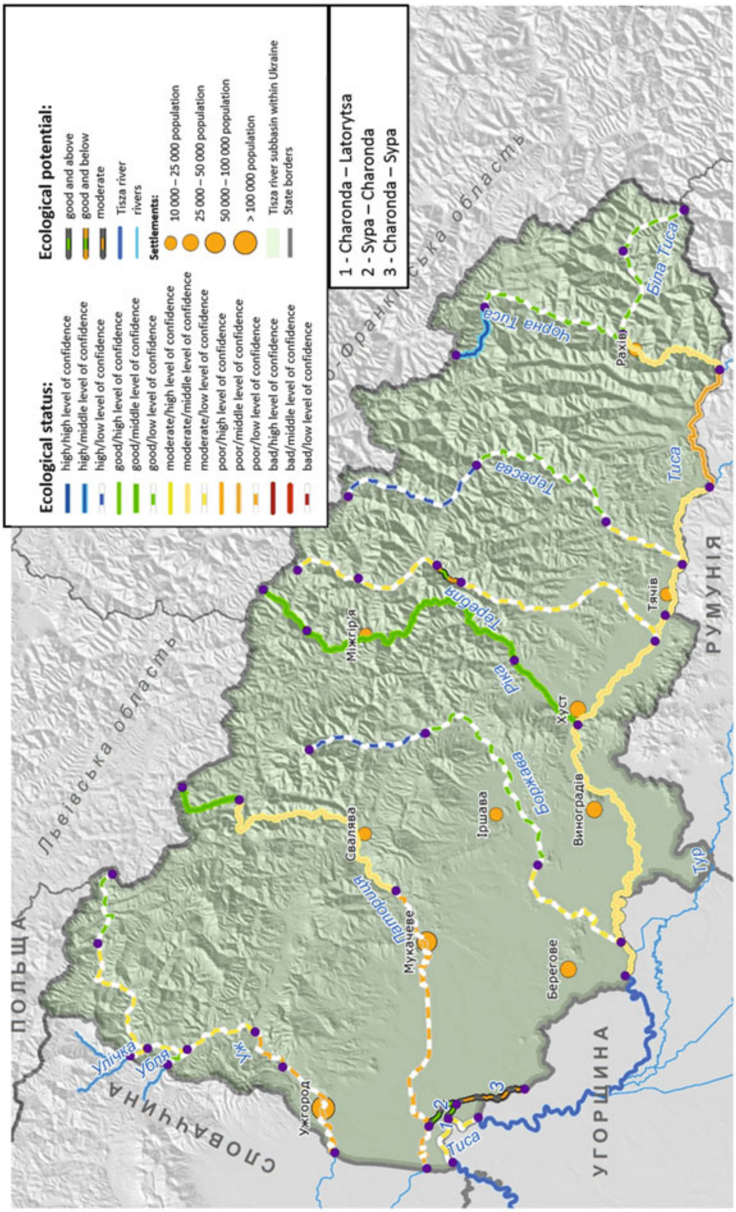

Fig. 6 Ecological status assessment

Based on the ecological status assessment, it can be seen that, of the total number (30) of water bodies, 3 have high ecological status (7.8%); 11—good ecological status (30.3%); 12—moderate ecological status (46.3%); 4—poor ecological status (15.6%). None of the water bodies have very poor ecological status.

The share of heavily modified water bodies (HMWBs) among the total number of river water bodies is relatively low (12%). The share of all four HMWBs in total length of all delineated surface water bodies is even smaller—3.5%.

2 Danube Delta Basin Analysis

The Ukrainian part of the Danube embraces 170 km from the mouth of the Prut River to the Black Sea coast. Downstream of Izmail city on the so-called Izmailskyi Chatal, the Danube divides into two arms: Tulchinsky (Romanian), and Kiliyskiy, which forms the border between Ukraine and Romania. Izmailskyi Chatal is the highest point of the delta. Ukraine has 20% of the delta (830 km^2), while 80% of the delta belongs to Romania (3370 km^2). If we compare the area of the Danube delta and the whole of its catchment, we can see that the delta forms slightly more than 1% of the total catchment area. At the same time, this is the third largest delta and associated marshes in Europe (after the Volga and Tergi) and, probably, the first by importance.

The Danube delta is unique in so far as this is the only intensively growing delta in Central Europe. A major hydrological feature of its waters is their turbidity, conditioned by a large quantity of suspended material and detritus deposits. Their average yearly content for a long-term period of observations is in the range 170–200 g/m^3 with variations from 107 up to 242 g/m^3 and a maximum of up to 2300 g/m^3. Total mass of solids flowing with the river reaches up to 100 million tonnes per year.

The large concentration of suspended matter in the Danube water causes development in the mouth zone of forking secondary delta, permanently progressing in the direction of the sea. The secondary Kilia delta, situated downstream of Vilkovo, is the youngest natural land of Europe and one of the continent's largest estuarine wetland complexes. The process of its formation began about 300 years ago and continues at the present. It is caused by such hydrophysical processes as the turbulent stirring of aqueous masses, sedimentation of suspended fragments, formation of bottom soil, fresh and salt waters mixing, flooding of vast territories, etc.

When the Danube flows into the sea and its current slows down, the suspended matter is precipitated. This process envelops considerable territories. As a result, alluvial deposits spring up in washes, brackish bays and gulfs, inland delta lakes and islands. This is the most active part—the estuary zone of advancement, that part of the delta hydraulically connected with both fluvial flow and sea. The islands are covered with lake-marsh vegetation (scrub). The unique aquatic-territorial complexes abound with unique biotopes, which ensure the possibility for existence of not only the usual widespread species, but also of rare, endemic and relict species that are representative of fauna and flora from past geological epochs.

2.1 Classification

According to the map B presented in the EU Water Framework Directive, transitional and coastal waters of the Black Sea belong to a sixth ecoregion—Mediterranean Sea.

Taking into account the main principles of delineation of transitional water bodies in the lower Danube in Ukraine, the only descriptor is the gradient of salinity. The tidal regime for the Black Sea is less than 1 m (Common... 2004), therefore this factor does not apply. Entering of marine saline waters is observed within Vilkovo (20 km), and the extent of freshwaters—for 35–40 km east from the coast to as far as Zmiiny island (Mykhailov 2004), or even further (Ivanov and Min'kovskaya 2008). Therefore, the total length of transitional waters is around 60 km. Their northern border is by Badyka Kut bay (45°29′14″; 29°38′29″), and the southern by *Kyrily* on *Kurylski* shallow waters (45°10′46″, 29°46′02″).

Taking into account the additional descriptors (current, salinity, openness for ways), the following types can be identified within the category "transitional waters":

- Oligohaline marine transitional waters (water upstream of the Bystry, Vostochny, Tsyganka, Starostambulsky arms);
- Mesohaline marine transitional waters (Zhebriyanivska bay above the Shabosh kut, Solony kut and Badyka kut);
- Oligohaline lake transitional waters (bays in Eastern and Northern part of delta of Kiliya arm, Lazorkin kut, Delyukiv kut, Potapiv kut, Anan'kin kut, Tsyganka kut, Bystry kut);
- Mesohaline marine transitional waters (bays in the Northern part of delta of Kiliya arm, Badyka kut, Solony kut and Shabosh kut);
- River transitional waters (delta of Kiliya arm).

2.2 Aquatic Biodiversity

In near-marine part of the Danube delta, hydrobio-coenoses are formed by organisms adapted to live in conditions of variable salinity and ionic water composition. A large part of the delta is overgrown by higher plants, represented in the lower Danube by 158 species. This flora is one of the landscape-establishing elements for aquatic diversity. It is defined that the main factors, affecting the vegetation abundance and species composition in the Kiliya delta is water mineralization level, level of water course isolation, its flow and water exchange, intensity of alluvium process, character of bottom sediments, and depth. Depending of their integrated impact in Kiliya delta, one can define six plant communities and uniform plant cover consisting of the Red Book species water chestnut (*Trapa natans* L.).

Development of phytoplankton in the Danube delta water courses in Ukraine is limited because of high water turbidity. Among 529 recorded algal species and forms, the dominant are *Bacillariophyta* and *Chlorophyta*. *Bacillariophyta* is represented mainly by *Nitzschia, Navicula*, *Synedra* and *Cymbella*. *Chlorophyta* is represented mainly by *Chlorococcales*, especially *Scenedesmus.* There are also a few *Cyanophyta, Euglenophyta, Dinophyta* and *Chrysophyta*, but their abundance is low. In general the phytoplankton biomass in the Kiliya delta of the Danube is much smaller compared with that of other large rivers of Ukraine. This is a result on the one hand of high river turbidity, and on the other hand the significant mass of higher water plants, limiting phytoplankton development. However, in recent years, in the summer low water period, when water turbidity is reduced, one has often been able to register intensive vegetation of phytoplankton with a biomass of up to 10–30 mg/dm^3 and even more so because of diatom development, with dominance of *Stephanodiscus hantzchii* (Grun. in Cl. et Grun.), which proves the significant eutrophication of Danube water (Ivanov and Karpezo 1996).

The animal life of the Ukrainian part of the Danube is very diverse. The zooplankton of water courses includes 369 invertebrate species and forms, among which are 189 *Rotifera* species, 90 *Copepoda* species and 90 *Cladocera* species. Other groups of water animals include insects, molluscs, *Cirripedia, Crustacea*, etc. Species composition and abundance of zooplankton differ significantly in different parts of the Danube and Danube delta. If in the riverbed part, its average number for the vegetation period is not more than 7000 individuals/m^3 (maximum—up to 14,000 individuals/m^3), then in arms and small branches, it is 67,000 individuals / m^3, and during the most productive spring season it is even 148–232,000 individuals/m^3. Low taxonomic composition of zooplankton is registered in bays of the upper (marine) part of the delta, characterized by significant fluctuations of water chemical composition; its average number here is 8–10,000 individuals/m^3. The highest values of zooplankton are determined in the stretches overgrown by *Trapa natans*, the lowest those overgrown by water lilies; the highest indicators of biomass are at the stretches of open water, the lowest those stretches overgrown by reeds.

For the lower Danube it is typical to have species diversity of bottom-dwelling invertebrates. During the surveys, 254 species of macrozoobenthos have been identified, most of which are freshwater (88%); 11% are brackish water species (Caspian relicts) and only 1% are Mediterranean forms. A comparatively small number of bottom-dwelling invertebrates are characterized by high frequency and abundance. By frequency, the following species dominate: *Polychaeta, Oligochaeta, Amphypoda, Chironomidae* and *Mollusca*. By biomass, the dominant group in the main course of the Danube since the middle of last century is *Tubificidae (Oligochaeta),* and at the same time its abundance in recent decades has increased significantly. Maximum values, registered downstream of Ismail in 2014, were 247,600 and 206 g/m^2, average—13,250 individuals/m^2 and 14.9 g/m^2. In the delta arms, the dominant group by frequency and abundance is *Oligochaeta* but, by biomass, molluscs dominate, mainly *Dreissena polymorpha* (Pallas) and *Lithoglyphus naticoides* (G. Pfeiffer). For the last 10 years, average multi-annual values of abundance in the delta arms are 7062 individuals/m^2 and 40.5 g/m^2. In the freshwater lakes, *Tubificidae* and *Chironomidae* (mainly *Chironomus plumosus* L.) are dominant. Species diversity and abundance of benthos is low because of the specific hydrochemical regime (hypoxia). In brackish bays, by abundance *Oligochaeta* and *Corophiidae* are dominant, by biomass—*Polychaeta*. It is quite usual to see larvae of *Chironomidae*. In estuary parts of arms, where saline and freshwaters mix, the most frequent are *Polychaeta*—*P. nereis* on *Nereididae* (70%) and *Bivalvia*—*Mya arenaria* (L.) (50%); by abundance, dominant groups are *Polychaeta* (1946 individuals/m^2), *Oligochaeta* (6415 individuals/m^2) and *Amphypoda* (11,210 individuals/m^2), and by biomass—*Bivalvia* (37 g/m^2). Study of structural-functional indicators of bottom invertebrates has allowed the definition, in the Ukrainian part of the lower Danube, four separate macrozoobenthos communities: those of the main river course, delta arms, internal ponds (fresh water lakes) and brackish lakes (Kharchenko and Lyashenko 1996, Lyashenko and Meteletskaya 2001). The main abiotic factors here are flow velocity, soil character, salinity, oxygen regime and other hydrochemical parameters.

There are more than 90 fish species in the Danube delta. Among these are many valuable and commercial species such as *Alosa kessleri pontica*, *Acipenser gueldenstaedtii*, *Huso huso*, *Acipenser stellatus*, *Cyprinus carpio*, *Sander lucioperca*, *Abramis brama*, etc. Of all the rivers of the NW Black Sea region, sturgeons spawn only in the Danube. In the lower Danube, there are 15 fish species listed in the Red Book of Ukraine and seven of them are listed on the European Red List, including *Hucho hucho, Salmo trutta labrax*, *Umbra krameri*, *Aspro streber* and *Aspro zingel*. The endemic species include Danube salmon, *Aspro streber*, *Gynnocephalus schraetser*, and *Gobio uranoscopus*. These fish can be seen only in the Danube (Voloshkevitch 1999). In general, the ichtyofauna of the Danube delta is characterized by significant dominance of freshwater fish compared to marine and brackish species. In recent decades, invasive species have become more and more widespread, including *Ctenopharyngodon idella*, *Hypophthalmichthys molitrix* and *H. nobilis*, etc. The following factors negatively affect the fish diversity: hydropower construction, navigation and poaching.

2.3 Pressures

Despite the high biodiversity and the world heritage importance of the lower Danube and its delta, they are under risk, caused by human activity. In the middle of the last century, the banks of the Danube and near Danube lakes were reinforced, and most of floodplains were transformed into agricultural lands, which led to deterioration of hydrological processes, washing out of pollutants from adjacent areas, and deterioration of water quality and natural ecosystems.

The significant negative factor affecting the development of ecosystems in the lower Danube is a bad ecotoxicological situation as a result of accumulation of different man-made pollutants in the lower part of the river. Comparative analysis of structural characteristics of hydrobiocoenosis over the last 50 years showed negative changes, initiated by man-made pollution of the river. It is recorded that the numbers of rare, relict and endemic species, vulnerable to poor water quality have been reduced, while at the same time those aquatic organisms resistant to high tropho-saprobity of water and other pollutants have increased. Up to the beginning of the present century, simplification of structural characteristics of hydrobiocoenoses, related to reduction of the dominant species and significant increase of their values, was identified. At present, some improvements of the environmental situation can be seen as well as enrichment of aquatic species composition. For example, in many arms of the Kiliya delta, during recent years, more and more massive hatchings of *Palingenia longicauda* (Olivier 1791) have been seen. In the marine part of the delta, south from Prymorske village, *Barnea candida* (Linnaeus 1758) can periodically be seen.

One more problem that is becoming more and more significant is invasive species—species of flora and fauna of other biogeographical zones previously never seen in Ukraine. Rich landscape and habitat diversity provides not only for native species, but also for invasive ones. This region has always been a place for active integration of invasive species. During the previous century, the lower Danube became a habitat for dozens of plants and animals, mainly surface and marine, and recently those of fresh and brackish waters. Their impact on native population should be studied.

The delta of the Danube is a gateway for the penetration of alien species into Europe; in recent years their expansion has continued, promoted by climate fluctuations, the intensification of economic exchanges, the development of water transport, and removal of the barriers earlier limiting the prevalence of many aquatic organisms. A considerable body of work (Zaitsev 2000; Son 2007; Stadnichenko and Zolotariov 2009; Dragoş and Niţă 2009; Zaitsev and Ozturk 2001), including that of the authors of the present chapter (Lyashenko et al. 2005; Lyashenko and Macovskiy 2011; Sanzhak and Liashenko 2010; Sanzhak et al. 2011), is devoted to the issue of macro-invertebrate intrusion into the ecosystems of the Danube's lower reaches.

Among the 'oldest' of the macro-invertebrate intruders, one can note the oligochaete ***Branchiura sowerbyi*** (Beddard)—a Sino-Indian species described by F. Beddard in 1892, from the pond of the Royal Botanic Gardens, Kew, in London (Beddard 1892). This worm was reported for the first time in the open bays of the fore delta of the Kiliya branch by N.P. Finogenova (Finogenova 1968) who made use of the earlier collection of Y.V. Markovsky (Markovsky 1955). Pursuant to our observation, *B. sowerbyi* is distributed mainly in the delta branches.

Sea acorns (***Amphibalanus*** (***Balanu) improvisus (Darwin), A. eburneus*** (Gould) and ***A. amphitrite*** (Darwin) penetrated into the Black Sea in 1844–1905 (Zaitsev and Ozturk 2001), and in the 1960s they were recorded by V.V. Polishchuk (1974) in the brackish-water bays, the mouths of branches and on the marine edge of the Kyliya delta. Only *A. improvisus* (Darwin) occurs widely in our collections from the mouths of branches and in the brackish-water bays.

The worm ***Urnatella gracilis*** (Leidy) is a freshwater representative of the *Entoprocta*, which penetrated into Europe in the early twentieth century (Gomoiu 2005). It originates from the eastern part of the USA and was described for the first time by J. Leidy in 1851 from the Schuylkill River, Pennsylvania (Leidy 1851). In the Danube, it was reported by M. Bachesku in 1954 (Băcescu 1954). It was found in the benthos in the Vostochnyi branch (Stadnichenko and Zolotariov 2009) and in the Danube–Sasyk channel.

Dutch crab ***Rhitropanopeus harrisii*** (Maitland) is known in the Black Sea from the middle of the 1940s (Macarov 1939). From the end of the 1960s its presence in the delta brackish-water bays was indicated by V.V. Polishchuk (1974), and in the modern period this species is widespread in phytophilous and bottom communities (Lyashenko et al. 2005).

Sand gaper mussel ***Mya arenaria*** (Linne) is a thermophilic species of Atlantic origin that readily tolerates desalinated waters. It penetrated into the Black Sea from the North Atlantic in the 1960s (Zaitsev and Ozturk 2001; Gomoiu 2005). It was recorded by us in the mouths of the delta branches.

The New Zealand gastropod ***Potamopyrgus antipodarum*** (***jenkensi***) (Smith) was recorded in various countries of Europe in the late nineteenth century (Son 2007). It was reported for the first time by Polishchuk (1974) in the brackish-water bays of the Danube delta; it was found by us in the Solonyi kut bay in 2010.

Anadara kagoshimensis (Tokunaga) [***A. inaequivalvis*** (Bruguière)] is a mussel from the Indo-Pacific, which immigrated into the Black Sea in the 1970s (Zolotarev 1996). It is common representative of the bottom-dwelling biocoenoses of the marine edge of the delta, open bays and the mouths of branches.

The following species have penetrated into the delta rather more recently; the issue of naturalization of some of them remains unresolved till now.

- Chinese swan mussel ***Sinanodonta woodiana*** (Lea) originates from the basins of large Far East and Chinese rivers. It was brought into Europe together with phytophagous fish, infected by its glochidia. These molluscs have been recorded by us in the branches and other basins of the delta since 2001 (Lyashenko et al. 2005).
- East corbicula ***Corbicula fluminea*** (Mueller) originates from the tropical and subtropical areas of the Eastern Hemisphere. Single samples were found by us for the first time in 2000 (Lyashenko et al. 2005), and since 2001 these molluscs have been reported in the majority of the water currents in the fore delta. Some researchers reported the penetration of *C. fluminalis* into the Danube as well (Son 2007), although, in our opinion, only the similar *C. fluminea* is naturalized in the lower reaches (Lyashenko and Macovskiy 2011).
- ***Ferrissia fragilis (Tryon)*** is a gastropod of North American origin, which has spread widely in Europe (Son 2007; the basic means of expansion is aquarium husbandry). It was found by us for the first time in 2009 in the phytophilous fauna of the Vostochnyi branch and later in other waterways of the delta.

Some authors (Son 2007) attribute the presence of molluscs of the family *Physiidae* [***Physella acuta*** (Draparnaud), ***Ph. skinneri*** (Taylor) and ***Ph. heterostropha*** (Say)] to immigration; they have been found in the Ochakovsky branch, the Kurile islands and the closed bays of the delta at different times (since 2002 to 2006) (Son 2007).

Mitten crab ***Eriocheir sinensis*** (Milne Edwards) was introduced to Western Europe in the early twentieth century, into the Elbe River basin, whence it settled along the west coasts of Europe and by the present time has colonised the estuaries and lower reaches of the large rivers of many European countries (Zaitsev 2000; Zaitsev and Ozturk 2001). Separate specimens were recorded in 1998 in the north-western part of the Black Sea, the fore delta of the Danube and the Odessa bay (Zaitsev 2000). It has not yet been found by us.

Colonies of the North Atlantic Hydrozoa ***Garveia franciscana*** (Torrey) [***Bougainvilla megas*** (Kinne)] was found among biofouling of the protective dam of the marine approach canal to the Bystryi branch in 2009 (Sanzhak and Liashenko 2010). It was recorded for the first time in 1923 in the Black Sea by G. Paspalev (1933), not far from Varna in Bulgaria; it is widespread in the epibioses of water passages and on the bottoms of ships in the Caspian, Norwegian, Baltic, Black and Azov Seas (Zaitsev and Ozturk 2001).

Statoblasts and a fragment of a tropical Bryozoa colony from India ***Lophopodella carteri*** (Hyatt) were found in 2010 (Sanzhak et al. 2011). The species was reported for the first time in Europe in the 1960s from the fore delta of the Volga (Abricosov and Kosova 1963), then in Bulgaria (Gryncharova 1968). The fast movement of this species is related to the migrations of waterfowl and more importantly by transport on ships.

Potential immigrants can include invasive species already recorded in the adjacent countries, and thus, according to the materials of the Joint Danube Surveys 2 (Joint... 2008), new species were recorded in the Romanian section of the Danube belonging to family *Chironomidae* of the genera *Cladopelma*, *Robackia*, *Telopelopia*, *Nilotanypus*, rare enough, dated to litoreophile complexes. North American crawfish *Orconectes limosus* (Rafinesque), well tolerating the fluctuations of waters roiliness and inhabiting the silted sections of the rivers (Parvulescu et al. 2009), was found in Germany, Austria, Serbia in the Danube in the mid-nineties of the twentieth century (Joint... 2008), and in Romania in 2009 (Parvulescu et al. 2009). The North American polyp *Craspedacusta sowerbyi* (Lankester), inhabiting the middle sector and the parts of the lower sector of the Danube (Vranovský 2003). Eastern shrimp *Palaemon macrodactylus* (Rathbun) from offshore Japan and China, well adapted for dwelling in a wide range of salinity and temperature conditions, has been found recently in the Black Sea in the territory of Bulgaria and Romania (Dragoş and Niţă 2009; Raykov et al. 2010). In our opinion, these species can be found also in the fore delta of the Kyliya branch of the Danube.

During recent decades, the environmental risks for the lower Danube, receiving as it does waters from 18 European countries, include new emerging contaminants, global climate change, change of sediment regime, hydropower and navigation.

2.4 Ecological Status Assessment

Analysis of reference values for each biotic group allows definition of the most sensitive parameters for ecological status determination for transitional water bodies (Table 3). It is comfortable to use for this, qualitative composition of biota, reference and dominant groups. These values can be obtained comparing species and taxonomic composition of communities for the reference period with the modern period. The percentage of shared species in both lists is used for assessment. Gradation of this parameter between the categories of ecological status is achieved by splitting the whole scale of its values (100%–%) at intervals equal to 5, 30, 30, 30 and 5%.

Deterioration of ecological status of water bodies is related to human activities, leading to the pollution of water courses or water transformation and modification. Therefore, many European countries use biotic pollution indices as one of the assessment criteria. Most often macro-invertebrates are used. One of the results of our multi-annual researches include adaptation and modification of widely used biotic pollution indexes in order to apply them to the lower parts of large rivers of the NW Black Sea region (Liashenko and Zorina-Sakharova 2013). Our proposal is to use the following biotic indices (TBI, BBI, and BMWP) for determination of saprobity and water quality for the delta water courses. Also the saprobic index Zelinka-Marvan (S_{ZM}), employed in the Danube delta for more than 30 years, is used in this work.

Species and taxonomic structure in the assessment is represented by two parameters:

- Presence of the reference species in each of the biotic communities-descriptors (Rich_fpl—phytoplankton, Rich_mft—macrophytes, Rich_zpl—zooplankton, Rich_mf—macrofauna) and
- Dominant groups (Dom_fpl, Dom_mft, Dom_zpl, Dom_mf), presented as % from reference values for these descriptors.

Generalized criteria for assessment of ecological status for transitional waters are provided in Table 4.

Assessment of ecological status for transitional waters showed significant variation in classes (Fig. 7). High ecological status was assigned to the Ochakivsky and Vostochny arms and the brackish water bays Solony kut and Badika kut. Moderate ecological status was assigned to the Bystry and Bilgorodsky arms, the brackish water bay Shabosh kut, all oligohaline bays (Anankin kut, Delyukiv kut and Bystry kut) and estuary marine waters (oligohaline marine transitional waters). The worst assessment result—poor ecological status—was determined for mesohaline transitional waters.

Table 3 Reference values for biotic communities in transitional waters in Lower Danube

River transitional water	
Block 1—Water quality (bioindication of water quality)	
Trent biotic Indeks (TBI mod.)	≥5
Saprobity by Zelinka and Marvan (S_{ZM})	2
Belgian Biotic index (BBI)	≥5
Biological monitoring working party index (BMWP)	≥41
Block 2—Structure of bottom invertebrates groups (number of bottom invertebrates species for reference conditions groups)	
Number of species	Ephemeroptera: >3 Trichoptera: > 5 Odonata: >5 Bivalvia: >3 Gastropoda: >3
Block 3—Biodiversity (indicative for reference conditions species, endemics and protected species)	
Phytoplankton	*Aphanizomenon elenkinii, A. flos-aquae, Gomphosphaeria lacustris, Merismopedia minima, Oscillatoria planctonica, Cyclotella kutzingiana, Fragilaria crotonensis, Melosira granulate, M. italica, Nitzschia stagnorum, Stephanodiscus hantzschii, Synedra ulna, Actinastrum hantzschii, Ankistrodesmus acicularis, A. angustus, Coelastrum microporum, C. sphaericum, Dictiosphaerium pulchellum, Micractinium pussilum, M. quadrisetum, Oocystis borgei, Pediastrum boryanum, P. duplex, Scenedesmus acuminatus, S. denticulatus, S. protuberans, S. quadricauda, Tetrastrum glabrum, Westella botryoides*.
Macrophytes	*Phragmiteas australis*, *Typha angustifolia*, *T. latifolia*, *Schoenoplectus lacustris*, *Bulbochoenus maritimus*, *Sparganium polyedrum*, *Butomus umbellatus*, *Carex riparia*, *Glyceria aquatic*, *Equisetum heleoharis*, *Stachus palustris*, *Dicrapis arundinacia*, *Solanum dulcamara*, *Calystegia sepium*, *Potamogeton nodosus*, *P. perfoliatus, P. pectinatus*
Zooplankton	*Anuraea cochlearis, A. aculeate, Brachionus pala, Polyarthra platyptera, Rattulus capucinus, Bosmina longirostris, Daphnia cucculata, Cyclops vicinus, Cyclop strenuous, Heterocope caspia, Calanipeda aquae-dulcis*
Macroinvertebrate	*Abra ovata, Chaetogammarus tenellus, Chironomus semireductus, Corophium bonelli, C. volutator, Criodrillus lacuum, Dikerogammarus haemobaphes, Gmelina costata, Gomphus flavipes, Hypaniola kowalewskyi, Idotea baltica, Isochaetides michaelseni, I. newaensis, Limnodrilus claparedeanus, L. udekemianus, Lithoglyphus naticoides, Niphargogammarus deminutus, Pontogammarus crasus, P. robustoides, Pterocuma pectinata, Stenogammarus compresus*
Block 4—Biotopes (Ecotopes, which provide biodiversity indicative for reference conditions ratio of the main types of biotopes)	

(continued)

Table 3 (continued)

Composition of bottom soil	*Silted sand*	*20%*
	Silt	*60%*
	Clay	*5%*
	Plant debris	*10%*
	Other	*5%*
Belt of aquatic vegetation		*2*
Mesohaline lake transitional water		
Block 1—Water quality (bioindication of water quality)		
Trophicity	*Mesotrophic*	
Block 2—Structure of bottom invertebrates groups (number of bottom invertebrates species for reference conditions groups)		
Number of species	Mollusca: >3 Polychaeta: >2 Crustacea: >5 Insecta: >4	
Block 3—Biodiversity (indicative for reference conditions species, endemics and protected species)		
Phytoplankton	*Thalassionema nitzschiodes, Diploneis bombus, Nitzschia longissima, N. closterium, Gyrosigma fasciola, G. spenceri*	
Macrophytes	*Phragmiteas australis, Schoenoplectus triqueter, P. pectinatus*, *P. perfoliatus, Myriophyllum spicatum*	
Zooplankton	*Notholca striata, Brachionus quadridentatus, B. angularis bidens, Lecane luna, Polyarthra vulgaris, Filinia longiseta, Keratella quadrata, Asplanchna priodonta, Acanthocyclops vernalis, Calanipeda aquae-dulcis, Moina dubia, Alona guttata, Brachionus plicatis, Synchaeta vorax, Halicyclops magniceps, Nitocra lacustris, N. typical, Nannopus palustris, Ectinosoma abrau, Mesochra aestuarii, Laophonthe mohammed, Harpacticus unimeris, Tachidius littoralis, Canuella perplexa*, *Oithona similis, Balanus*, *Penilia schmackeri, Nocticula miliaris, Tintinnopsis campanula*	
Macroinvertebrate	*Corophium volutator, Nereis succinea, Abra alba, Mesopodopsis slabberi, Mesomysis kroyeri, M. intermedia, Paramysis baeri, Idothea baltica, Sphaeroma serratum, Theodoxus danubialis, Th. fluviatilis, Lymnaea ovata, Planorbis planorbis, Pontogammarus robustoides, P. obesus, P.maeoticus, Corophium curvispinum, Balanus improvisus, Sigara linnei, S. lugubris*, *Notonecta lutea, Haliplus, Enochrus minutus, Galerucella nymphaeae, Leoichiton fagesii, Caenis horaria*	
Block 4—Biotopes (Ecotopes, which provide biodiversity indicative for reference conditions ratio of the main types of biotopes)		
Composition of bottom soil	*Silted sand*	*10%*
	Silt	*40%*
	Plant debris	*40%*
	Other	*10%*
Belt of aquatic vegetation		*2*

(continued)

Table 3 (continued)

Oligohaline lake transitional water		
Block 1—Water quality (bioindication of water quality)		
Trophicity	*Mesoeutrophic*	
Block 2—Structure of bottom invertebrates groups (number of bottom invertebrates species for reference conditions groups)		
Number of species	Ephemeroptera: >4 Trichoptera: >5 Odonata: >5 Coleoptera: >5 Heteroptera: >5 Gastropoda: >3 Diptera: >7	
Block 3—Biodiversity (indicative for reference conditions species, endemics and protected species)		
Phytoplankton	*Anabaenopsis elenkinii, A. flos-aquae, Oscillatoria planctonica, Cyclotella meneghiniana, Cymatopleura elliptica, Fragilaria crotonensis, Stephanodiscus hantzschii*, *Synedra pulchella*	
Macrophytes	*Phragmiteas australis, Typha angustifolia, Sparganium erectum, Nymphaea alba*, *Myriophyllum verticullatum, Sagittaria sagittifolia*	
Zooplankton	*Synchaeta, Anuraea cochlearis, A. aculeate, Polyarthra platyptera, Asplanchna, Heterocope caspia, Eurytemora velox, E. grimmi*, *Calanipeda aqua-dulcis, Acanthocyclops vernalis*	
Macroinvertebrate	*Stylaria lacustris, Tubifex tubifex, Limnodrillus sp., Nais sp., Gmelina costata, Chironomus, Paramysis baeri, Limnomysis benedeni, Laccophilus variegatus, Haemonia appendiculata, Hyphydrus ferrugineus, Chaetarthria seminulum, Limnebius picinus, Ochthebius pussilus, Noterus crassicornis, Berosus luridus, B. spinosus, Galerucella nymphaeata, Coelambus parallelogramus, Enochrus bicolor*, *Limnaea stagnalis, Planorbis planorbis, Lymnaea ovata, Lymnaea auricularia, Planorbarius corneus*, *L. palustris, Acroloxus lacustris, Gyraulus albus, Cricotopus, Tanytarsus, Glyptotendipes, Endochironomus, Corynoneura, Enallagma cyathigerrum, Crocothemis erythrea, Ischnura pumilo, Erythroma najas, Nymphula nymphaeata, Acentropus niveus*	
Block 4—Biotopes (Ecotopes, which provide biodiversity indicative for reference conditions ratio of the main types of biotopes)		
Composition of bottom soil	*Silt*	*100%*
	Sand	*80%*
Belt of aquatic vegetation		*3*
Marine transitional water		
	Mesohaline	Oligohaline
Block 1—Water quality (bioindication of water quality)		

(continued)

Table 3 (continued)

Trophicity		No data	No data
Block 2—Structure of bottom invertebrates groups (number of bottom invertebrates species for reference conditions groups)			
Number of species		Crustacea: >4 Polychaeta: >3 Mollusca: >3	Crustacea: >2 Polychaeta: >2 Mollusca: >2
Block 3—Biodiversity (indicative for reference conditions species, endemics and protected species)			
Macrophytobenthos		*Cystoseira barbata*, *Ulva rigida*, *Enteromorpha sp.*	x
Zooplankton		*Acartia glausi, Diaptomus gracilis, Chydorus sphaericus, Bosmina longirostris, Podon polyphemoides*	*Notholca acuminate, Brachionus calyciflorus, B. angularis, B. plicatilis, Keratella quadrata, Polyarthra vulgaris, Acanthocyclops americanus, Acartia glausi*, *Chydorus sphaericus*, *Bosmina longirostris, Alona rectangular, Penilia avirostris, Daphnia sp., Ceriodaphnia pulchella, Moina micrura*
Macroinvertebrate		*Pontogammarus maeoticus, Nereis succinea, Corophium volutator Abra ovata, A. alba, Cardium edule, Hydrobia ventrosa, Scala ventrosa, S. communis, Bittium reticulatum, Retusa variabilis, Nereis succinea, Nemphtys hombergii, Gammarus locusta, Ampelisca diadema, Gmelina costata, Bathyporea guilliamsoniana, Iphinoe maeotica, Gebia litoralis, Carcinus maenas, Heterograpsus lucasii, Diogenus pugilator, Idotea baltica, Sphaeroma serratum*	*Pontogammarus maeoticus, Aloidis maeotica, Hydrobia ventrosa, Nempthis hombergii, Spio filicornis, Cylichnina robagliana*, *Cardium edule, Tritia reticulata*, *Pontogammarus maeoticus, Gammarus aequicauda, Corophium volutator, Pterocuma pectinata, Upogebbia littoralis, Carcinus mediterraneus, Rhitropanopeus harrisii tridentata, Ballanus improvisus*
Block 4—Biotopes (Ecotopes, which provide biodiversity indicative for reference conditions ratio of the main types of biotopes)			
Composition of bottom soil	*Sand*	*30%*	*30%*
	Silted sand	*30%*	*30*
	Silt	*60%*	*60%*
Belt of aquatic vegetation		*1*	*x*

Table 4 Criteria of determination of ecological status for transitional waters in the lower Danube

Parameter of ecological status	Category and score of ecological status				
	High	Good	Moderate	Poor	Very poor
	5	4	3	2	1
Saprobity and water quality (only for river transitional waters)					
S_{ZM}	1.6[a]–2.0	2.1–2.5	2.6–3.0	3.1–3.5	>3.5
TBI	≥5	4	3	2	0–1
BBI	7–8[a]	5–6	3–4	2	0–1
BMWP	>100	71–100	41–70	39–11	0–10
Taxonomic diversity					
Reference species	100%–95%	94%–65%	64%–35%	34%–5%	0%–4%
Dominating groups	100%–95%	94%–65%	64%–35%	34%–5%	0%–4%
Protected species	X				
Invasive species					X

[a]Indexes exceeding reference values are not taken into account in further assessment

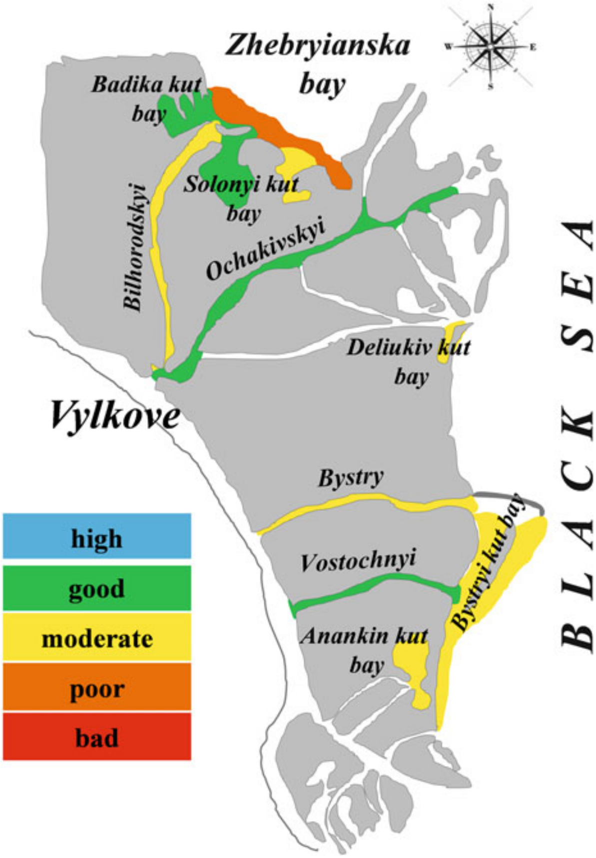

Fig. 7 Result of ecological status assessment for water bodies in the Kiliya delta of the Danube

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Drina River (Sava's Tributary of Danube River) and Human Impact in Albania

Rigers Bakiu

1 Introduction

The Sava river is the third longest Danube tributary, and the largest by discharge. The length of the Sava River from its main source in the western Slovenian mountains to its mouth into the Danube in Belgrade is about 944 km (ISBRC 2009). It runs through four countries (Slovenia, Croatia, Bosnia and Herzegovina, and Serbia), and connects three of the four capitals: Ljubljana in Slovenia, Zagreb in Croatia, and Belgrade in Serbia. The fourth capital—Sarajevo, in Bosnia and Herzegovina—also lies within the Sava River Basin. The basin, with an area of 97,713 km^2, covers considerable parts of Slovenia, Croatia, Bosnia and Herzegovina, Serbia and Montenegro, and a small portion of Albanian territory. With its average discharge of about 1564 m^3/s, the Sava River represents the most important Danube tributary, contributing almost 25% to the Danube's total discharge at their confluence in Belgrade. The Sava River is very important for the Danube River Basin also for its outstanding biological and landscape diversity. One of the first order, main and right tributaries of the Sava River is the Drina. The Drina basin is 20,320 km^2 and its total length some 346 km, with Albania's share of the basin about 179 km^2 or 0.2% (ISBRC 2009).

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2 General Characterization of the Drina River

The Drina river starts at the confluence of its two headwater, the Crni Drim (Black Drina) which begins at the Macedonian city of Struga near the Albanian border, and the longer Beli Drim (White Drina), at the city of Kukës in the Trektan area of eastern Albania (Fig. 1). Measured from there until its mouth on the Adriatic Sea, the Drina is 160 km long. However, measured from the source of the White Drin, its length is 335 km, making it the longest river that runs through Albania (Streissguth 2011). The Black Drina (Crn Drim in Macedonian, Drini i Zi in Albanian) flows out from Lake Ohrid, in Struga, and runs through the Republic of Macedonia and Albania. The White Drina (Beli Drim, Cyr. Бели Дрим, in Serbian, Drini i Bardhë in Albanian) originates from Mt. Žljeb, north of the town of Peć in the Dukagjin region of Kosovo, and runs from there into Albania (Tockner et al. 2009).

From Kukës, the Drina flows through northern Albania, first flowing through the Has area to the north, passing through the towns of Spas and Fierzë, and then, upon reaching the Dukagjini area, it descends to the south, flowing through Apripë e Gurit, Toplanë, Dushman, Koman, Vjerdhë Mazrrek, Rragam, and Pale Lalej. At Vau i Dejës, it enters the low Shkodra Field and splits into two arms. One empties into the Bay of Drina (Albanian: Pellg i Drinit) in the Adriatic Sea south-west of the city of Lezhë (The Mouth of Drina, Albanian: Gryk'e Drinit). The other empties into the Bojana River near Rozafa Castle. Even though the shorter branch by 15 km, the section that reaches the Bojana is called Great Drina (Drini i Madh in Albanian), because it brings much more water than the longer branch that reaches the sea. The

Fig. 1 Map view of the Drina River in Albanian territory (Google Earth 2015)

Table 1 General characteristic of the Drina River (Tockner et al. 2009)

Mean catchment elevation (m)	868
Discharge (km^3/year)	11.4
Specific discharge (L/s km^2)	17.5
Mean annual precipitation (cm)	105.3
Mean air temperature (°C)	8.9
Number of ecological regions	4
Land use (% of catchment)	
Urban	0.7
Arable	21.7
Pasture	4.3
Forest	36.6
Natural grassland	26.2
Sparse vegetation	5.2
Wetland	0.8
Freshwater bodies	4.5
Water stress	
1995	1.1
2070	1.2
Fragmentation	3
Number of large dams (>15 m)	3
Native fish species	56
Nonnative fish species	16
Large cities (>100,000)	2
Human population density (people/km^2)	98

Great Drina also once reached the sea but a major flood in 1858 cut it off, and it breached through to the Bojana. The Great Drina a is very wide and brings a huge amount of water (320 m^3/s) but, being short, some maps indicate it as a lake. After Vau i Dejës, the longer branch continues to the south, passing through Bushat, Mabë, Gajdër, Lezhë and Medes. South of Lezhë it enters the low and flooded littoral area and, flowing through the marshes, finally reaches the Adriatic sea. General characteristics of Drina River are reported in Table 1.

The Drina flows through mountainous terrains and wide, densely populated valleys. The lowland section has been dyked. In the Albanian part, half of the arable land is irrigated, whereas the mountainous areas remain virtually undisturbed.

3 Palaeogeography

The Balkan Peninsula has developed over the course of several orogenic cycles from the Late Palaeozoic to the present following the collision between the Eurasian and African tectonic plates. The current orographic regime of the Balkans is the result of the Alpine orogenesis during the past 250 million years (from late Triassic to the

Quaternary). The Alpine orogenesis began with the rifting of Pangea, the development of tectonic rift valleys, and the advance of the Tethys Sea between Eurasia and Africa–Arabia. Widespread carbonate marine sedimentation (limestones, dolomites and marls) continued through the Triassic and Cretaceous (Tockner et al. 2009). During the late Jurassic and early Cretaceous significant orogenic activities caused the break-up of the continental crust within the Tethys Sea, where ophiolites, situated today along two parallel belts, have developed. A Cretaceous to Eocene compressive deformation that migrated from the east to the west of the Balkans was followed by the generation of deep rift valleys, which were filled up by flysch and molasse (Eocene–Miocene, becoming younger from east to west). During the late Tortoninan (c. 8 Ma BP), widespread extensional tectonics caused intense fracturing of the central continental part, the invasion of the sea and the connection of the Mediterranean with the Black and Caspian Seas, both remnants of the Paratethys (Tockner et al. 2009). In the mid- to late Miocene, the initial rift structures of most of the Balkan rivers, for example the Strymon, Nestos, Axios, Neretva, Aliakmon and Acheloos, were formed along large faults, together with the rifts of Lakes Ohrid, Prespa and Doirani (Tzankov et al. 1996; Karistineos and Ioakim 1989; Medzida et al. 2006; Hinsbergen 2004; Lykoudi and Angelaki 2004). The Albanian Alps are situated at the north-eastern part of the country with quite clear boundaries. In the south they extend as far as the Drini Valley (in the sector between Fierza and Vau i Dejës), which separates them from the Puka highlands. Paleogeographic development of the Alps originates from the Paleozoic, when they were representing a single entity. Later on, during the Mesozoic, their differentiation started in the Alps ridge and in the Cukali trough. In the tectonic zone of the Alps, disjointed terrigenous material accumulated, initially later on replaced by carbonatite lavas (Shumka and Trajce 2009). Meanwhile, in the tectonic zone of Cukali, terrigenous materials were being deposited throughout this period. Between the middle and upper Triassic, the Alps territory emerged above the water, thus exposing it to continental conditions. This emergence was accompanied by the development of the bauxite stratum that can be found today in this region (Shumka and Trajce 2009).

4 Climate

The Drina basin has the lowest average air temperature (8.9 °C) of all the basins examined, although its downstream section exhibits a Sub-Mediterranean climate with mild, wet winters and hot summers (mean annual air temperature: 16–1 °C). In Albania, mean precipitation ranges from 3000 mm (Albanian Alps) to 1300 mm (southern part). The Albanian Alps are the area with the highest precipitation in the territory of Albania. On average, there is more than 2400 mm rainfall per year; meanwhile the overall country average is 1450 mm. A significant parameter that indicates Mediterranean climate features is the proportion of rainfall during the cold season compared to the yearly amount of rainfall. In this case (according to the data available from several years) this proportion is 68–72% (Tockner et al. 2009). The analysis of monthly rainfall shows that November is the wettest month with on average 360 mm of rainfall. On the other hand, the driest month is July, with on average only 88 mm of rainfall.

5 Hydrology and Biogeochemistry

The Drina river originates from the Lake Ohrid-Prespa karstic system. Lake Prespa (surface area: 274 km^2, basin: 1300 km^2, mean depth: 16 m, maximum depth 47 m) contributes to Lake Ohrid about half of its karstic groundwater inflows (Amataj et al. 2007). During the past 20 years, a decline of the water level in Lake Prespa has been observed. Lake Ohrid discharges 0.69 km^3/year through an artificially controlled outlet into the Black Drina. It is a deep lake (surface area: 358 km^2, basin: 1310 km^2, mean depth: 155 m, maximum depth: 288 m). Lake Shkodra (basin area: 5180 km^2), receives its waters mainly by the Moraca River (99 km long) and drains into the 44 km long Buna River that joins the 1.5 km before the mouth. The hydrological regime of Buna and the water level of Shkodra depend upon the flow of the Drina. During winter floods, the Drina floods back into the Buna, and consequently the lake experiences flooding from Drina water (Faloutsos et al. 2006). As a result, the lake surface varies from 372 to 542 km^2 and the maximum depth exceeds more than five times the mean (8 m). In the mountainous basin are located three groups of glacial lakes (Lura, Ballgjaj and Dhoski). Snowmelt in the upper part of the river causes discharge maxima in May, while in the lower section maxima occur in December. Seasonal discharge variation increases downstream (Table 2).

In the western Balkans represented by the Drina basin, high precipitation in combination with flysch bedrock causes specific sediment yields of 1000–16,000 tones/km^2/year. In autumn, initial heavy rains falling on desiccated soils often cause landslides, especially where unconsolidated sediments prevail. During the first flush events, there often occurs 50–95% of the annual sediment transport (Poulos et al. 1996). The Drina has experienced a 13-fold sediment reduction compared to pre-industrial rates (REAP 2006).

Of all the rivers examined in Balkans, the Drina shows a maximum DIN (Table 3). The Drina also exhibits the highest nitrate concentration and it is one of the rivers that score 'bad' in nitrate quality according to a classification system developed by Skoulikidis et al. (2006). Concerning nitrite, the Drina river is classified as 'moderate'. Maximum ammonia levels place Drina in 'good' status. In the Drina, the ammonia proportion is minimum (0.7–1.1%).

Table 2 Discharge characteristics of the Drina river (in m^3/s) (Tockner et al. 2009)

Station	Period	A (km^2)	NQ	MNQ	MQ	MHQ	HQ	MHQ/MNQ
Ura e Dodes	1976–1984	5400	27	47.8	98.2	164	302	3.4
Vau i Dejes	1960–1968	12,368	13	66.8	339	613	772	9.2

Table 3 Water quality characteristics of Drina river (Tockner et al. 2009)

Station		DO (mg/l)	N-NO_3 (mg/l)	N-NO_2 (µg/l)	N-NH_4 (µg/l)	TP (µg/l)	DIN (mg/l)
Near lake Shkodra	Average	8.6	4.6	16.3	37.75	36	4.65
	Median	8.6	1.465	16.3	35.25	31	1.52
	Range	2–12	0.035–12	1–65	10–80	9–90	0.046–12.2

Increase in the human population and the development of tourism cause harmful changes in ecosystems, with consequential changes to the qualitative and quantitative compositions of biocenosis. It is therefore possible to investigate conditions in some ecosystems by looking at the composition of the organisms that live in them—bioindicators. Being rather tolerant to different environmental conditions, many rotifer species are good indicators of water quality and can be used for the ecological monitoring of water bodies (Sladacek and Tucek 1975; Reh 1997; Kostoski et al. 2001). A qualitative study was carried out by Shumka and Miho (2008), of seasonal dynamics during 2001–2004. The samples were taken from localities in the eastern littoral zone of the lakes as a part of the Drina watershed. Saprobiological analysis was carried out by the standard Pantle-Buck method (Pantle and Buck 1955) based on qualitative and relative quantitative composition of Rotifera, Cladocera and Copepoda species. As reported by the authors, data taken from this compilation work show the enormous importance of the Drina watershed. A checklist of more than 1000 taxa of phytoplankton and a considerable number of zooplankton (species or other taxa) were found in all (Table 4), where about 25 belong to centric diatoms and the remaining to pennatae. For each species, the habitat where it was found and the relevant author is reported. The so far reliably known autecological data, occurrence in Central Europe, and relative trophic index is reported for most of the species. The number of taxa is relatively high, if we consider that the total number recorded for the whole of Europe is about 1600 (Krammer and Lange-Bertalot 1986–1991; Lange-Bertalot 2001). Of the total number recorded, more than 60 taxa are known to be endemic to the region, most of them occurring in Lake Ohrid. More than 120 taxa belong to the Red List of the Central Europe, considered as endangered species, which mean that they grow up in rare habitats.

6 Flora and Fauna

The rivers in the western and southern Balkan Peninsula often have similar, but structurally varied alpine riparian vegetation. Further downstream along the river valleys, Mediterranean mountain vegetation develops. Oriental plane (*Platanus orientalis*) is the most ubiquitous tree species along Balkan rivers, especially in the western and southern parts of the peninsula. In open depositional zones, thickets of olive willow (*Salix eleagnus*) are characteristic throughout the western Balkans,

Table 4 Presence of various zooplankton species in course of the Drina catchment (Shumka and Miho 2008)

Nr.	Species	Ohrid Lake	Prespa Lake Micro	Prespa Lake Ma	Fierza A. Lake	Shkodra Lake
	Rotatoria					
1	*Macrohaetus subquadratus*		+			
2	*Tricotria pocillum*					+
3	*Platyas patullus*					+
4	*Brachionus quadridentatus*		+	+		
5	*Brachionus caciciflorus v.brycei*		+	+	+	+
6	*Brachionus c.v. dorcas*					+
7	*Brachionus unceolaris*					+
8	*Brachionus unceolaris v. sericus*		+			
9	*Brachionus plicatus*					+
10	*Brachionus forficula*					+
11	*Brachionus diversicornis*		+			+
12	*Brachionusangularis*	+	+	+	+	+
13	*Lophocaris salpina*					+
14	*Lophocarisoxystemon*					+
15	*Mytilina crassipes*		+			
16	*Mytilina mucronata*		+			+
17	*Euchlanis mentea*					+
18	*Euchlanis dilatata*					+
19	*Dipleuchlanis propatula*		+			
20	*Anuraeopsis fissa*		+			
21	*Keratella cochlearis*	+	+	+	+	+
22	*Keratella.c.v. macracantha*		+			
23	*Keratella cochlearis v. hispida*		+			
24	*Keratella ticinensis*					+
25	*Keratella valga*					+
26	*Keratella quadrata*		+	+		
27	*Kellicotia longispina*	+	+	+	+	+
28	*Notholca acuminate*					+
29	*Squantinella rostratum*		+			
30	*Squatinella tridentatus v. mutica*					+
31	*Lepadella ovalis*		+			
32	*Lepadella patella*	+	+	+	+	+
33	*Lepadella rhomboids*		+			

(continued)

Table 4 (continued)

Nr.	Species	Ohrid Lake	Prespa Lake Micro	Prespa Lake Ma	Fierza A. Lake	Shkodra Lake
34	*Lepadella ehrenberqi*					+
35	*Lecane luna*	+	+	+	+	+
36	*Lecane curvirostris*		+			
37	*Lecane elsa*		+			
38	*Lecane nana*					+
39	*Lecane elasma*		+			
40	*Lecane quadridentaka*					+
41	*Lecane hamata*		+			
42	*Lecane closterocera*		+			
43	*Lecane bulla*		+			
44	*Lecane lunaris*	+	+	+	+	+
45	*Lecane obtuse*					+
46	*Scaridium longicaudum*					+
47	*Monommata aequalis*					+
48	*Cephalodella forficula*		+			
49	*Cephalodela misgurnus*	+	+			
50	*Decphalodela giba*					+
51	*Trichocerca bicristata*					+
52	*Trichocerca capucina*	+	+	+	+	+
53	*Trichocerca similes*		+			
54	*Trichocerca longispina*	+	+	+		+
55	*Trichocerca myersi*		+			
56	*Trichocerca rattus*	+	+	+		+
57	*Trichocerca pusilla*		+	+		
58	*Trichocerca porcellus*					+
59	*Trichocerca rectangularis*		+			
60	*Asplanchna priodonta*		+	+		+
61	*Polyarthra vulgaris*	+	+	+	+	+
62	*Polyarthra trygla*		+	+		
63	*Synchaeta pectinata*					+
64	*Pleosoma truncatum*	+	+	+		+
65	*Testudinella mucronata*					+
66	*Testudinella patina*		+			
67	*Testudinella incise*					+
68	*Testudinella pseudoliptica*		+			
69	*Testudinella palladina trilobata*	+				
70	*Pompholyx sulcata*		+			
71	*Pompholyx complanata*		+	+		+
72	*Pedalia mira*		+			

(continued)

Table 4 (continued)

Nr.	Species	Ohrid Lake	Prespa Lake Micro	Prespa Lake Ma	Fierza A. Lake	Shkodra Lake
73	*Pedalion* sp.	+				
74	*Dissotroca aculeata*	+				
75	*Rotari rotatoria*	+				
76	*Phylodina megalotrocha*	+				
77	*Epiphane* sp.		+	+		
78	*Ascomorpha ecuaudis*		+	+		+
79	*Filinia longiseta*	+	+	+	+	+
	Cladocera					
1	*Sida crystalina*	+	+			+
2	*Diaphanosoma brachiurum*	+	+	+	+	+
3	*Daphnia pulex*	+?				
4	*Daphnia pulicaria*	+				
5	*Daphnia longispina*	+	+	+		+
6	*Daphnia magma*					+
7	*Daphnia cucullata*		+	+		
8	*Scapholeberis mucronara*	+			+	
9	*Simocephalus vetulus*	+	+	+		
10	*Simocephalus serrulatus*	+	+	+	+	+
11	*Ceriodaphnia laticaudata*		+			
12	*Bosmina coregoni*					+
13	*Bosmina longirostris f. typical*		+	+		
14	*Bosmina longirostris f. brevicornis*			+		
15	*Bosmina longirostris f. pellucida*		+			
16	*Bosmina longirostris f. similes*		+			
17	*Acroperus harpae*	+	+		+	+
18	*Alona rectangulus*	+	+	+	+	+
19	*Alona gutatta*		+			
20	*Alona quadrangularis*		+	+		
21	*Alonella excise*	+	+	+	+	+
22	*Alonella exigua*					+
23	*Pleuroxus aduneus*		+	+		+
24	*Pleuroxus laevis*					+
25	*Chydorus sphaericus leonardi*	+	+	+	+	+
26	*Leptodora kindti*		+	+		+
27	*Rinchotalona rostrata*	+				

(continued)

Table 4 (continued)

Nr.	Species	Ohrid Lake	Prespa Lake Micro	Prespa Lake Ma	Fierza A. Lake	Shkodra Lake
	Copepoda					
1	*Eudiaptomus gracilis*	+				
2	*Archtodiaptomus steindachneri*	+	+	+		
3	*Archtodiaptomus kerkyrenchis*		+	+		
4	*Mesocyclops leukarti*	+	+	+		+
5	*Macrocyclops albidus*		+	+	+	+
6	*Eucyclops serrulatus*		+	+	+	
7	*Eucyclops macruroides*		+			
8	*Thermocyclops oithonensis*		+			
9	*Cyclops ochridanus*	+				
10	*Megacyclops viridis*					+
11	*Acanthocyclops vernalis*					+
12	*Diacyclops bicuspidatus*					+

including Albania. In the western Balkans important lowland forests are present along Lake Shkodra. However, in most areas hardwood hygrophilous woods with ash or oak are extremely rare and often only small stands remain of the surviving trees. The large western Balkan deltas share similar landscape features (Koumpli-Sovantzi 1983; Sarika et al. 2005). These deltas (like the Drina river delta) are bounded by limestone hills, islets and large lagoons with barrier spits along the shore. Rich hydrophyte communities, which include *Potamogeton* spp., *Myriophyllum* spp., *Polygonum* spp., and helophytes (extensive beds of reeds (*Pragmites australis*), *Scirpus*, *Carex* and *Typha* spp.) cover the main river channel. Complex riparian galleries (*Salix* spp., *Populus* spp., *Ulmus minor*, *P. orientalis*, *Fraxinus* spp.) fringe the deltas. Deciduous scrubs, such as *Tamarix* spp., cover brackish coastal lagoons, while Chaste Tree (*Vitex agnus-castus*) prevails along inland freshwater wetlands. Halophilous, chenopod dwarf shrubs (*Salicornia*, *Arthrocnemum* and *Halocnemum* spp.) often form extensive communities in river mouths and coastal salt marshes. Along sandy shores, ammophilous associations form shifting dunes colonized by *Ammophia arenaria*, *Agropyrum mediterraneum* and *Cakile maritime* and are fringed by pine woods and juniper thickets.

In the mountains, some 134 glacial lakes are situated mainly in the Lura (Burreli), Ballgjaj (Bulqiza) and Dhoksi (Peshkopi) regions at altitudes of 1500–1800 m a.s.l. Generally, they are small, formed mainly over magmatic (mainly of ultrabasics) and terrene formations. The most famous and well preserved are the 12 Lura lakes; they are surrounded by dense forests of birch and Bosnian pines (*Pinus heldreichii* and *P. leucodermis*). Not much is known about their flora and fauna. About 430 forms of diatoms were described recently from the lakes by Miho and Lange-Bertalot (2001), mostly oligotrophic (Table 5).

Table 5 The most abundant diatom taxa (>3%) with their relative trophic and tolerance values (Miho and Lange-Bertalot 2001)

Name of species	Lura	Ballgjaj	Dhoksi	Ecological values
Cyclotella sp. (aff *cyclopuncta* Häck. var. ?)	0.1–27.2	0.2–5.6	3.4–56.3	–
C. radiosa (Grun.) Lemm.	0.1–13.7	0.1		–
Achnanthes flexiella (Kütz.)Brun agg.	0.1–3.5	0.1–0.5	1.4	ot/os
A. laevis Oestr. var. *laevis*	0.1–2.2	0.3–3.6	0.2–0.7	tol/os-bms
A. minutissima Kütz. gr. (var. *gracillima*)	4.4–47.2	20.8–47.3	16.7–22.7	tol/bams (ot/os)
Amphora oligotraphenta Lange-B. & Kramm.	0.1–0.2	0.2–3.9	0 1–12.6	ol-bmt/os
A. pediculus (Kütz.) Grun.	0.1–3.8	0.3–0.4	0.2	tol/bams
Brachysira neoexilis Lange-B.	0.4–6.7	0.3–1.1	0.2	ol-bmt/os
Caloneis bacillum (Grun.)Cl&$$$;.	0.1–0.9	0.1–4.0	0.1	am-eut/bms
Cymbella cesatii Raben.	1.1–7.0	2.1–8.8	1.0–2.5	ot/os
C. descripta Hust.	0.1–1.1	0.1–3.2		ot/os
C. microcephala fo. minores Grun.	1.3–18.4	1.4–10.1		ol-bmt/os-bms
C. silesiaca Bleisch	1.2–5.1	0.1–14.7	1.3–5.9	tol/ams
C. ventricosa Ag.	0.1–0.3	2.7–22.6	0.1–3.9	–
Eunotia arcus Ehr.	0.1–3.6	1.0–6.5	0.2	ol-bmt/os
Fragilaria construens (Ehr.)Grun. gr.	0.1–25.1	0.1–6.6	1.1	tol/bms
F. nanana Lange-B.	0.3–8.5	0.1–21.9	0.1–11.9	ol-amt/os-bms
Navicul minima Grun. gr.	0.1–3.0	0.2		tol/ams-ps
Navicula nov. sp. (aff. *schoenfeldii* Hust.)	0.2	0.1–4.3	0.2	–
Nitzschia bryophila Hust.	0.2–3.5			–
N. denticula Grun.	0.1–3.5			ol-bmt/os
N. graciliformis Lange-B. & Sim.	2.1	0.9–3.2	0.2	tol/bms
N. gracilis Hantzsh	0.1–7.7	0.3–1.0		tol/bms
N. lacuum Lange-B.	0.1–0.8	0.7–7.0	0.7	tol/os-bms
N. palea var. *debilis* (Kütz.) Grun.	1.5–6.7	0.1–1.5	3.0	tol/–
N. tropica Hust.	0.1	3.2		–

Tolerance value: *ot* oligotrafent, *ol-bmt* oligo-β-mezotrafent, *ol-amt* oligo-α-mezotrafent, *tol* tolerant, *am-eut* α-mezo-eutrafent, *ind* indifferent. Valenca saprobike: *os* oligosaprobe, *bms* deri β-mezosaprobe, *bams* deri β-a-mezosaprobe, *ps* deri polisaprobe, − unknown (Hofmann 1994)

Around 134 glacial lakes are situated mainly in Lura (Burreli), Ballgjaj (Bulqiza) and Dhoksi (Peshkopi) regions at altitudes of 1500–1800 m a.s.l. Generally, they are small, formed mainly over magmatic (mainly of ultrabasics) and terrene formations. The most famous and well preserved are the 12 Lura lakes; they are surrounded by dense forests of birch and pines (*Pinus heldreichii* and *P. leucodermis*). Not much is known about their flora and fauna. About 430 forms of diatoms were described recently by Miho and Lange-Bertalot (2001), most of them oligotrophic ones (Table 5).

The mountains on the right side of the Drina river course are characterized by many medicinal plants, which are economically important for rural communities of these areas. The endemic species Albanian wulfenia (*Wulfenia baldacci*) is found in Shtegu i Dhenve at high altitudes, and the endemic *Petasites doerfleri*, *Lilium albanicum* and *Viola ducagjinica* all grow in these areas. In addition, *Teucrium arduini*, *Micromeria parviflora*, *Athamantha turbith* and *Asperulla scutellaris* all grow together with the Balkan endemic species *Campanula albanica*. Other medicinal plants that are considered threatened such as *Colchicum autumnale*, *Gentiana lutea* and *Atropa belladonna* can also be found here.

The Drina river system alone (including the associated Lakes Ohrid, Prespa and Skadar) contains more than 30 endemic freshwater fish species. Lakes Ohrid and Prespa are geologically ancient (Plio-Pleistocene) and as such they accommodate several local endemic species and subspecies (Ohrid: *Salmo* (Salmothymus) (Acantholingua) *ohridanus*, *S. letnica*, *Pseudophoxinus minutes* and *Rutilus ohridanus*; Prespa: *Chalcalburnus belvica*, *Chondrostoma prespense*, *Barbus prespensis*, *Cobitis meridionalis*, *Phoxinellus prespensis* and *Rutilus prespensis*). Two additional species endemic to the Drina have been recently described: Skadar rudd (*Scardinius knezevici*) (Bianco and Kottelat 2005) and Drina brook lamprey (*Eudontomyzon stankokaramani*) (Holcik and Soric 2004). Two Dalmatian salmonids are also found in the Drina: *S. marmoratus* and *S. obtusirostris* (Tockner et al. 2009).

Drini trout or mountain trout (*Salmo farioides*) (Karaman 1938) (Fig. 2) is included as a special species in the list of Shkodra lake fishes (Dhora and Smajlaj 2007), but in the list of the Albanian trout it is considered to be a distinct species. It has been found in rivers flowing into the Adriatic sea, in Kirk river (Croatia), in Radica—branch of Black Drini (Macedonia), in Bistrica near to Peja and near to the Prizreni– branch of the White Drini river (Kosovo), in the streams that flow to Ohrid lake; in Valbona river, Thethi river, Kiri river, all of which are branches of Drina river, in Cemi river, Crnojevica river and Klosi river—a branch of Mati river. During

Fig. 2 *Salmo farioides* (Valbona river, a branch of Drina river) (Shumka and Trajce 2009)

Fig. 3 Balkan Lynx (*Lynx lynx martinoi*) near Puke, Photo: K. Korro http://www.pbs.org/wnet/nature/wild-balkans-photo-gallery-rare-animals-of-the-balkans)

the last 10–15 years both of these trout have been much damaged by illegal fishing. The local residents have continually used explosives for fishing, which is very harmful, because it kills not only adult individuals, but also the fry and even the eggs (during the reproduction season). Besides explosives, electricity is also used to catch the trout, which is as harmful as the explosive; (in some cases even people have been damaged by this illegal fishing). Another way of fishing is catching the trout with baskets especially in those places where the trout spawn; this kind of fishing should be prohibited during the December–January reproduction period.

In the stream waters of the Valbona and Shala rivers, branches of the Drina river, the globally endangered mammal otter (*Lutra lutra*) is living, in the same area as other protected mammals such as brown bear (*Ursus arctos*), wolf (*Canis lupus*), Balkan lynx (*Lynx lynx martinoi*) (Fig. 3) (IUCN/SSC 2014), fox (*Vulpes vulpes*), wild goat (*Capra aegagrus*) and roe deer (Shumka and Trajce 2009); while the wild birds consist of rooster [blackcock], wild chicken [hazel hen], golden eagle (*Aquila chrysaetos*) (Fig. 4), falcons (Falconidae) and hawks including common buzzard (*Buteo buteo*) (BirdLife International 2004; Clements 2000).

Fig. 4 Golden Eagle (*Aquila chrysaetos*), Photo: BirdLife International, 2007

7 Albanian Economic Transition and the Environmental Impact

Environmental problems in Albania have evidently increased since the end of the socialist regime, when the economy was centralized by the state and private ownership and activity were forbidden. In 1991 Albania left the communist epoch, as the poorest country of Europe. More than 65% of its population lived in villages and were employed in state agricultural enterprises or cooperatives or state industrial factories. These all ceased activity and most fell into ruin due to the lack of state control and administration. As a consequence, massive emigration abroad occurred in 1990–1993, mainly to Greece and Italy and within the country towards coastal regions, mainly to Tirana, Durresi, Shkodra, Fieri and Vlora. In 1997, about 54% of the Albanian population lived in the lowlands near the coast, resulting in a density of 179.3 inhabitants per km^2 (NEA 1999). The economy slowly transformed from state-owned to private. Besides the diminished state ownership, private and foreign enterprises started to compete in the food industry, commerce, construction, transport, tourism and agriculture. These drastic changes within the fragile reality of the Albanian economy generated environmental overuses and abuses, whereby the aquatic ecosystems were the most exposed and unprotected. Aiming at a rapid development, the means employed were often uncontrolled and unsustainable. Several present-day environmental problems are directly or indirectly linked to aquatic ecosystems, such as urban and industrial waste management, water pollution or land erosion, and serious problems are linked to the management of harmful solid industrial waste, which is disposed throughout the territory (Cullaj et al. 2005).

According to the UNEP (2000) assessment, about 1500 tons of chemicals and toxic remnants from previous industrial activity, i.e. pesticides, were present and are still harmful to rural and urban communities. During the past decades, mining, enrichment and metallurgy industries have produced high quantities of solid or liquid waste, often dumped on riverbanks or directly into rivers. In the years of highest production of copper, about 650,000 tons per year of solid waste was dumped in the towns of Rubiku, Rresheni, Burreli, Puka, Shkodra and Korca, as well as about ten million m^3 of polluted water released yearly into the rivers Fani, Drini and Mati (Shehu and Malja 1998).

In the upper Drina basin, iron and chromium mining along with industrial activity affect Lake Ohrid, while copper, chromium, iron and nickel mining and processing (albeit at a reduced rate in recent years) contaminate the middle and lower river sections as well as Lake Shkodra. Shkodra Lake is also threatened by the Moraca river that carries wastewater from an aluminum smelter in Montenegro (UN/EC 2002), which is still in full working regime (pers. comm., Rigers Bakiu). Unsustainable agricultural practices have led to an increase in non-point pollution and erosion (Faloutsos et al. 2006). Gravel extraction from the riverbed favors bed incision. Moreover, the river and lakes are affected by untreated or insufficiently treated municipal wastewater. Besides large reservoir construction, other major hydrological interventions include stream diversions to Lakes Prespa and Ohrid. Finally, illegal logging impacts many tributaries.

Fig. 5 Lake Fierza

8 Economic Importance

The Drina is extremely important for the Albanian economy, especially for its electricity production. Three dams are built over its cascades producing most of Albania's electricity (Tockner et al. 2009). The artificial Lake Fierza (Albanian: Liqeni i Fierzës) created by the dam at Fierzë is the largest artificial lake in Albania, covering 97 km^2 (Fig. 5).

The second largest lake is also built on the Drina river. Lake Vau i Dejës (Liqeni i Vaut te Dejës in Albanian) has an area of 26 km^2 (Fig. 6).

Construction of Fierza power station caused some controversy in the 1980s. Lake Koman (Fig. 7) Lake Vau i Dejës was formed when the rugged Drina valley was dammed in the early 1970s, allowing Albania to quickly develop its own industrial base and become an energy exporter (Tockner et al. 2009).

Even large rivers like the Vjosa, the Seman system with Devoll and Osum as well as Skumbin are still not interrupted by dams (Vjosa is interrupted by a major dam under construction, 2012). Only the Drina river is mostly turned into a chain of hydropower reservoirs (Figs. 8, 9, 10 and 11).

Fig. 6 Lake Vau i Dejes

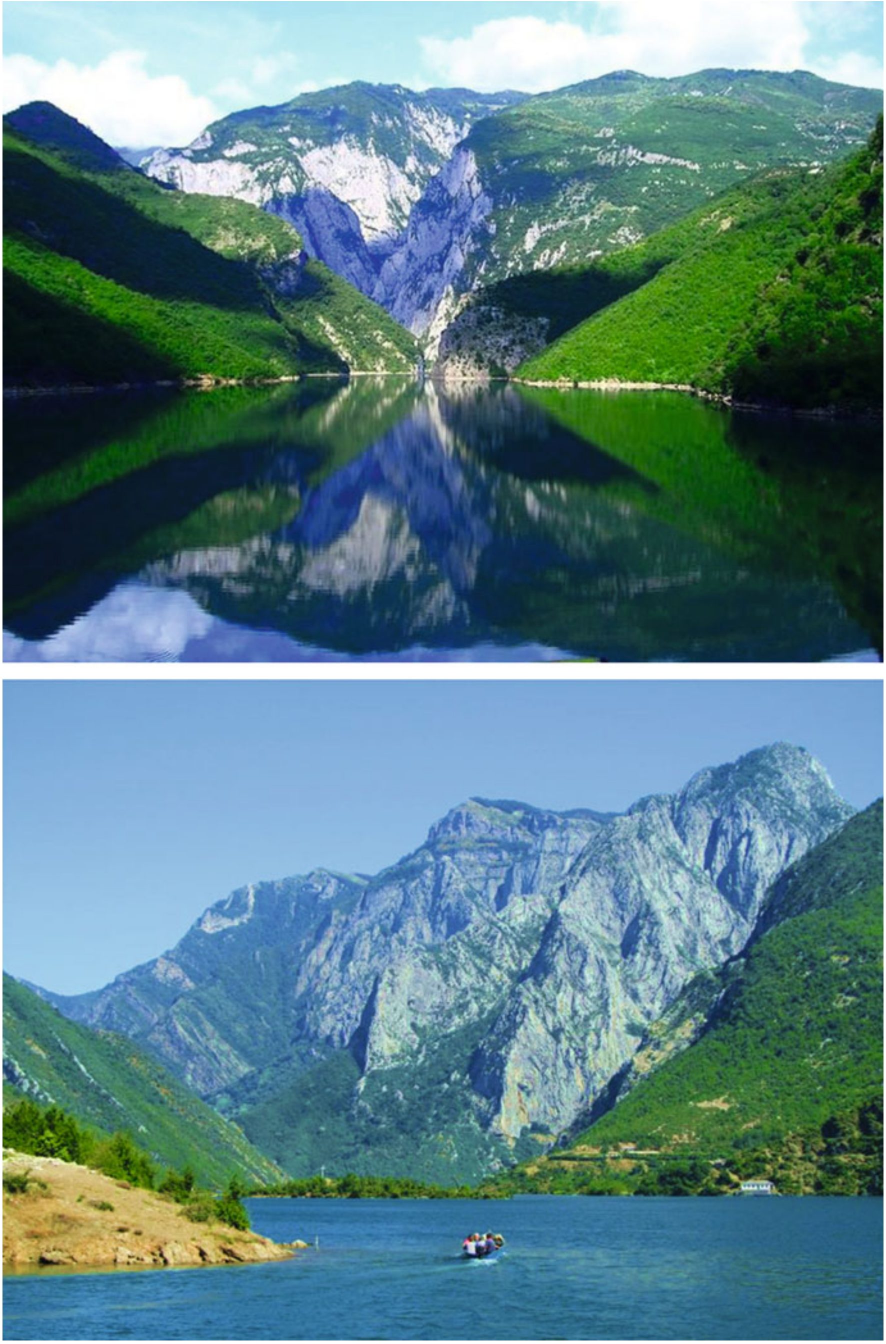

Fig. 7 Lake Koman

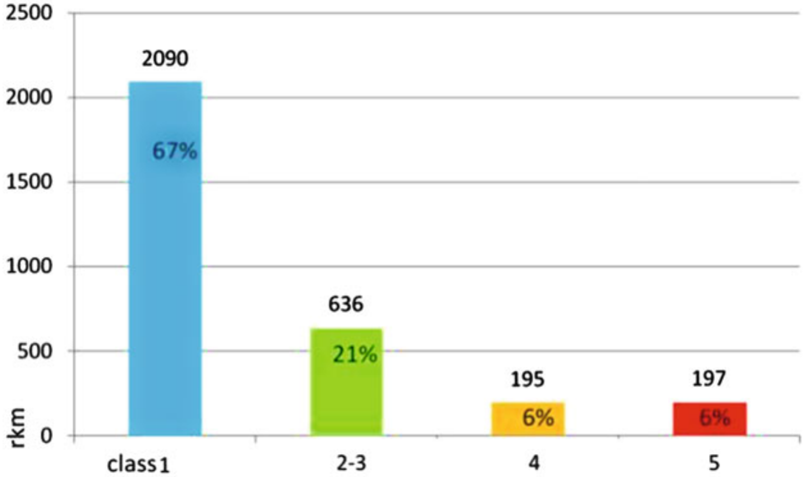

Fig. 8 Hydromorphological assessment in rkm and percentage for Albania (Schwarz 2012)

Hydromorphological assessment class	Description
Class 1	Pristine and near-natural
Class 2-3	Slightly and moderately altered
Class 4	Strongly altered
Class 5 Impoundments	Totally altered

Fig. 9 Hydromorphological assessment and examples as illustration (Schwarz 2012)

In Fig. 9 is shown the assessment and examples for each of the hydromorphological assessment class.

The Drina river is the largest river in Albania that is used for hydropower and the chain of major dams summed up to more than the half of the Iron gate

1 impoundment with some 170 rkm. Dams along the Drina supply major energy for Albania (about 90%, 1350 MW, of total power production; World Bank 2003). Other major dams can be so far found only in the northern part of the country (Figs. 10 and 11). All rivers in mountainous reaches are subject to hydropower development (Schwarz 2012).

Probably the great emphasis of the Albanian government towards the rise of the energy sector is suppressing the country's development problem about the management and conservation of biodiversity.

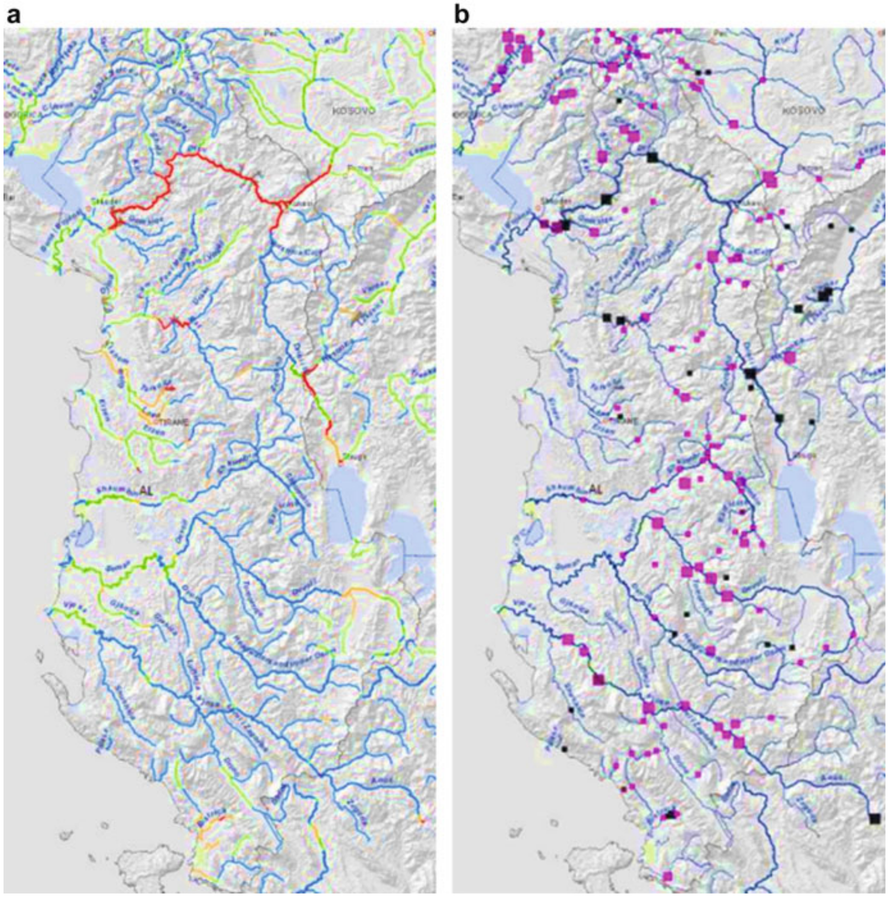

Fig. 10 Hydromorphological assessment (**a**) and hydropower plants (**b**) for Albania (Schwarz 2012)

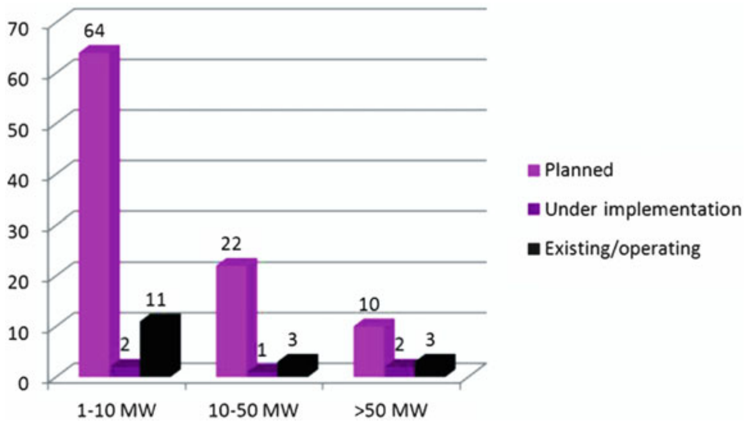

Fig. 11 Distribution of hydropower plants for Albania (Schwarz 2012)

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Characteristics of the Danube Drainage Area in the Republic of Macedonia

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1 Introduction

The catchment of the Danube River in the Republic of Macedonia consists of the source waters of the Binačka Morava, a tributary of the Južna Morava that represents the shorter headwater of the Velika Morava, which flows into the Danube near Smederevo.

The catchment area of the Binačka Morava straddles the border territory of northern Republic of Macedonia and southern Republic of Serbia (territory of Kosovo), whereas its upper part lies in Macedonia, on the northern slopes of the Skopska Crna Gora Mountain, to the south bordering on the basin of the Vardar River, which flows into the Aegean Sea in the Gulf of Salonica.

The source of the Binačka Morava consists of several small rivers, the Ključeva and Tanuševska being the main ones. Beside these two rivers, in the north-north-eastern part of this area are the Igriška and Ibrišimska rivers, and in the eastern part is the Crvena Voda River (Red Water River). All these five watercourses, and additionally three or four smaller gullies, are part of the Danube Basin, and all together occupy an area of 54.3 km^2 (Fig. 1).

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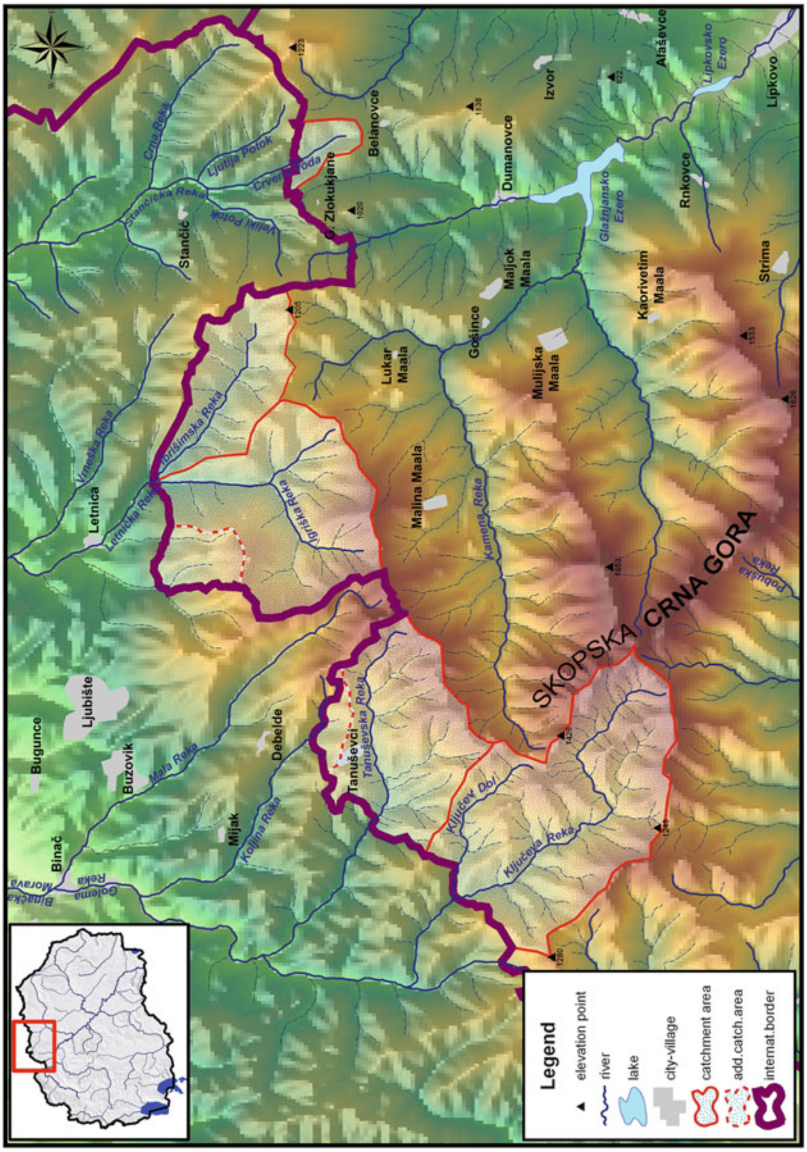

Fig. 1 The catchment of the Danube River in the Republic of Macedonia—Spring parts of Binačka Morava

The Binačka Morava emerges on to the territory of Kosovo by the confluence of the Golema Reka (Big River) and Mala Reka (Small River) at the village of Binač (Stojov 1990).

2 Hydrological and Geographical Characteristics

2.1 Ključeva River

The spring of the Ključeva River lies below the Gorogled mountain peak (1608 m) which is the adjoining point of four river catchments, namely the Kučeviška, Brestjanska, Kamena and Ključeva itself, and is located near the highest point of Skopska Crna Gora—the peak Ramno (1651 m). Except for the Ključeva River, all the others are part of the Vardar Basin. The catchment of the Ključeva River, together with its tributary Ključev Dol, covers an area of 19.4 km^2. The basin has an S-shape and generally a north-west aspect. The length of the Ključeva River in Macedonian territory is 8.42 km, and then it crosses the border into Kosovo (820 m).

The approximate average water discharge of the Ključeva River before its exit from Macedonia, is 590 l/s. The highest water levels occur in spring—in April, May and June, mainly as a result of the spring snowmelt and rainfalls. The minimum water discharge occurs in August and September, but also in January as a result of freezing temperatures.

2.2 Tanuševska River

The spring of the Tanuševska River is located below Kodra Fura peak (1492 m), on Kopiljača Mountain, covers an area of 10.7 km^2, and has a north-west aspect. The length of the Tanuševska River in Macedonia is 4.87 km, and then it enters Kosovo.

The approximate average water discharge of the Tanuševska River before its exit from Macedonia, is 270 l/s. The highest water levels occur in spring. The minimum water discharge occurs in August and September.

2.3 Igriška River

The Igriška River is totally a Macedonian river, and its catchment covers an area of 13.4 km^2. Its spring lies below the peaks Dva Groba (1286 m) and Kodra Fura (1492 m), of Kopiljača Mountain. At its beginning the river has the name Zdravačka River. The catchment has a north-west aspect. The total length of the Igriška River is 5.30 km.

The approximate average water discharge of Igriška River is 130 l/s. The highest water levels occur in April, May and June. The minimum water discharge occurs in August and September.

2.4 Ibrišimska River

The Ibrišimska River is also a completely Macedonian river. Its spring lies below the peak Topan (1179 m) on Stančić Mountain, covers an area of 6.08 km^2 and has a north-west aspect. The length of the river is 4.26 km.

The approximate average water discharge of Ibrišimska River is 60 l/s. The highest water levels occur in spring—in April, May and June. The minimum water discharge occurs in August and September, but also in January as a result of freezing temperatures.

The springs of both the Igriška and Ibrišimska rivers are located north of the village of Brest (Malina Maala). The two rivers join at the entrance to Kosovo, thus creating the Letnička River which flows into Binačka Morava near the village of Klokot.

2.5 Crvena Voda River

The spring of the Crvena Voda River lies below Mal Kamen (1040 m), near the village of Gorno Zlokukjane on Macedonian territory, covering an area of 1.43 km^2. The catchment has a northern aspect. The length of the Crvena Voda in Macedonia is 1.21 km. It flows north to the village of Donje Zlokućane, whence it continues under the name Zlokućanska Reka. From the village of Stančić, the river is called Stančićka Reka.

The approximate average water discharge of the Crvena Voda River before its exit from Macedonia, is 14 l/s and less. The highest water levels occur in spring. The minimum water discharge occurs in August and September.

Besides these rivers in the Macedonian part of the basin, there are also several dry ravines that gravitate into Binačka Morava's catchment, the principal being Debelodolska dry ravine (near the village of Debelde, north of Tanuševci) with a catchment of 1.01 km^2 in area, and the dry ravines around the locality of Gabrovina, occupying an area of 2.23 km^2 (Stojov 1990).

The upper part of Binačka Morava catchment's area is distinguished by forested uplands and grasslands (Fig. 2).

Fig. 2 Mountainous areas and pastures in the spring part of Binačka Morava catchment

3 Geological Characteristics

According to the Basic Geological Map of the Republic of Macedonia (1988), in the River Ključeva catchment area there are conglomerates, sandstone and clay (flysch); in the River Tanuševska catchment area there are quartz-sericite shale and albit-biotic shale, as well as conglomerates, sandstone and clay (flysch); in the Igriška River catchment area there are lines of quartzite; and in the Ibrišimska River catchment area there are conglomerates, sandstone and clay, as well as a small amount of diabases (Fig. 3).

4 Characteristics of the Climate

The upper part of the Binačka Morava catchment, in the territory of Macedonia, has different climatic characteristics. In its highest parts, above 1100 m, the climate is of the mountainous type. Actually, this mountain climate is falls into two parts: at altitudes above 1300 m there is forest-mountain continental climate, while below 1300 m down to 1100 m there is under-forest-mountain continental climate. At lower altitudes, between 1100 and 900 m, the climate is cold, continental.

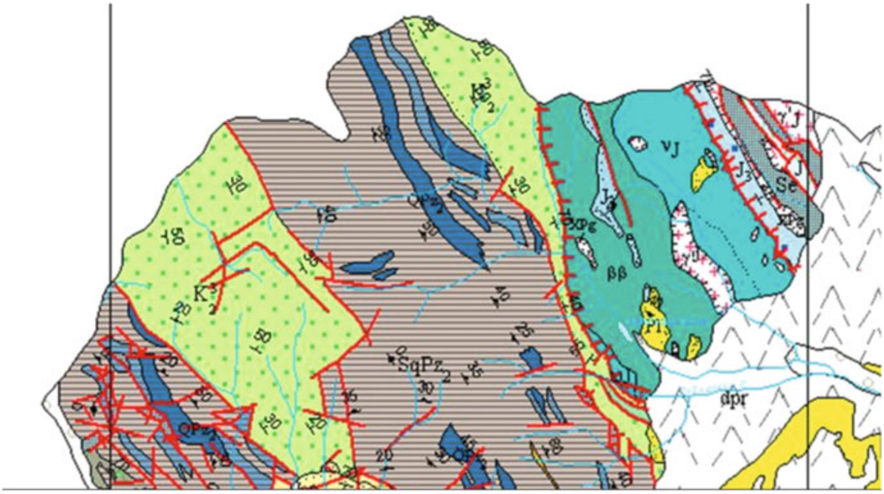

Fig. 3 Geological map of spring part of Binačka Morava catchment

5 Distribution of Vegetation

The area of the Binačka Morava catchment in Macedonia has been proposed as an important plant area, according to KBA's criteria (Melovski et al. 2012). The flora in the lowest part, at an altitude of 500–750 m, is composed of the forest association of Hungarian oak and Turkey oak (*Quercetum frainetto-cerris*), Rudski (1940) 1949. In the area at an altitude of 600–900 m, the dominant vegetation is the association of Sessile Oak-Hornbeam (*Querco-Carpinetum serbicum*), Rudski (1940) 1949. At some points, at altitudes between 800 m and 1000 m, there can be found areas with *Carpinetum orientalis scardicum* Krasnići 1968 (on slopes of southern aspect), or with beech, *Fagetum montanum* Jovanović 1953 (Rudski 1949), which extends up to an altitude of 1500 m. All these forest associations are intermixed with grassland associations (Kojić 2002).

6 Fauna

6.1 Invertebrate Fauna

6.1.1 Crayfish

According to Karaman (1976) two crayfish of family Astacidae occur in freshwater habitats in the Republic of Macedonia: noble crayfish *Astacus astacus* (Linnaeus 1758) and stone crayfish *Austropotamobius torrentium* (Schrank 1803). However, at present there is insufficient information originating from Macedonia on the

Fig. 4 Binačka Morava catchment (Ključeva River) in Macedonia and stone crayfish

distribution of these indigenous species, especially the stone crayfish. Furthermore, *A. torrentium*, which prefers freshwater habitats where it is encountered, receives relatively little publicity and conservation attention in Macedonia, in spite of its key role in aquatic food chains and functioning of the ecosystem.

With regard to Skopska Crna Gora Mountain, stone crayfish was reported only by Subchev (2007), but the author did not state in which watercourses it lives. So, it is not clear whether the taxon was reported in the River Vardar basin or the Binačka Morava catchment (Danube basin) on the territory of the Republic of Macedonia. For this reason, a hydrobiological investigation was carried out in the mountainous and forest part of the Ključeva and Tanuševska rivers (Binačka Morava catchment) during a field campaign in October 2016.

The habitat for the expected occurrence of *A. torrentium* was checked during the day using hand net and electro-fishing techniques. The results show that this cold-adapted crayfish inhabits the forest part of the Ključeva River, which is characterised by a rocky bottom and fast water flow (Fig. 4). Additionally, the river is not exposed to anthropogenic influences, such as domestic and industrial pollution and habitat loss and degradation (with damming, water abstraction and channelization of river bed), which contributes to the existence of stable populations of the species.

European Habitat Directive 92/43/EEC ranks *A. torrentium* in Annex II among the animal and plant species of Community interest, the preservation of which requires designation of Special Areas of Conservation within the Natura 2000 network. Moreover, the species is included in Appendix III of the Bern Convention and Annex V of EU Habitats Directive 92/43/EEC, while in Macedonia it is designated as a protected wild species (Official Gazette of the Republic of Macedonia, No. 139/2011).

This study is the first systematic approach to making an inventory of the stone crayfish population in the part of the Binačka Morava catchment belonging to Macedonia and could serve as a valuable source of data for nature conservation and protection of *A. torrentium* and its habitats.

6.2 Vertebrate Fauna

Although relatively small in territory, the Republic of Macedonia has an important position on the global map of biological diversity hotspots. Macedonia's biological diversity is relatively well studied, but unfortunately insufficient data are available on the vertebrate fauna within the Danube Basin area. Nevertheless, there are data about the diversity of vertebrate fauna in the wider area of the Skopska Crna Gora and Binačka Morava drainage.

6.2.1 Fish

The fish fauna of the rivers belonging to the Danube basin in Macedonia has never been studied. In October 2016 field studies were organized in three rivers (Ključeva, Ključev Dol and Tanuševska) from the Danube basin in the Republic of Macedonia. At all sampling sites the presence of only one fish species was established, namely brown trout (*Salmo trutta* Linnaeus 1758) (Fig. 5). Trout populations are stable and comprise specimens of all age categories.

6.2.2 Amphibians and Reptiles

Ten amphibian species were found in this area, of which three belong to the order Caudata (*Salamandra salamandra*, *Lissotrition vulgaris* and *Triturus macedonicus*), and seven to the order Anura (*Bombina variegata*, *Bufo bufo*, *Bufotes viridis*, *Hyla arborea*, *Rana dalmatina*, *Rana graeca* and *Pelophylax ridibundus*) (Vukov et al. 2013).

The Herpetofauna is present as 16 species, of which two belong to the suborder Cryptodira (*Testudo hermani* and *Testudo graeca*), eight to the suborder Lacertilia (*Ablepharus kitaibelii*, *Anguis fragilis*, *Lacerta viridis*, *Lacerta agilis*, *Lacerta trilineata*, *Podarcis muralis*, *Podarcis tauricus* and *Podarcis erhardii*) and six to the suborder Ophidia (*Natrix natrix*, *Natrix tessellata*, *Coronella austriaca*,

Fig. 5 *Salmo trutta* from Tanuševska River

Dolichophis caspius, *Zamenis longisimus* and *Vipera ammodytes*) (Ralev et al. 2013; Sterijovski et al. 2014; Tomović et al. 2014, 2015; Ljubisavljević et al. 2015; Urošević et al. 2015). This region is also important from the aspect of batracho- and herpetofaunal diversity, and the detection of two more amphibian (*Ichthyosaura alpestris* and *Rana temporaria*) and four reptile species (*Emys orbicularis*, *Darevskia praticola*, *Elaphe quatuorlineata* and *Platyceps najadum*) should be expected. Also, from the biogeographical point of view, the area of Skopska Crna Gora is most significant because it is the place where sub-Mediterranean and Mediterranean species overlap with mid-European ones.

6.2.3 Birds

The only available data about the bird fauna are those from Kojić (2002), where he states the presence of 55 bird species in 12 orders: Ciconiiformes (*Ardea cinerea* and *Ciconia ciconia*), Anseriformes (*Anas platyhynchos*), Falconiformes (*Accipiter gentilis*, *Accipiter nisus*, *Buteo buteo* and *Falco tinnunculus*), Gallioformes (*Phasianus colchicus*, *Coturnix coturnix* and *Perdix perdix*), Charadriiformes (*Scolopax rusticola*), Columbiformes (*Columba livia f. domestica* and *Columba palumbus*, *Streptopelia decaocto* and *Streptopelia turtur*), Cuculiformes (*Cuculus canorus*), Strigiformes (*Tyto alba*, *Asio otus*, *Athene noctua* and *Strix aluco*), Caprimulgiformes (*Caprimulgus europaeus*), Coraciiformes (*Coracius garrulous* and *Upupa epops*), Piciformes (*Dendrocopos major*, *Dendrocopos syriacus* and *Picus viridis*), Passeriformes (*Alauda arvensis*, *Hirundo rustica*, *Motacilla flava*, *Lanius collurio*, *Lanius excubitor*, *Troglodytes troglodytes*, *Turdus merula*, *Luscinia megarhynchus*, *Acrocephalus palustris*, *Sylvia atricapilla*, *Sylvia communis*, *Parus major*, *Parus caeruleus*, *Certhiabrachydactyla*, *Emberiza hortulana*, *Miliaria calandra*, *Fringilla coelebs*, *Carduelis carduelis*, *Carduelis cannabina*, *Carduelis chloris*, *Passer domesticus*, *Passer montanus*, *Sturnus vulgaris*, *Oriolus oriolus*, *Garrulus glandarius*, *Pica pica*, *Corvus coronix*, *Corvus monedula*, *Corvus corax*). Having in mind that the analyzed area is located between two regions (Šar Planina—170 species recorded, and Pčinja—130 species recorded) characterized by their high level of diversity and considered Important Bird Areas (IBAs) (Simić and Puzović 2008; Velevski et al. 2013), it is likely that the diversity of birds in the wider area of the Skopska Crna Gora and Binačka Morava drainage is considerably higher than that reported so far.

6.2.4 Mammals

First, we must have in mind that the number of mammal species listed below should be considered approximate. This is especially true regarding certain groups, for example bats. The possible presence of some species is concluded due to the existence of their known areas and suitable habitats in the area of Skopska Crna Gora and Binačka Morava drainage. The order Insectivora is present as four species

(*Erinaceus roumanicus*, *Talpa europaea*, *Crocidura suaveolens* and *Neomys fodiens*), but the presence of four more species is also possible (*Sorex minutus*, *Sorex araneus*, *Crocidura leucodon* and *Neomys anomalus*). There are four species of the order Chiroptera (*Rhinolophus ferrumequinum*, *Myotis myotis*, *Pipistrellus pipistrellus* and *Plecotus auritus*), although it is likely that 18 more bat species are present (Milan Paunović personal communication). *Lepus europaeus* is the only representative of the order Lagomorpha. The order Rodentia is represented by 11 species (*Sciurus vulgaris*, *Spalax leucodon*, *Microtus levis*, *Microtus subterraneus*, *Apodemus flavicollis*, *Apodemus sylvaticus*, *Apodemus agrarius*, *Rattus rattus*, *Mus domesticus*, *Mus musculus* and *Glis glis*), with the possible presence of four more (*Arvicola amphibious*, *Ondatra zibethica*, *Microtus arvalis* and *Muscardinus avellanarius*). The order Carnivora is also present, with 11 species (*Canis lupus*, *Canis aureus*, *Vulpes vulpes*, *Ursus arctos*, *Mustela nivalis*, *Mustela putorius*, *Martes martes*, *Martes foina*, *Meles meles*, *Lutra lutra* and *Felis silvestris*), although the presence of two more species is probable (*Vormela peregusna* and *Lynx lynx*). The order Artiodactyla is represented by two species (*Sus scrofa* and *Capreolus capreolus*) (Kojić 2002; Stojanov et al. 2010; Vladan Bjedov personal communication).

Generally, the mammal fauna present can be regarded as a typical fauna of a considerably wider environment, i.e. one characteristic for the area of European deciduous, coniferous and mixed forests. A special peculiarity is the presence of Mediterranean species, such as southern vole (*Microtus levis*). Perhaps more detailed investigations would confirm the presence of some other Mediterranean species, for instance *Apodemus epimelas*, *Microtus felteni* and *Microtus guentheri*. Considering that these are generally more thermophilic and xerophilic species, their presence should be expected in the area of lower altitude. A similar situation applies to the possible presence of marbled polecat (*Vormela peregusna*), a species that also prefers thermophile, rocky habitats, although it is often found at higher altitudes as well.

7 Threats to Wildlife

The most important disturbance factor is uncontrolled deforestation for obtaining firewood and the construction of agro-ecosystems (Figs. 6 and 7). Deforestation causes changes in the water regime, erosion and occurrence of landslides on steep terrains. In addition, uncontrolled hunting and fishing are present, as well as collection of rare and endangered species of plants and fungi. All these factors together result in reduction of floral and faunal diversity (Kojić 2002).

Fig. 6 Deforestated area

Fig. 7 Preparation of firewood

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Long-Term Changes in the Ecological Conditions of the Iskar River (Danube River Basin, Bulgaria)

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1 Introduction

In 2004 a *National Strategy for the Development and Management of Water Sector up to 2015* (Council of Ministers, R. Bulgaria 2004) was adopted in Bulgaria. The strategic goal was to provide a long-term sustainable use of water resources for drinking, municipal and industrial purposes in the conditions of transboundary river basin management, considering the global climate change and ensuring ecological sustainability of the aquatic systems. The implementation of this goal should respond to the legislation aiming at improving the water quality, such as the Water Act (2000) in Bulgaria, as well as the EU Water Framework Directive (EU WFD, 2000/60/EEC), the Urban Waste Water Treatment Directive and the Nitrates Directive.

In the implementation of the EU WFD, the Danube River Basin District Management Plan (DRBM Plan) was elaborated by the International Commission for the Protection of the Danube River (ICPDR 2009, updated in 2015). The DRBM Plan for the basin-wide scale focus on rivers with catchment areas over 4000 km^2 and lakes over 100 km^2; while waters with smaller catchment and surface areas are part of the national RBM Plans. The DRBM Plan and its underpinning research, monitoring and analysis have identified four main challenges in relation to the quality of water (both surface and groundwater, both chemical and ecological status) across the Danube River Basin: pollution by organic substances; pollution by nutrients; pollution by hazardous substances; and hydromorphological alterations (ICPDR 2009, updated in 2015).

The territory of Bulgaria belongs to two drainage basins, with the main watershed the Stara Planina (Balkan) Mountains: the Black Sea drainage basin (c. 57% of the

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territory) and Aegean Sea drainage basin (c. 43%). The Black Sea drainage basin divides into the Danube River basin (c. 42%) and the Black Sea basin with direct drainage into the Black Sea (15%) (Kopralev 2002). Water management has been organised at national and river basin levels, with Bulgaria being divided into four river basins: the Danube River, Black Sea, East Aegean Sea and West Aegean Sea. The Danube River basin is the largest in the territory and contains around 20 larger rivers, the majority of which flow from the northern hills of the Stara Planina or Predbalkana Mountains. The only river that flows from the Rila Mountains is the Iskar River. Two rivers have a total surface catchment area of over 4000 km^2—the Iskar and Yantra Rivers. The Danube River Basin Directorate at the Ministry of Environment and Water of Bulgaria (DRBD-MEW) has developed a Management Plan for the Danube River Basin for the period 2010–2015, which was adopted in 2010, and updated in 2015.

The Iskar River is the longest inland river in Bulgaria. It crosses one of the country's most urbanised and densely populated areas—the capital city Sofia and its surroundings; and it plays a major role in water supply for drinking, household and industry, discharge of sewage, irrigation, power generation, etc., in the area. This has subjected it to growing pressure from human activities for long periods of time.

This chapter presents a review of the available information about human activities in the Iskar River basin, Bulgaria, and their impact on the hydrological and ecological conditions of the river. The data presented and the case study illustrates the long-term changes in the ecological status based on benthic macroinvertebrates and fish. The results of this and similar studies can contribute to the implementation of the Management Plan for the Danube River Basin in Bulgaria, as well as for the DRBM Plan.

2 The Iskar River Basin: Geographical, Geomorphological and Climatic Characteristics

The Iskar River is the longest Bulgarian river—368 km from its sources; and it has the third largest catchment area in Bulgaria (8646 km^2) (Fig. 1). It is formed by the confluence of the rivers Cherni Iskar, Levi Iskar and Beli Iskar, which flow from the Rila Mountains, the highest mountain range in the Balkan Peninsula (Mt Moussala, 2925 m a.s.l.). The Prav Iskar River, tributary of the Cherni Iskar River, which is accepted as the initial source of the Iskar River, flows out of Chamovsko Lake (2500 m a.s.l.) at the foot of Damga Peak in the Rila Mountains. The Iskar River is the only river that has managed to maintain its original north-east direction, after the multiple uplift of the mountain systems in the Balkan region during the Quaternary. It flows into the Danube River near the village of Gigen (Marinov 1957) (Fig. 1).

The Iskar River has 25 tributaries that are over 15 km in length. The largest right tributaries are the rivers Lesnovska, Batuliiska, Malak Iskar and Zlatna Panega; and the major left tributaries are Palakariya, Blato and Slivnishka. The density of the river network in the Iskar catchment is 1.1 km/km^2. The average slope of the

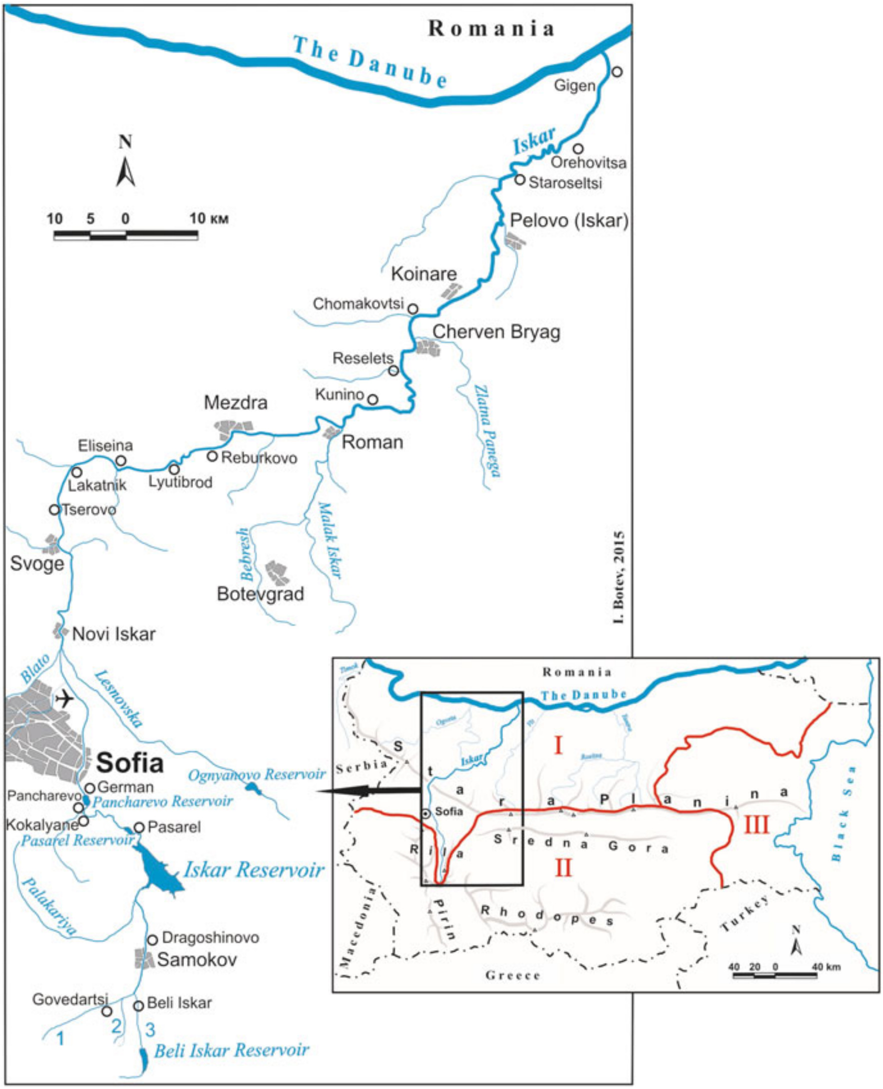

Fig. 1 The Iskar River basin. 1—the Cherni Iskar River; 2—the Levi Iskar River; 3—the Beli Iskar River

catchment is 6.7‰ (a maximum value of 233‰ and minimum of 0.75‰) (Marinov 1957). Forests cover around 30% of the catchment area.

The Iskar River crosses seven geographical areas of Bulgaria (Georgiev 1991):

Rila and Pirin Mountains This area contains the sources of the river and high-mountain tributaries. The river valleys are deep with steep banks. The longitudinal slopes are big. The catchment area is covered by pine forests. The river beds are covered with large stones and gravel.

Kraishte The area is distinct with its valleys and hills, low and medium mountain relief. The Iskar River passes through the highest altitude valley in Bulgaria—the Samokov plain (950 m a.s.l.). The river valley is wide and mostly taken up by agricultural land. The river bed is shallow, wide (over 100 m) and covered with gravel and sand.

Srednogorie The river valley is mountainous, surrounded by the Vitosha and Plana Mountains in the west, and by the Lozents and Ihtiman Mountains in the east. The river flows through the Plana-Lozenets (Urvich) Gorge, which is 24 km long, beginning at the Iskar Reservoir and ending at the village of German.

Sofia Plain This starts at the village of German, which is the beginning of the river's middle reaches (Fig. 1). The plain has an average altitude of 540 m a.s.l. The river has developed a dense river network. In the southern part the river slope is steeper. At Novi Iskar, the river leaves the Sofia plain and enters the Stara Planina Gorge.

Stara Planina (Balkan) Mountains The river passes through the deep Stara Planina Gorge (the slopes are over 200–300 m in height) (Fig. 2). The length of the gorge between Novi Iskar and Lyuti Brod is 67 km. In the upstream part, the river

Fig. 2 Iskar River Gorge at Gara Lakatnik (Photo: Zdravko Hubenov)

slope is low, 0.75%, the river bed wide, many meanders and isles are formed; downstream the slope increases to an average of 4.1%, and the river bed becomes deep and narrow.

Predbalkana Mountains The Iskar River forms its next gorge, which begins at the village of Lyuti Brod and ends at the town of Cherven Bryag (Fig. 3). The length of this gorge is around 64 km, its average slope is 2.59% −1.38%. The relief is hilly and low mountainous with well-defined karst morphological complexes. In places, the river creates significant meanders and isles.

West Danube Plain Characterised by plain-hilly relief, with a maximum altitude of around 500 m a.s.l. The river lower reaches begin at Cherven Bryag (Fig. 1).

The larger part of the Iskar River basin belongs within the temperate climatic zone, and only the most upstream part is in the transitional continental climatic zone (Kopralev 2002). The average January temperatures in the plain and hilly parts are between 0.0 and −1.5 °C, while in the mountains they reach −8.0 and −9.0 °C. The average July temperatures in the Danube plain are 22–24 °C, while in the mountains they decrease to 10–11 °C. The temperatures during spring and autumn are almost the same. The following mean multiannual water temperatures, related to the mean altitude of the water bodies in the Iskar River basin, have been recorded: Cherni Iskar River at Govedartsi −4.3 °C; Beli Iskar River −4.7 °C (1800 m a.s.l.); Palakariya

Fig. 3 The Iskar River Gorge at Karlukovo (Photo: Teodora Trichkova)

River at Relyovo −8 °C; Lesnovska at Dolni Bogrov −8.9 °C; Iskar at Novi Iskar (945 m a.s.l.) −11.2 °C; Iskar at Reburkovo (935 m a.s.l.) −11 °C; Iskar at Kunino (831 m a.s.l.) −11.3 °C; and Iskar at Orehovitsa (706 m a.s.l.) −12.4 °C (Kopralev 2002).

For different parts of the Danube River basin, the average multiannual precipitation ranges from 500 to 1000 mm. The snow cover in the high mountain parts is established at the end of September, and the number of days with a constant snow covers ranges from 180 to 250. In the lowest parts this period is 50–70 days (Marinov 1957).

3 Water Use in the Iskar River Basin

The water of the Iskar River has been used for municipal and industrial water supply, irrigation and power generation.

Water Supply for Drinking and Municipal Purposes In the upper reaches of the Iskar River, four reservoirs have been constructed—Beli Iskar, Iskar, Pasarel, and Pancharevo (Figs. 1 and 4). Water for drinking and household needs is provided by the reservoirs Iskar and Beli Iskar, by water intake in the river upper reaches, by

Fig. 4 Iskar Reservoir (Photo: Teodora Trichkova)

groundwater and by spring water. The largest water supplier is the Iskar Reservoir (impounded in 1955) with a water volume of 673.106 m^3 which provides drinking water for Sofia, the Bulgarian capital (Anastasov 2002).

Industrial Water Supply For more than 35 years, the Iskar River was used for water supply to the Kremikovtsi Metalworking Plant, one of the largest industrial enterprises in the Balkan Peninsula, located in the Sofia plain. The construction of its facilities began in 1960 and the first production capacities were put into operation in 1963 to produce cast iron, steel, coke, etc. More than 20,000 people used to work there. In the 2000s, metal processing and production gradually declined, and in 2009 the metal production plant was closed.

One large reservoir, Ognyanovo Reservoir (with a surface area of 4.16 km^2), one smaller, Botunets Reservoir (0.42 km^2), and several smaller man-made lakes were built in the Lesnovska River catchment to provide water for the needs of the Kremikovtsi Metalworking Plant. Additionally, many of these and other lakes in the catchment have been used as sand-pit lakes. Since 1980, most of them have been abandoned, but others (Chepintsi, Negovan) are still used for sand extraction. Some of the lakes are currently being used for recreational purposes.

Downstream of Novi Iskar town, the Iskar River was used to provide water for a Copper-Working Plant in Eliseina (built in 1905 and currently not functioning), as well as for different factories in Svoge, Mezdra and Cherven Bryag.

Irrigation The development of the irrigation systems of the Iskar River began in the 1950s with the construction of the Iskar Reservoir (1955), and continued throughout the 1970s in the upper, middle and lower reaches of the river.

Currently there are five individual irrigation systems (Anastasov 2002):

- *Samokov Irrigation System,* with the main water supplier the Alino Reservoir and the rivers Iskar and Beli Iskar (irrigated agricultural land of 1713 ha);
- *East Sofia Plain Irrigation System,* with the main water supplier the Iskar Reservoir, where the water comes after intermediate regulation at Pancharevo and Ognyanovo Reservoirs (irrigated land 17,285 ha);
- *West Sofia Plain Irrigation System,* with its main water suppliers being pumping stations, the Blato River, drilling wells, etc. (150 ha);
- *Botevgrad Irrigation System,* with the main water suppliers the Malak Iskar River and Bebresh Reservoir (3863 ha);
- *Byala Slatina Irrigation System,* with the main water supplier the Iskar River (30,925 ha).

Power Generation There are 19 hydroelectric power plants (HPP) in the river basin, e.g. Lukovit HPP at the Zlatna Panega Reservoir (put in operation in 1938), Beli Iskar HPP at the Beli Iskar Reservoir (1957), Pasarel and Kokalyane HPPs at the Iskar Reservoir (Anastasov 2002). The HPPs have been constructed in different periods, e.g. Koinare HPP (downstream of the village of Koinare 1947), Mezdra HPP (downstream of the town of Mezdra, 1950), Iskra HPP (upstream of Roman, 2005), Kaleto (upstream of Mezdra, 2010), Karlukovo (downstream of the village of

Fig. 5 Lakatnik hydroelectric power plant—part of the hydrosystem “Middle Iskar”, before impoundment (2008) (Photo: Lyubomir Kenderov)

Karlukovo 2010), Cherepish (downstream of Zverino 2012), and Kunino (upstream of the village of Kunino, 2013).

The construction of the hydrosystem “Middle Iskar”, which consists of 9 hydroelectric power plants in the area of Svoge—Eliseina, was planned and started in 2004. So far, five of the hydroelectric power plants—Lakatnik (July 2008) (Fig. 5) Svrazhen (May 2009), Tserovo (April 2012) (Figs. 6 and 7), Prokopanik (June 2013), and Opletnia (July 2013)—have been put into operation, while the others are still in the process of completion and construction (Figs. 6 and 7).

4 Human Impact in the Iskar River Basin

The intensive human activities in the Iskar River basin began in the period 1950–1955. The consequences are shown by the following impacts:

Impact in the Catchment Area from agriculture, forestry, water abstraction, expanding urbanisation, opencast mining, sand and gravel mining. The effects of these activities were the discharge of wastewater polluted by organic substances and nutrients from domestic residences, commercial properties and agriculture,

Fig. 6 Tserovo hydroelectric power plant—part of the hydrosystem "Middle Iskar"; its construction started in 2010 (Photo: Lyubomir Kenderov)

especially downstream of Sofia city and the town of Svoge; the discharge of wastewater polluted by toxic substances from the industrial region in Sofia; direct discharge of untreated mine effluent from Eliseina mine, etc.

Hydromorphological Changes related to water abstraction, hydropower generation, flood protection, etc. The most significant impact was due to the construction of the reservoirs. The effects were changes in the natural hydrological regime, especially downstream of Sofia city, where the water had relatively constant levels yearlong; changes in the habitat types, and from there, in the entire type of aquatic ecosystems—from lotic into lentic, with all the consequences affecting the biodiversity and ecosystem functioning.

5 Hydrological Conditions

5.1 Water Discharge Regime

The national hydrometric system for water discharge monitoring in the Iskar River basin is composed of 19 hydrometric stations. Four of them are located on the main

Fig. 7 View to Tserovo hydroelectric power plant after its construction (2014) (Photo: Lyubomir Kenderov)

river, and the rest are on the tributaries. The national hydrological monitoring started in 1935–1936. The historical records for this period do not illustrate the natural (undisturbed) regime of discharge, since even as early as 1934 the first stage of Sofia water supply system was completed. This was the Beli Iskar hydropower system located in the upper reaches of the Iskar River. However, since the water intake facilities were of mountainous type, they did not change dramatically the discharge during low-water periods. In the upper reaches and in the Rila Mountain tributaries, the summer low-water period (the average monthly discharge minimum) takes place in September, while the winter low-water period is in February and/or January. During droughts or cold autumn seasons, the summer low-water period transfers over to winter and lasts 6–7 months (Dakova 1994). The main spring-summer high-water period (the average monthly discharge maximum) is during May–July, with around 60–70% of the annual discharge (Kopralev 2002).

The water discharge downstream of the Iskar Reservoir has been regulated to a significant degree. For example, at Govedartsi (upstream of the reservoir), the river has an inequality coefficient of 6.7; at Novi Iskar (downstream of the reservoir) this coefficient becomes 2.3 as a result of accumulation of water from the spring-summer discharge maximum; while further downstream its value increases to 2.8 at Kunino and 3.6 at Orehovitsa. The more rapid increase in fluctuations of discharge toward the mouth is due not only to the reduced regulating influence of the reservoir, but also to the better expressed spring discharge maximum under the influence of the Stara Planina tributaries, as well as the effect of water abstraction for irrigation (Kopralev 2002).

The values of the annual water discharge for the period 1961–1998 varied in a wide range: in the Rila tributaries it was about 500 l/s, gradually increasing downstream and reaching almost 54,000 l/s at the mouth. Generally, the values of the variation coefficient were not high—around 0.3 (Anastasov 2002).

The average rate of discharge in the main river for the period 2003–2004 was 4.55 l/s/km^2 (DRBD 2004). In the upper reaches (Rila Mountains), the rate of discharge had the highest value (36.4 l/s/km^2, Cherni Iskar River), which gradually decreased downstream until it reached the Sofia Plain. In the Stara Planina Mountains, the rate of discharge again increased to 7.47 l/s/km^2, and after the confluence with the Zlatna Panega River, its value decreased to 6.52 l/s/km^2.

5.2 Suspended Sediment Discharge and Fluvial Processes

The historical records on suspended sediment flow in Bulgaria are from 1951. In the Iskar River, two periods of disturbed suspended sediment discharge regime have been accepted: 1951–1968, with higher number of months of low sediment discharge; and after 1969, with lower number of months of low sediment discharge (Rainov and Dakova 1994). The changes in the suspended sediment discharge in the river basin are a result of a number of factors, such as: activation or reduction of the erosion processes; deforestation; reservoir construction (Iskar, Ognyanovo); flow regulation and river bed alterations nearby existing hydroelectric power plants; release of suspended contaminants with municipal or industrial origin (Kremikovtsi Metalworking Plant, mining industry); sand mining in the Sofia plain; waste water from animal farms, etc. (Rainov and Dakova 1994).

The total suspended sediment discharge in the Bulgarian rivers ranges most frequently from 10–15 to 300–400 t/km^2/y, with an average value for the whole country of 125 t/km^2/y (Kopralev 2002). The average suspended sediment discharge in the Iskar River is lower than the average for the country, with the exception of the station at Novi Iskar (173 t/km^2/y). About 100,000 tonnes of sand are dumped in the river annually, without using any treatment facilities. The maximum values of suspended sediment discharge are much higher than the average for the country (836 t/km^2/y). The exception is the upstream station at Levi Iskar River, with a maximum value of 89 t/km^2/y. The historical records at some of the stations in the Iskar River basin show a tendency of decrease, beginning in 1973 and continuing in 1981–1995 (Kopralev 2002).

Human impact is the main cause of the fluvial processes in the Iskar River basin. For example, the river bed downstream of the Iskar Reservoir has overgrown with trees and shrubs and has narrowed significantly. This is also observed in the sections downstream of the reservoirs Pasarel and Pancharevo, where there are buildings and facilities within the river bed itself. In the Sofia plain, the river bed has been entirely changed mainly because of the sand and gravel mining activities. In the middle reaches, the changes in the main river bed are not significant, but in the lower reaches, the fluvial changes appear again due to the existing sand and gravel quarries (Rainov and Dakova 1994).

6 Water Chemistry

Most of the surface water in the Iskar River basin belongs to the hydrogen carbonate-sulphate-sodium type (the uppermost tributaries in the Rila Mountains), and the hydrogen carbonate-calcium-sulphate type (middle and lower reaches) (Kopralev 2002).

In the period 1975–1990, a continuous increase in the total mineral content of surface water along the river course was reported. Maximum values were observed downstream of Novi Iskar, immediately after the discharge of waste water from Sofia city. In the downstream part of the middle and lower reaches, almost equal values (390–410 mg/L) were recorded and noticeable increase was observed only at the mouth (450 mg/L) (Tsankov 1994).

During this same period 1975–1990, the organic content in the waters of the Iskar River, reached its maximum again downstream of Novi Iskar. The maximum values were recorded in the period 1975–1982 (a maximum biological oxygen demand 5 (BOD5) of 99.0 mg/L and a maximum permanganate oxydability of 79.2 mg/L). After the construction of the Sofia waste water treatment plant (1984), there was a noticeable improvement within 16–19%. In the downstream section, as a result of the self-purification potential of the river, the organic content gradually decreased compared to Novi Iskar, and at the mouth it reached an average BOD5 of 12.4 mg/L and permanganate oxydability of 9.6 mg/L (Tsankov 1994).

In the period 1981–1990, the amount of nutrients in the water of the Iskar River changed unevenly and randomly along the river course. Only the content of nitrate nitrogen was comparatively low, while the content of nitrite ions, ammonium ions and iron was high (Tsankov 1994).

The pH was neutral. The average values in the period 1983–1990 ranged from 6.78 to 7.53, while along the river course there was a slight increase in acidification (Tsankov 1994). During the same period, the waters of the Iskar River contained phenols. Their main source was assumed to be the Kremikovtsi Metalworking Plant. Maximum amounts were registered at Novi Iskar, and the concentration toward the mouth decreased (Tsankov 1994).

In 2003 and 2004, a monitoring of the physico-chemical parameters of surface water in the Iskar River basin by the Danube River Basin Directorate, showed 4 (out of 10 investigated) critical points, with heavily polluted waters (DRBD 2004):

- the Iskar River downstream of the town of Samokov (upper reaches)—high amounts of organic pollutants, nutrients, undissolved substances, as a result of

waste water discharge from Borovets (mountain ski resort), Samokov and untreated village sewage;
- the Lesnovska River at Dolni Bogrov (middle reaches)—constant pollution with nutrients and phenols; low dissolved oxygen content, increased concentration of sulphates, phosphates, manganese, cyanide and iron as a result of waste water discharge from industries and the Kremikovtsi Metalworking Plant;
- the Iskar River at the town of Novi Iskar (middle reaches)—high concetrations of BOD5 and nutrients, constant pollution with phenols, phosphates, nitrate nitrogen and oil products, as well as accidental pollution by copper, iron and lead from the waste water of Sofia city;
- the Kalna River downstream Botevgrad (middle reaches)—undissolved substances, nutrients, manganese and low dissolved oxygen concentrations as a result of waste water from Botevgrad and village sewage (DRBD 2004).

Considerable pollution from municipal waste water discharge was also detected downstream the towns of Elin Pelin, Kostinbrod, Svoge, Mezdra and Roman.

7 Biodiversity

High animal diversity has been recorded along the whole reaches of the Iskar River and its tributaries in different periods of study. A total number of 765 taxa of invertebrate animals (protozoans, worms, leeches, molluscs, crustaceans, insects, etc.) and 199 taxa of vertebrate animals (of which 53 are fish, 7 amphibians, 3 reptiles, 132 birds and 4 mammals) were reported (Paspalev and Peshev 1955; Karapetkova 1994; Russev et al. 1994). However, the various human activities in the river basin, such as engineering construction and river regulation activities, deforestation, pollution, overfishing and poaching, etc., have had a negative impact on the species diversity and the state of the animal populations. Here more detailed information on the benthic macroinvertebrates and fish is presented.

7.1 Benthic Macroinvertebrates

First data on the oligochaete fauna in the Iskar River were published by Uzunov (1980). The author recorded 23 species, of which the most frequently found were: *Stylaria lacustris*, *Aulophorus furcatus, Nais simplex*, *Nais elinguis*, *Ophidonais serpentina*, *Tubifex tubifex*, *Limnodrilus hoffmeisteri,* and *Eiseniella tetraedra.* In the summary book on the limnology of the Danube tributaries, a total of 54 oligochaete taxa, 42 of them identified to species level, were reported for the Iskar River (Russev et al. 1994).

Data on some species of leeches were published by Augener (1925) and Arndt (1943), who reported the finding of *Helobdella stagnalis* in the mountainous part of the Iskar River (tributary of Levi Iskar). Russev and Janeva (1976) reported on the occurrence of the species *Glossiphonia complanata*, *Alboglossiphonia heteroclita*, *Helobdella stagnalis*, *Hemiclepsis marginata*, *Haemopis sanguisuga*, *Erpobdella monostriata*, *Erpobdella octoculata,* and *Dina lineata*. In the upper reaches, the authors found *E. monostriata, E. octoculata* (at the confluence of the rivers Cherni Iskar and Beli Iskar), and *Dina lineata* (upstream part of the Cherni Iskar).

Of the six gammarid species (Amphipoda) that occur in Bulgarian rivers, mainly *Gammarus balcanicus* was found in the Iskar River. It was newly described from the Iskar River and other water basins by Schäferna (1923). Later, Kaneva-Abadjieva (in Golemansky 1964) identified it from material collected in the Iskar River at Pancharevo and in the Zhitolyub spring near Lakatnik Station. The species was reported in the Iskar River also by Janeva and Russev (1989) and Russev et al. (1994). The other crustaceans commonly found in the river basin were Asellus aquaticus (Isopoda), abundant and often dominant in the benthic community in sections with higher organic pollution (middle reaches) (Kenderov and Janeva 2009); and Austropotamobius torrentium (Decapoda) reported in the Zheleznishka River, a right tributary of the Iskar River upstream of Sofia city, and the Gabrovnitsa River, a right tributary of the Iskar River in the Iskar Gorge, Stara Planina Mountains (Kenderov et al. 2010; Todorov et al. 2014).

A small number of dragonfly species was reported in the Iskar River. During a Danube survey, in the estuary zone of the river, near the village of Gigen, Beshovski (1965) found larvae of *Calopteryx splendens*, *Ischnura elegans*, *Gomphus flavipes,* and *Ophiogomphus cecilia,* as well as *Gomphus vulgatissimus,* a very rare species in the Danube River. In the Iskar River, the rheophilic *C. splendens*, *G. flavipes, G. vulgatissimus,* and the relatively rare species *O. cecilia* were reported (Beshovski 1967). Janeva and Russev (1989) confirmed *C. splendens* and *Platycnemis pennipes*, which are common in all large Bulgarian rivers. A total of 13 dragonfly species were reported in the whole river basin (Russev et al. 1994).

A total number of 62 mayfly taxa, 56 of them identified to species level, were reported in the Iskar River (Russev et al. 1994). Russev and Doshkinova (1985) studied the productivity of the order Ephemeroptera at two sites—upstream of Kokalyane village and in the Vedena River, in the period 1981–1982. A total of 20 mayfly species were recorded, of which the representatives of the genus Baetis had the highest abundance (60%) and the highest biomass (37.8%).

Russev (1971) recorded the species *Taeniopteryx hubaulti* from the order Plecoptera in the Iskar River upstream Samokov town, and described it as new for the fauna of Bulgaria. A total of 60 stonefly taxa, 51 of them identified to species level were reported in the Iskar River (Russev et al. 1994).

Regarding the order Trichoptera, Kumanski (1971) reported the following caddisfly species in the river upper reaches: *Rhyacophila nubila*, *Agapetus ochripes*, *Psychomyia pusilla*, *Tinodes unidentatus*, *Micrasema minimum*, *Chaetopteryx stankovici*, *Chaetopterygopsis sisestii,* and *Annitella triloba*.

First data on the qualitative composition of the family Chironomidae in the Iskar River were published by Dimitrov (1962). Later Stoichev (1994) made a faunistic review of the group in the Danube River and its tributaries. He presented a list of

47 chironomid midges occurring in the Iskar River. Most frequently found (pF over 50%) were the following species: *Chironomus riparius, Cryptochironomus gr. defectus, Paratendipes nudisquama*, *Cricotopus algarum*, *Cricotopus gr. Sylvestris,* and *Larsia curticalcar*. Later, Stoichev (1996) published additional data on some of the chironomid species in the Iskar River, most of which were frequently found and dominant species in other Bulgarian water bodies as well (*Chironomus plumosus, Ch. riparius, Cr. defectus, Tanytarsus bathophilus, C. algarum,* and *C. gr. sylvestris*).

The following impacts on the benthic macroinvertebrate community as a result of human activities in the Iskar River basin have been identified (Kenderov and Apostolov 2008; Kenderov and Janeva 2009; our data):

- *Pollution with organic substances*: The heavy organic pollution downstream of Sofia and Svoge eliminated most of the species; the community was formed by only a few, mainly eurytopic taxa, adapted to low oxygen conditions (*Nais barbata, T. tubifex, L. hoffmeisteri, Limnodrilus udekemianus,* and *Ch. plumosus*). The represented species developed in extremely high abundance and produced considerable biomass.
- *Pollution with hazardous substances*: The high concentrations of xenobiotics and heavy metals in the section downstream of Eliseina destroyed the benthic community; in these conditions very few species survived, and they were represented by single specimens with low biomass (*N. elinguis, L. hoffmeisteri, E. octoculata, Baetis lutheri, Hydropsyche incognita,* and *Ch. riparius*).
- *Accumulation of fine sediments, siltation*: As a result of the intensive sand and gravel mining in the section downstream of Samokov, fine sediments (clay, sand) accumulated a few kilometres downstream. Thus, the type of substrate has changed (from stony to sandy) and most of the aquatic insect larvae have disappeared from the benthic macroinvertebrate community.
- *Hydromorphological alterations as a result of the construction of hydroelectric power plants in the middle reaches*: The change from flowing to stagnant conditions in the area of the hydroelectric power plants Lakatnik and Svrazhen destroyed all rheophilic insect larvae and favored the development of species with preference for muddy substrate, such as the representatives of the families Tubificidae (Oligochaeta) and Chironomidae (Diptera). Moreover, the stagnant conditions allowed the development of high densities of plankton organisms. Migrating to the downstream sections, the plankton served as a food of filter-feeding caddisflies, which developed in large abundance (e.g. downstream of Svrazhen HPP) and replaced most of the other functional feeding groups of invertebrates from the benthic community. Another consequence of the hydroelectric power plant construction was that the construction materials used for the bank protection (stones) almost entirely destroyed the existing bottom invertebrate fauna. The newly formed habitats were colonised subsequently by new species. The first colonisers were the active swimmers—leeches and mayfly larvae (*Baetis* sp.), while the last to join the recovering community (after about a year) were the attached organisms—larvae of Simuliidae and Trichoptera.

- *Introduction of invasive alien species*: In 2005–2006, the invasive alien Chinese pond mussel (*Anodonta woodiana*) was recorded only in the lowermost reaches (at Gigen). However, the species spread very quickly upstream, and in 2009 it was found near Orehovitsa, about 20 km from the mouth, while in August 2011 the species was already near Pelovo (Iskar), 50 km upstream from the mouth (Hubenov et al. 2012). Another invasive bivalve, the Asian Clam (*Corbicula fluminea*), was recorded at the sites near Gigen and Orehovitsa in 2004–2009, while in August 2011, the species was already abundant at Chomakovtsi, 80 km upstream from the mouth. In 2010, the species was found in Negovan Lake, Sofia plain, at altitude of 525 m a.s.l. (Hubenov et al. 2013). The highly invasive zebra mussel (*Dreissena polymorpha*), has also been found in the Iskar River basin. In 2008 during a monitoring of seven sand-pit lakes and two reservoirs located along the Lesnovska River, the species was recorded in Chepintsi Lake, and newly recorded in Negovan Lakes, Kazichene Lake and Ognyanovo Reservoir (Kozuharov et al. 2009; Trichkova et al. 2009). The highest abundance and biomass were recorded in Chepintsi Lake, which was probably the earliest one infested. The spread of zebra mussel in the basin of the Lesnovska River was assumed to be a result of human-assisted transport of larvae or adult individuals with the help of fishing equipment and boats.

7.2 Fish

Data on the species composition and distribution of the ichthyofauna in the Iskar River and its tributaries was summarised by Drensky (1921), Chichkoff (1939), Paspalev and Peshev (1955) and Karapetkova (1994). The fish species composition in the middle reaches in the period 1996–2004 was studied by Raikova-Petrova and Hamwi (2004). Data on some biological characteristics of dominant fish species in the middle reaches were reported by Hamwi et al. (2005, 2007, 2009) and Raikova-Petrova et al. (2006, 2008). Species composition and ecological characteristics of fishes in the Palakariya River were published by Dikov et al. (1988) and Pavlova and Pehlivanov (2009). Pehlivanov et al. (1989) reported on the abundance and behaviour of juvenile perch in the littoral zone of the Iskar Reservoir. The ichthyofauna in the sand-pit lakes in the Sofia plain was studied by Raikova-Petrova et al. (2009), Iliev and Raikova-Petrova (2010), and Uzunova et al. (2010).

In the 1920s–1930s, about 43 fish species were reported in the Iskar River basin (from the upper reaches to the river mouth) (Drensky 1921; Chichkoff 1939). In the uppermost reaches, the so called "trout zone", which extended from the Iskar River sources to the confluence of the Rivers Cherni Iskar, Levi Iskar and Beli Iskar, the ichthyofauna was represented by *Salmo trutta fario*, rarely *Oncorhynchus mykiss* (introduced), *Phoxinus phoxinus, Barbatula barbatula* and *Cottus gobio*. Downstream from the upper reaches, the following species appeared: *Alburnoides bipunctatus, Barbus petenyi, Gobio gobio* sensu lato, *Squalius cephalus, P. phoxinus*, *Romanogobio kessleri, Romanogobio uranoscopus, Sabanejewia* *balcanica*, etc. The fish fauna in the middle reaches was dominated by *Alburnus alburnus*, *Barbus barbus, Chondrostoma nasus, Cyprinus carpio, G. gobio* sensu lato, *S. cephalus, Silurus glanis,* etc. The lower reaches—from the mouth of the tributary Zlatna Panega River at the town of Cherven Bryag to the Danube River—were inhabited by: *Abramis brama, A. alburnus, B. barbus, Carassius carassius, C. nasus, C. carpio, Rutilus rutilus, Scardinius erythrophthalmus, S. cephalus, Tinca tinca, Esox lucius, S. glanis,* etc.; and some typical representatives of the Danube River fish fauna, such as: *Acipenser ruthenus*, *Aspius aspius*, *Leuciscus idus*, *Lota lota*, *Sander lucioperca,* and *Zingel* spp. (Drensky 1921; Chichkoff 1939).

In this period, the Iskar River was used for intensive commercial fishing of regional importance, with 7–8 tonnes of fish being caught annually in the upper and middle reaches (Drensky 1921). Fishes of bigger size and age were common—for example, in 1923, in the section Mezdra–Roman (middle reaches), the following catches were reported: chub (*Squalius cephalus*) 60 cm long, barbel (*Barbus barbus*) 70–80 cm, nase (*C. nasus*) 50 cm, carp (*C. carpio*) 80 cm, burbot (*Lota lota*) 60 cm, asp (*Aspius aspius*) 80 cm, pike (*Esox lucius* 100 cm, and wels catfish (*Silurus glanis*) 100 cm. (Karapetkova 1994).

The main impacts on the ichthyofauna in this period were reported to be the draining of wetlands and backwaters in the Sofia plain, river regulation and channelisation, construction of weirs (upstream of Pancharevo), pollution from the copper mining industry at Eliseina, and overfishing (Drensky 1921).

In the period 1950–1952, a total of 43 species were recorded in the Iskar River (Paspalev and Peshev 1955). Some of the newly reported fishes were *Carassius gibelio* (caught upstream of Kroshovene) and *Lepomis gibbosus* (in the lowermost reaches), as well as *Neogobius fluviatilis* (2–3 km upstream of the mouth). Most frequently found and abundant in the catches were Romanian barbell (*Barbus petenyi*), barbel (*B. barbus*, nase (*Carassius nasus*), carp (*Cyprinus carpio*), chub (*Squalius cephalus*) and brown trout (*Salmo trutta fario*).

The following negative impacts on the ichthyofauna caused by human activities in the 1950s (before the impoundment of the Iskar Reservoir) were reported (Paspalev and Peshev 1955):

- Massive die-offs of fish within large sections were caused by the discharge of industrial waste water (from factories in Sofia, Novi Iskar, Eliseina, and Mezdra), as well as municipal pollution;
- The construction of dams and weirs for hydropower (at Pasarel, Pancharevo, Mezdra, Chomakovtsi, Koinare, Orehovitsa, and Staroseltsi) prevented the migration of fish; a fish passage was provided only at Mezdra. Furthermore, the diurnal fluctuations in water level nearby the hydroelectric power plants disturbed the fish spawning.
- The river regulation in the lower reaches (which started in the 1930s) resulted in reduction and destruction of spawning and nursery grounds—firstly, in the inshore zone of the river, and secondly, due to disconnection of the river from the adjacent wetlands, side-arms, and backwaters.

- Building of irrigation canals without protection facilities for juvenile fish (at Reselets, Koinare, Krushovene, and Baikal).
- Poaching.

Karapetkova (1994) published a list of 52 fish species, occurring in the Iskar River. The list was based on published data and field surveys **in 1986 and 1991**. The list included a new alien species *Pseudorasbora parva*, which was first recorded in the upper reaches, upstream of the Iskar Reservoir in 1983 (Jankovic and Karapetkova 1992). The author reported negative changes in species and dominant composition of the ichthyofauna compared to the previous studies. The most numerous in the past—*S. cephalus, C. nasus, C. carpio*, etc.—were replaced by *A. brama, A. alburnus, B. barbus, B. petenyi, R. rutilus* and others, most of them typical representatives of the lower reaches. Negative changes appeared also in the total fish stocks. They had decreased significantly, and even destroyed partially or completely in some river sections for short or longer periods of time (Karapetkova 1994). The changes affected further the age and length structure of fish populations. In the studied period, specimens of low size and age prevailed in the catches (Karapetkova 1994).

The negative impact on the species composition, abundance, size and age structure of fish populations in the 1980s was a result of a cumulative effect of many factors, most important of which were the impoundment and influence of the Iskar Reservoir in the upper reaches, the excessive fishing and poaching, as well as the significant and constant deterioration of water quality in the upper and middle reaches (Karapetkova 1994).

In the 1990s–2000s the situation in the river began to improve very slowly. A waste water treatment plant was built in Sofia in 1984. In the 1990s many industrial activities in the Sofia region and downstream in the middle reaches ceased. In the period 1996–2004, the ichthyofauna *in the **middle reaches*** (in the section Svoge–Eliseina) was represented by 10 species, dominated by *A. bipunctatus, B. petenyi* and *S. cephalus* (Raikova-Petrova and Hamwi 2004). The studies on biological characteristics of populations of *A. bipunctatus* and *S. cephalus* (age and size composition, growth rate, condition, fecundity, and feeding) showed a gradual recovery of the fish populations as a result of the improved water quality and food availability (Hamwi et al. 2005, 2007, 2009; Raikova-Petrova et al. 2006, 2008).

The fish fauna in the Iskar River middle reaches was also influenced by the ichthyofauna established in the sand-pit lakes in the Sofia plain. Most of these lakes were artificially stocked and currently been used for recreational fishing. A total of 15 species were reported in the sand-pit lakes along the Lesnovska River, among them three species alien to Bulgaria (*P. parva, L. gibbosus* and *Gambusia holbrooki*) (Iliev and Raikova-Petrova 2010; Uzunova et al. 2010; our data). The dominant species in the lakes were *A. alburnus, C. gibelio, R. rutilus, L. gibbosus* and *P. fluviatilis* (Iliev and Raikova-Petrova 2010; Uzunova et al. 2010).

*In the **upper reaches*** of the Iskar River, the fish fauna was influenced to a lesser degree by the human activities. In 1985, 15 species were recorded in the Palakariya River, among them some species of conservation concern, such as *R. kessleri* and

R. uranoscopus (Dikov et al. 1988). Most abundant were *B. petenyi* and *S. cephalus* which represented together 52% of total abundance and 66% of total biomass. Some of the newly recorded species to the ichthyofauna of the river were *P. parva*, *Oxynoemacheilus bureschi* (previously reported only for the Aegean Sea basin), and *P. fluviatilis*. It was assumed that their occurrence was a result of their penetration from the Iskar Reservoir (Dikov et al. 1988). In a subsequent study in 2008, the species composition of the Palakariya River was almost unchanged. A total of 12 species were recorded, the introduced *O. mykiss* being newly recorded (Pavlova and Pehlivanov 2009). Based on the fish species composition and population parameters of *B. petenyi*, the ecological status of the Palakariya River was assessed as "bad" in the upper and middle reaches and as "moderate" in the lower reaches up to the confluence with the Iskar River. These results were explained with local impacts, such as pollution by nutrients and organic substances from agriculture and animal farms in the adjacent villages, as well as hydromorphological alterations in the upstream part of the river (Pavlova and Pehlivanov 2009).

In 2009, nine species were recorded in the Iskar upper reaches, at Pasarel (downstream of Iskar Reservoir) (our data). Frequently found were *P. phoxinus, S. cephalus* and *C. strumicae*, while common species were: *B. petenyi*, *G. gobio* sensu lato and *R. amarus* as well as the species *C. gibelio, P. parva,* and *P. fluviatilis*, whose occurrence reflected the influence of the reservoirs.

In 2005, a total of 13 fish species were recorded *in t*he Iskar lower reaches (in the section from Reselets to the river mouth, at 3 sampling sites) (Trichkova, Stefanov, Vassilev). The species *A. alburnus*, *C. nasus*, *G. gobio* sensu lato, *P. parva* and *S. cephalus* were common in the whole section. The species *A. bipunctatus, B. petenyi* and *Sabanejewia balcanica* were found at the upper sites, while *A. aspius, C. gibelio, L. idus, Rhodeus amarus,* and *L. gibbosus* in the lowermost reaches.

In August 2011, a total of 23 fish species were recorded in the same section (from Reselets to the river mouth, at 8 sampling sites) (our data). Newly recorded species in the main course of the Iskar River were *Neogobius melanostomus* and *O. bureschi*. The Ponto-Caspian goby *N. melanostomus* reached upstream to Staroseltsi. The translocated species *O. bureschi* appeared relatively abundant in the section from Reselets to Glava (b/n Koinare and Pelovo) (Stefanov et al. 2014). As already mentioned above, the species was recorded previously in the Palakariya River (upper reaches), but probably its appearance in the middle-lower reaches has been a result of secondary introduction in the Iskar River. Some species expanded their range of distribution compared to the previous studies. *A. bipunctatus* and *B. petenyi* were considered initially as inhabitants mainly of the upper reaches and upper part of middle reaches in the Iskar River (Drensky 1921; Chichkoff 1939). Yet Paspalev and Peshev (1955) reported *A. bipunctatus* as occurring also in the middle reaches downstream to Roman, and *B. petenyi* downstream to Chomakovtsi. The authors assumed that this was a result of river regulation and increased water velocity in the middle reaches. During our study, the two species were found in the whole lower reaches downstream to Orehovitsa. In the previous studies, the species *R. uranoscopus* was reported in the Iskar upper reaches and near Sofia (Chichkoff

1939; Paspalev and Peshev 1955) as well as in the Palakariya River (Dikov et al. 1988; Pavlova and Pehlivanov 2009). We found a single specimen at the site near Reselets at the confluence with the small tributary Reselets River. It is possible that the species entered from this river. Other species expanded their range upstream. For example, the Ponto-Caspian goby *N. fluviatilis* was found at Glava which is about 60 km from the mouth.

Most frequently found in this section were *B. petenyi*, *C. gibelio*, *R. amarus* and *S. cephalus*, followed by *A. alburnus* and *B. barbus*. The species S. cephalus and R. amarus were characterised with relatively high abundance within the whole study section. In the lowest part of the middle reaches and upper part of lower reaches, most abundant were *A. bipunctatus* (at Reselets) and *B. petenyi* (at Glava), followed by *O. bureschi*. In the lowermost reaches (Orehovitsa and Gigen) besides *S. cephalus* and *R. amarus*, with high abundance were *B. barbus* and *C. nasus.* The following species were represented by single specimens at single sites: *R. uranoscopus* and *S. glanis* in the upper part (Reselets–Koinare), and *A. brama, C. carpio, Romanogobio vladikovi, R. rutilus,* and *N. melanostomus* in the lower section (Pelovo–Gigen).

The following impacts of local character were observed in this section of the river: discharge of waste water from household and industry at Cherven Bryag; flow regulation; sand and gravel mining and processing; agriculture activities and animal grazing; fishing and poaching; spread of alien and translocated species.

8 Ecological Conditions in the Iskar River: Assessment of Ecological Status Based on Macroinvertebrates—Long-Term Changes—A Case Study

The aim of this case study is to make a comparative review of changes in the ecological status based on benthic macroinvertebrates in the Iskar River, in three study periods—the 1950s–1960s, 1980s–1990s and 2000s.

8.1 Material and Methods

8.1.1 Study Periods

The first studies on the ecological conditions in the Iskar River based on benthic macroinvertebrates were connected to the water quality deterioration downstream of Sofia city in the 1950s–1960s. On the one hand, the increased urbanisation in this period intensified significantly the organic pressure, and on the other hand, the industrial development caused pollution with heavy metals, oil products and xenobiotics in the river. This first stage of studies was conducted in 1956–1957, 1964, and 1968–1969 (Russev 1959, 1968).

The second stage of ecological studies in the Iskar River was related to the effectiveness of the Sofia waste water treatment plant, which began its operation in 1984. The studies were carried out in the periods 1985–1986 and 1991–1992 (Janeva and Russev 1989; Russev and Janeva 1994).

The recent studies focused on assessment of ecological status of the Iskar River and its tributaries (Kenderov et al. 2008; Kenderov and Janeva 2009; Kenderov et al. 2017; Yotinov et al. 2017); and on monitoring of changes in the ecological status based on benthic macroinvertebrates, microbiology and water chemistry in connection with the construction and operation of the hydrosystem "Middle Iskar", consisting of nine hydroelectric power plants in the period 2004–2017 (Topalova et al. 2005; Parvanov et al. 2007; our data).

8.1.2 Sampling Sites

Mainly sites with critical human impact were sampled in the first study period (1956–1969), in order to monitor the effects of pollution and processes of self-purification in the Iskar River. The sampling sites were located as follows (see also Fig. 1): (1) Upper reaches (2 sites): the Cherni Iskar and Iskar River upstream of Kokalyane; (2) Middle reaches (5 sites): the Iskar River downstream from Sofia, upstream of Svoge, at Eliseina, upstream of Roman, and upstream of Cherven Bryag; (3) Lower reaches (5 sites): downstream from Koinare, at Pelovo (Iskar town), at Orehovitsa, at the mouth near Gigen. Additionally, some tributaries, such as the Malyovishka River, Batuliiska, and Malak Iskar were sampled.

In the period of the monitoring of effects of the Sofia waste water treatment plant on benthic macroinvertebrates and assessment of ecological status, the sampling sites were located from Novi Iskar (the most polluted site) downstream to the mouth. In 1985–1986, all 10 sites in the middle and lower reaches were sampled. In 1991, four sites, located in the middle reaches: downstream Sofia, at Eliseina, upstream Roman, upstream Cherven Bryag, and one site in the lower reaches, at Gigen, were sampled. In 1992, only the site at Orehovitsa was sampled.

In the period 2004–2017, the number of sampling sites increased significantly, because of the necessity of ecological assessment of the river, especially in the upper reaches; and of the ecological monitoring in the middle reaches related to the construction of the system of hydroelectric power plants. A total of 23 sampling sites along the main river and four sites at the tributaries (the Beli Iskar, Palakariya, Iskretska, and Lesnovska rivers) were sampled. Of the Iskar River sites, 12 were monitored in the previous studies, while 11 were newly selected. These are: (1) Upper reaches: upstream of Samokov; at Dragoshinovo, upstream of Iskar Reservoir, Sofia—Gorublyane district; Sofia—Druzhba district; (2) Middle reaches: at Tserovo, at Lakatnik, at Svrazhen, upstream of Gabrovnitsa, upstream of Mezdra; (3) Lower reaches: at Staroseltsi.

8.1.3 Methods

The benthic macroinvertebrate samples were collected by a hand-net (ISO 7828/1985). A multihabitat sampling approach was applied, covering various habitats: stones, sand, clay, mud, submerged vegetation, etc. As each sample was collected for the same period of time (20 min), the samples were considered semi-quantitative. In the period 2004–2011, additional quantitative samples were collected from stony-gravel habitats, using a Surer net (ISO 8265-1988). The collected material was fixed in formaldehyde or alcohol. At the laboratory, the material was identified to the species and genus level.

The following methods were used for the assessment of the saprobic status of the river: the saprobic ranking system of Zelinka and Marvan (1961) and its modification by Rothschein (1962); the indicator list of Sládeček (1973) and its adaptations for the conditions of the Bulgarian rivers (Janeva 1979; Russev 1979; Kovachev 1979; Uzunov et al. 1988). In the recent studies, the saprobic index of Pantle and Buck (1955) was also applied. The species diversity and composition of the benthic community were analysed using different parameters after Simpson (1949), Pielou (1966), Margalef (1958), and Shannon and Weaver (1963).

To ensure comparability between different methods for the assessment of ecological status used in different study periods, the results were unified based on the concept of the ecological quality ratio (EQR) required by the EU Water Framework Directive (EU WFD, 2000/60/EEC), and the current national legislation (Ordinance N-4/2012 (2013) for characterisation of surface waters. Official Journal # 22, 05.03.2013, MOEW, Bulgaria). According to this concept, the EQR value = 1 represents type-specific reference conditions (river ecosystems unaffected by human activities); and EQR values close to 0—bad ecological status (river ecosystems under strong human impact).

The following ecological quality scale has been applied:

Ecological status	EQR	Saprobic range
High	1–0.85	From xenosaprobity to improved β-mesosaprobity
Good	0.84–0.58	Stable β-mesosaprobity
Moderate	0.57–0.38	Deteriorated β-mesosaprobity
Poor	0.37–0.25	From improved to stable α-mesosaprobity
Bad	<0.25	Stable α-mesosaprobity and worse

8.2 Results and Discussion

8.2.1 Historical View

The first data on the saprobic status of the Iskar River were published by Russev (1959, 1968). The author reported xenosaprobic and oligosaprobic character of the water in the upper reaches from the river sources to Samokov, with the saprobic index (after Rothschein 1962) in the range from $S_R = 61.0$ to $S_R = 85.5$ (1956–1957 and 1964). Downstream of the Iskar Reservoir, the saprobic index reached β-mesosaprobity (S_R = 57.2–48.5). At Kokalyane village, the saprobic status again improved to oligosaprobity (S_R = 65.3–71.6). Besides the established decrease in value of the index, the ecological status of the river ecosystem can be classified as "high", and in some cases as "good", according to EQR.

The major organic pollution from Sofia city caused considerable decrease in the values of the saprobic index in a large section downstream. At Novi Iskar the saprobic status was assessed in the range from α-mesosaprobity to polysaprobity (1956–1957), or at the border of polysaprobity and isosaprobity (S_R = 10.0–12.5 in 1964). Based on these data, the ecological status can be considered as "bad". The most deteriorated status was reported downstream of Sofia city in 1968–1969, when the macroinvertebrates disappeared, and the fauna was represented only by Protozoans. The saprobic status was determined as iso-saprobity. Further downstream in the middle reaches, the pollution from the Sofia region was reduced as a result of the river self-purification potential. In 1956–1957 the saprobic status was improved to β-mesosaprobity upstream of Svoge (S_R = 39.0–45.5) and Eliseina ($S_R = 46.5$), or "moderate" ecological status; while in 1964 the saprobic status did not exceed polisaprobity (Svoge, S_R = up to 18.3) and α-mesosaprobity (at Eliseina and Cherven Briag, S_R = 25.3–30.0), corresponding to "bad" ecological status. The highest pollution from Sofia in 1968–1969 reduced substantionally the self-purification potential of the river downstream. Polysaprobity was achieved again at Lakatnik and Svoge (S_R = 14.0–18.4) (Russev 1959, 1968).

In the lower reaches the self-purification potential of the river increased compared to the middle reaches. In 1964, the saprobic index was in the range S_R = 64.0–44.0 between Koinare and Gigen, determining "high" and "good" ecological status. In the following study period (1968 and 1969), an improvement was not reached in the section between Reselets and Staroseltsi (S_R = 13.3–20.2), and the ecological status remained "bad". Only in the lowermost section near Gigen and Orehovitsa, β-mesosaprobity was achieved (S_R = 35.0–44.0), corresponding to "poor" and "moderate" ecological status (Russev 1968; Russev and Janeva 1994).

In the following periods (1985–1986, 1991–1992), Janeva and Russev (1989) and Russev and Janeva (1994) studied the effects of the newly constructed Sofia waste water treatment plant on the saprobic status of the river. The results in 1985–1986 showed an improvement of all parameters compared to the previous studies. A total of 131 taxa of benthic invertebrates were recorded, of which: 30 (22.9%) were chironomids, 27 (20.6%) oligochaetes, and 17 (13.0%) mayflies. The river was determined as "relatively clean" at the site upstream of Sofia (at Kokalyane village). However, the degree of organic and industrial pollution at Novi Iskar did not decrease significantly; a poly-α-mesosaprobity and polysaprobity (S_R = 0.0–30.0) was detected, corresponding to "bad" ecological status.

The section between Svoge and Roman was reported as the most polluted one. It was characterised by unstable benthic community composition; the saprobic status ranged from deteriorated α-mesosaprobity to polisaprobity (S_R = 20.3–31.1), corresponding to "bad" and „poor" ecological status. Dominant taxa were the oligochaetes. The maximum self-purification potential was observed in the section from Roman to the mouth, where 84 zoobenthic taxa, dominated by chironomids, were recorded.

A progressive increase in values of the saprobic index was reported in the lower reaches ($S_R = 26.5–42.3$, from Koinare to Pelovo), due to initial stabilisation of the zoobenthic community and reduced intensity of the saprobic processes. The ecological status in this section was determined as "poor" and "moderate". From Pelovo to the mouth, a stable α-mesosaprobity ($S_R = 25.9–29.3$) was reported, or the ecological status can be classified as "poor" and "bad".

In 1991, the river self-purification potential increased, and an improvement in the ecological status from "bad" at Novi Iskar ($S_R = 19.3–21.1$, polysaprobity) to "moderate" in the section from Svoge to the mouth (Cherven Bryag $S_R = 44.9$; Gigen $S_R = 42.5$) was found (Russev and Janeva 1994). This was considered as a result of the seven-year operation of the Sofia waste water treatment plant and the high water levels during that year.

8.2.2 Current Environmental Conditions

Recent data on the ecological status of the Iskar River in the period 2004–2006 were published by Kenderov et al. (2008) and Kenderov and Janeva (2009). The ecological status was assessed based on the composition and structure of benthic macroinvertebrate community in the three main river zones: upper, middle and lower reaches.

The **upper reaches** of the Iskar River, including the Cherni Iskar and Beli Iskar, were characterised by the highest species richness. A total of 240 taxa of benthic invertebrates were recorded, and they represented 77.7% of all taxa found in the cachment in this study period. Most numerous were the class Oligochaeta, represented by 44 taxa, order Ephemeroptera (43 taxa), order Trichoptera (36 taxa), family Chironomidae (20 taxa) and order Plecoptera (17 taxa). Most numerous were the species with a preference for pristine waters with low organic content: *Dugesia gonocephala*, *Crenobia alpina*, *G. balcanicus*, *Baetis alpinus*, *Ephemerella mucronata*, *Epeorus sylvicola*, *Rhythrogena gr. hybrida, Leuctra pseudosignifera*, and *Rhyacophylla nubila.* The species indicators of organic pollution, such as the oligochaetes *Limnodrillus claparedianus, L. hoffmeisteri, N. barbata,* and the leeches *E. octoculata, D. lineata, H. stagnalis,* were found only in the section downstream of Samokov. In the uppermost reaches (upstream of Samokov and the rivers Beli Iskar and Cherni Iskar), most abundant were the representatives of Ephemeroptera, Plecoptera and Trichoptera; while downstream of Samokov, most abundant were the chironomids and oligochaetes.

The structure of the benthic macroinvertebrate community in the upper reaches, which was characterised by high species richness and diversity as well as lack of dominant species, determined a "high" and "good" ecological status. The application of the saprobic index of Pantle and Buck (1955) confirmed these results. The index showed mainly an oligosaprobity: from $S_{PB} = 0.80$ (the Iskar upstream Kokalyane) to $S_{PB} = 1.45$ (the Cherni Iskar). An exception was the few kilometre section downstream of Samokov, where the saprobic index was in the range of α-mesosaprobity—$S_{PB} = 2.74$ in the spring of 2004, and $S_{PB} = 2.67$ in the summer of 2005. In these cases, the ecological status was determined as "poor" owing mainly to organic pollution with local character. The good self-purification potential of the river was demonstrated by the fact that only 8 km downstream (the inflow of the Iskar Reservoir), the saprobic status improved to β-mesosaprobity, and the ecological status to "good", during the whole 2004–2006 study period. Compared with the previous studies (1964–1970, Russev 1968; Russev and Janeva 1994), the ecological status in the upper reaches did not show significant changes and the river ecosystem remained in a natural state, with an exception of the section immediately downstream of the town of Samokov.

In the **middle reaches**, a low number of taxa were recorded. The heavy pollution with organic and hazardous substances in this section in the past (Russev and Janeva 1994) and in the present influenced negatively the development of a stable macrozoobenthic community. In 2004–2006, a total of 130 taxa were recorded, representing 42.1% of the total number of taxa found in the Iskar River. The most important for the formation of the benthic community was the class Oligochaeta, which was represented by 41 taxa. The representatives of the order Ephemeroptera were reduced to only 11 taxa, the order Trichoptera to 13 taxa, and the order Diptera varia to 8 taxa. The class Hirudinea was represented by the highest number of species (8), compared to other river sections. Representatives of the order Plecoptera were not found.

The lowest number of species was recorded in the section with the highest organic pollution (Novi Iskar–Eliseina). Almost all species were typical indicators of heavily polluted waters: the oligochaetes *N. barbata*, *T. tubifex*, *L. hoffmeisteri*, *Limnodrilus profundicola*, and *L. udekemianus*, the isopod *A. aquaticus*, the chironomid larvae *Ch. plumosus,* etc. In contrast, the orders Trichoptera and Ephemeroptera, typical indicators of clean waters, had the highest abundance in the downstream part of the middle reaches (Roman–Cherven Bryag), where more intensive self-purification processes were evident. Most abundant in this section were the species indicators for improved ecological status, such as: *Dendrocoellum lacteum, Dugesia* sp., *Calopteryx splendens, Platycnemmis pennipes, Caenis macrura,* and *C. pseudorivulorum.*

The ecological status in various sections of the middle reaches reflected the structure of the benthic macroinvertebrate community and the saprobic situation. In the most polluted section (downstream of Sofia), the benthic community was almost destroyed, represented by only a few species, developed in high abundance. In this section, some of the lowest values of species diversity index (after Shannon and Weaver 1963) were detected. The saprobic index was in the range of polysaprobity or α-mesosaprobity, therefore the ecological status was assessed as "bad". The high self-purification potential further downstream resulted in improvement of the ecological status. At the site upstream of Svoge, the saprobic index showed α-mesosaprobity and even deteriorated β-mesosaprobity (in the summer of

2004 and 2006), therefore, the ecological status was assessed as "poor". At the most downstream sites of the middle reaches (upstream Roman and Cherven Bryag), a stable β-mesosaprobity was registered, showing that the ecosystem was already fully restored, and the ecological status was assessed as "good". The results showed that in 2004–2006, the self-purification potential in the middle reaches was much higher compared to the previous studies (1991, Russev and Janeva 1994), and an improvement in the ecological status ("good") was reached within a much shorter distance.

In the **lower reaches**, the Iskar River remained in a "good" ecological status, ensured by the self-purification potential of the upstream river sections. In 2004–2006, the number of taxa recorded reached 142 taxa (46% of all taxa in the river). The most represented groups were the same—the order Ephemeroptera (17 taxa), family Chironomidae (19 taxa), and the class Diptera var. (12 taxa). Stenotopic species, typical for the improved ecological conditions, such as: *P. pennipes*, *D. gonocephala*, *G. balcanicus* and *C. macrura,* as well as other mayfly species from the families Baetidae, Caenidae, Heptageniidae, and Ephemerellidae, were established. At the same time, the species composition of the benthic community was influenced by the faunistic complexes of the Danube River, e.g. the gastropod *Holandriana holandrii,* the oligochaete *Isochaetes michaelseni* and the invasive alien bivalves *Corbicula fluminea* and *Anodonta woodiana.* The structural parameters of the benthic community fully reflected the improved ecological conditions: the dominance index remained low in almost all cases, while the species evenness and species diversity were high. The only exception was the river mouth zone, where development of the benthic community was suppressed, because of the changes in hydrological conditions and unfavourable bottom substrate due to the influence of the Danube River.

The improved ecological status in the lower reaches was confirmed also by the saprobic index, which showed in most cases a stable β-mesosaprobity. Again, the exception was the river mouth zone, where a polysaprobity (spring 2004) or deteriorated α-mesosaprobity (spring 2005) was determined. Compared to the previous studies (1991–1992), the entire section of the lower reaches had improved its ecological status, with the exception of the lowermost section, where significant changes were not detected.

9 Conclusions

The Iskar River, a Danube tributary, is the longest Bulgarian inland river, flowing through seven geographical areas of Bulgaria. It crosses one of the most urbanised and densely populated areas in Bulgaria—the city of Sofia and its surroundings; and it plays a major role in water supply for drinking, household and industry, discharge of sewage, irrigation, and power generation in the area.

The exploitation of the Sofia water supply system started in the 1930s. More intensive human activities in the Iskar River basin began in the 1950s with the construction of the Iskar cascade of reservoirs. In the 1950s–1970s with the development of agriculture in the region, the irrigation system in the Iskar River basin was developed. The 1960s–1990s were characterised with an intensive industrial development—construction and operation of the Kremikovtsi Metalworking Plant (production of cast iron, steel, coke), opencast mining, sand and gravel mining, power generation, etc. The last 20 years have been characterised with expanding urbanisation of the Sofia region, as well as with continuous development of hydroelectric power generation in the river's middle reaches.

The long-term and growing human pressure in the Iskar River basin has resulted in hydrological and hydromorphological changes, deterioration of water quality and adverse effects on the biodiversity and ecosystem functioning. Pollution with organic and hazardous substances caused changes in species composition and structure of benthic macroinvertebrate community. Accumulation of fine sediments and the hydromorphological alterations resulted in changes in bottom substrate and reduction and loss of habitats, leading to elimination of many benthic macroinvertebrate species and their replacement by eurytopic species. The negative impact on fish populations was expressed in changes in species composition, abundance, population size and age structure. Massive die-offs of fish within large sections in some periods were caused by municipal and industrial waste water discharge. The lost lateral and longitudinal connectivity of the river has caused reduction or loss of fish habitats, spawning, nursery and feeding grounds along the entire river course. Another important impact has been the introduction, establishement and rapid spread of invasive and alien species of molluscs and fish within the Iskar River basin.

The results from the assessment of ecological status based on benthic macroinvertebrates reflected the character and intensity of the human impact in different periods of study and within different sections of the river course. During the studies in the 1950s and 1960s, the ecological status in the upper reaches was "high" and "good". However, in a large section downstream Sofia city, a polysaprobity or "bad" ecological status was reported during almost all periods of study (1950s–1990s). Further downstream in the middle and lower reaches, due to the self-purification potential of the river, the ecological status improved from „bad" and „moderate" (middle reaches) to „high" and "good" (lower reaches) in the 1950s and 1964. As a result of the intensive pollution downstream of Sofia (up to iso-saprobity) in 1968–1969, the self-purification potential of the river decreased considerably. The entire middle reaches and the main part of the lower reaches remained in a "bad" ecological status. A „poor" and „moderate" ecological status was reached only at the mouth. In the 1980s and early 1990s, an improvement of the ecological status was observed as a result of the operation of the newly constructed Sofia waste water treatment plant. The ecological status in the whole section of middle and lower reaches was improved to „moderate".

In the 2000s, the ecological status in the upper reaches did not show significant difference from the previous periods, it was determined as "high" and "good". In the middle reaches, the most polluted section, the ecological status was assessed from "bad" (downstream of Sofia) to "good" (upstream of Roman and Cherven Bryag). The self-purification potential was much higher compared to the previous studies, and an improvement in the ecological status was reached within a much shorter distance. In the lower reaches, the Iskar River remained in a “good” ecological status. Compared to the previous periods, the entire section of the lower reaches improved its ecological status, with the exception of the lowermost section, in which significant changes were not detected.

Although the recent results from the assessment of ecological status based on benthic macroinvertebrates in the Iskar River showed an improvement compared to the previous study periods, the ecological status in large sections, in particular in the middle reaches, have been still assessed as “bad” and “poor”. The analysis of the Danube River Basin Directorate showed that 10 water bodies in the Iskar River basin, mainly in the middle and lower reaches, are classified nationally at risk from organic pollution and pollution from hazardous substances. These water bodies are also at risk of not achieving at least “good ecological and chemical status” by 2015, according to the requirements of the EU WFD. Urgent actions need to be taken for the implementation and further development of the programme of measures for each water body within the Iskar River basin included in the Management Plan for the Danube River Basin in Bulgaria for the period 2010–2015.

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Human Impact Effects on Târnava River Basin Aquatic Biodiversity (Transylvania, Romania)

Angela Curtean-Bănăduc and Doru Bănăduc

In the circumstances in which water is irreplaceable now in the present as it was in the past and will be in the future, the biodiversity of water related elements has become one of the predominant subjects for discussion that concern academic, administrative and civil society. All through history the human impact on aquatic biodiversity elements has generated new and varied categories of pressures and threats. The Danube River watershed is certainly one of the principal areas of such human activities-induced modifications (Bănăduc et al. 2016).

29% of the Danube Watershed belongs to the Romanian national territory. Just a brief look on the Romanian geographical map is enough to reveal the fact that Transylvania is encircled like a stronghold by the Carpathian Mountains, and over seven million people base their existence there on rich water capital in the form of streams and rivers flowing from this mountainous amphitheatre, in Danube tributaries of diverse magnitude.

The natural and cultural legacy are increasingly endangered both by natural risks and results of human activities (Hapciuc et al. 2016), and different river basins are in the same situation from this perspective. Târnava River Watershed is a very good such case.

Târnava River Watershed (Fig. 1) is located in the central part of the Romanian Carpathians arc water reserve, draining the Transylvania Depression, especially its southern zone the Târnavelor Plateau, and varies considerably in climate, hydrology, geology, relief.

With a watershed surface of 6157 km^2, a length of 249 km and a decreasing altitude of approximately 1250 m, Târnava River is the second main tributary of the Mureş River, representing 21% of its watershed. It is brought into existence at the confluence of Târnava Mare River (3606 km^2 watershed surface, 221 km length) and

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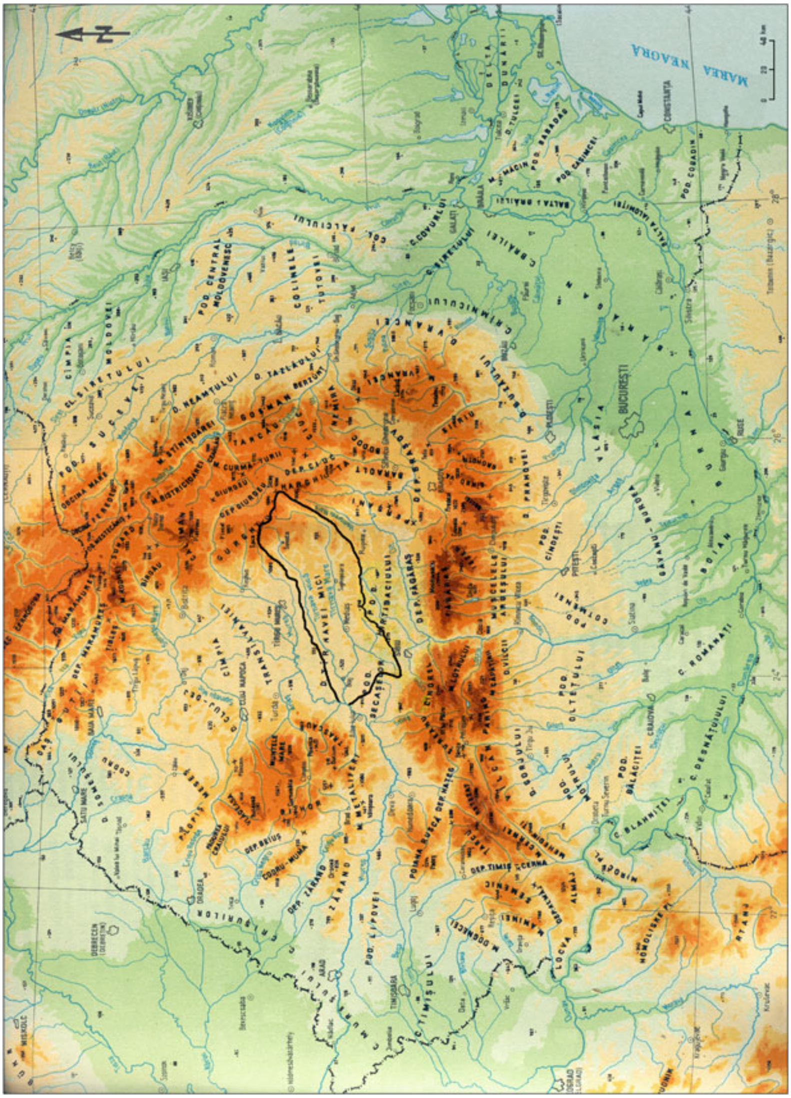

Fig. 1 The Târnava River Watershed study unit location (Badea et al. 1983 modified)

Fig. 2 The Târnava River at the confluence of Târnava Mare and Târnava Mică rivers

Târnava Mică River (2049 km^2 watershed surface, 191 km length) near the town of Blaj (Fig. 2). The first tributary originate from the western part of the volcanic mountain Harghita Şumuleului at 1441 m altitude and the second from the southern part of the volcanic mountain Saca (1777 m) at 1190 m altitude. This depressionary geological sinking and its unequal tectonic compartmentalization, lithologic diversity (sands, sandy clay, pebbles, marls and tuffs) of sedimentary deposits, as well as their dimensions and tectonization, determined two principal attributes of these two rivers, their waterbeds parallelism and north-east to south-west prevailing direction, impinge with an influential impact on the zonation of the lotic ecosystems of interest (Badea et al. 1983).

This researched unit is disjoined unevenly into two major physiographic zones: the smaller mountain high-elevation part in the east (between Târnava River springs and Praid/Brădeşti localities sector), and the larger Târnavelor Plateau in the central and western, lower-elevation part (between Praid/Brădeşti and the junction with Mureş River).

Precipitation and the underground water provide a rather stable multi-annual average water flow, Târnava River discharging into the Mureş River in the proximity of Mihalț locality, with a multi-annual water discharge of around 25 m^3/s, and about 20 kg/s alluvial suspensions discharge. The riverbed inclination is at least in the middle and lower part reduced. Both Târnava Mare and Târnava Mică rivers are meandering type streams transversing the Târnava Plateau, excluding the anthropogenically altered lotic sectors (Badea et al. 1983).

The geological sinking of this depression area and its unequal tectonic compartmentalization, lythological diversity (pebbles, sands, sandy clay and fewer marls and tuffs) of sedimentary deposits, as well as their thickness and tectonization, have determined two main characteristics of these two rivers, their valleys parallelism and their north-east to south-west general orientation, likewise the neighbouring important rivers: the Mureş, Hârtibaciu and Olt, characteristics with a substantial potential primary impact on the studied lotic ecosystems zonation.

The rivers and streams vary among cool, clear, and woody upstream basins with volcanic substratum and steep slopes in the upper areas, through transitional coarse substratum in the Sub-Carpathian zone, to lukewarm, slow-flowing, meandering, and fewer or unforested river sectors banks with low slope inclination and sandy-silty substrata in Târnavelor Plateau area.

In Târnava Mare and Târnava Mică basins there prevails very similar land use, forestry/small-scale localities typical for the highland zones and agriculture/industry/moderate sized settlements, typical in over a third of the basins' (lower) zones.

In the uppermost region of Târnava Mare River the hydrological characteristics are damaged by mismanagement of the Zetea Dam Lake and by different hydrotechnical works (river banks modification and embankment, meanders cut off, marshes and floodplain drainage, agriculture, industry, urban and rural wastewater discharges) affecting the hydrological characteristics in the lower basins sectors.

The scale of these rivers, their natural significance, and destructive categories of human activities, justify an ecological study in the area (Tufescu 1966; Roşu 1980; Badea et al. 1983; Posea et al. 1982; Curtean-Bănăduc et al. 2001; Bănăduc 2005).

Data revealed in this work summarize the outputs of extensive studies in the reference period 2000–2015. The diversity of fish communities (Bănăduc 2005) and of the benthic macroinvertebrate communities (Curtean-Bănăduc 2005a, b; Robert and Curtean-Bănăduc 2005) was assessed in correlation with biotope characteristics (slope, multiannual average flow, riverbed width, depth, substratum type, presence of pools, riffles, runs and bends, channel modification, chemical characteristics of the water) (Curtean-Bănăduc 2005a, 2015). An inventory of the main human pressures was created, and their impact on lotic type ecosystems in the reference area was assessed.

To examine the structure of communities of benthic macroinvertebrates and fish correlated with biotope factors, 24 sectors along the Târnave rivers were studied (Fig. 3), selected according to the characteristics of the morphological characteristics of the minor and major riverbeds, to the main confluences and the types and degrees of anthropogenic pressures. Some southern Târnava Mare River tributaries—Şaeş, Stejăreni, Criş, Mălâncrav, Laslea and Valchid—were also analyzed (Fig. 3).

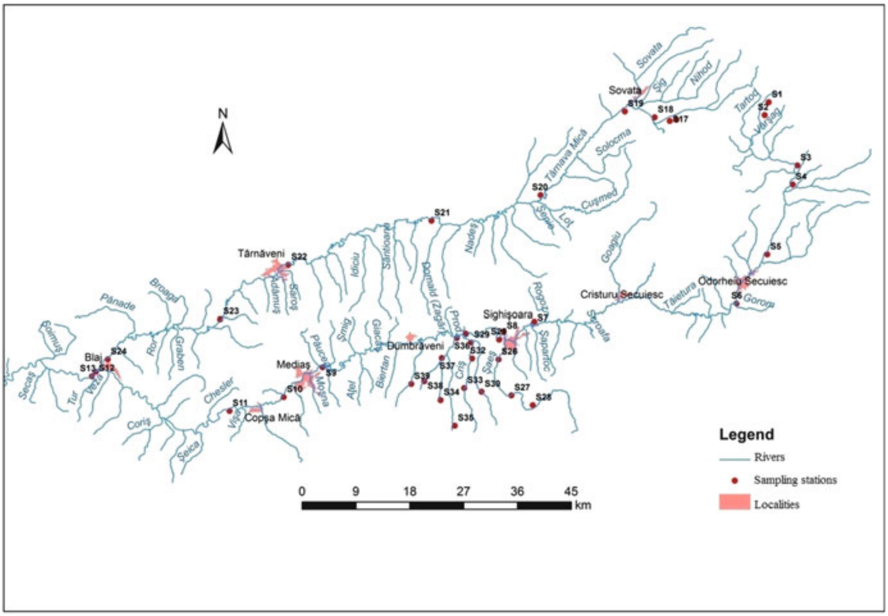

Fig. 3 Sampling area

1 Human Impact

The river basins have been settled throughout human history and have had a major relevance for the economic development and much else. In the twentieth century, these areas also acquired an accepted "ecological" value (Cameron and Matless 2011) and well-confirmed image (O'Connor 2004). The second largest European waterway, the Danube River, comprises one of the most natural, historical, cultural and economically important of such basins (Bănăduc et al. 2016).

The natural and cultural heritages are more and more endangered both by natural and human threats (Hapciuc et al. 2016). The river basins are clearly not exempt in this respect, and Târnava River basin is an eloquent example (Curtean-Bănăduc et al. 2005).

During the first Stone Age periods, the Paleolithic and Mesolithic, the economy was based on gathering, fishing, hunting and a timid beginning of plant cultivation; humans used only several rudimentary tools made of wood, bone and stone so their influence in the Tarnave watershed was negligible in time but their integrated communion with nature remained at a level never equalled since. During the Neolithic era, the first incipient expansion of clearing and plant cultivation, animal domestication and husbandry, as well as the occurrence of stable human settlements (dwellings made of twigs and adobe, some with platforms and/or rudimentary elements of earthen and/or log fortifications), triggers practically "a first stage of man's breaking up with nature". Primitive man is no longer constantly on the move and on the lookout for resources, content with what he can procure to alleviate his necessities, but begins to transform the environment he lives in to accommodate his needs. This is "the moment" when a first influence of man on the environment becomes observable, the resulting effects remaining though insignificant in terms of timescale. More well-known traces of human civilization from the Stone Age in the Târnave watershed have been discovered in Odorheiu Secuiesc, Mugeni—Porumbeni, Cristuru Secuiesc, Mediaş, Bahnea—Bernadea, etc. (Curtean-Bănăduc et al. 2001).

Today the following categories of human impact are present in the Târnava Watershed: hydrotechnical works, insufficiently treated/cleaned sewage, river substratum mineral exploitation/over-exploitation, manure leakage, artificial standing water, industry, river embankment, deforestation, pouching, etc., the first three of these inducing the highest impact on the lotic systems.

2 Hydrotechnical Works

In the upper Târnava Mare River and Târnava Mică River, and their tributaries are numerous small- and medium-sized dams with artificial standing water upstream of them; the presence of uncharacteristic fish species in this upper area such as chub (*Squalius cephalus*) and gudgeon (*Gobio gobio*), reveals some geomorphological and hydrological anthropogenically induced changes (Bănăduc 2005). Such small/medium-sized concrete dams are also present in almost all the important downstream riverine cities.

The biggest dam and dam lake of the basin is in the Târnava Mare River Zetea locality upstream sector (between S3 and S4, Fig. 3). These closely adjacent dam and lake have significantly fragmented the lotic habitats, and decreased the quality of the lotic communities as a "crèche" for long-lasting fresh generations of *Squalius cephalus* and *Gobio gobio* eurivalent fish species, decreasing the biotic integrity and creating an abnormal fish zone change from the more upper altitudinal speaking trout zone to the lower Balkan barbel zone (Bănăduc 2005).

The macroinvertebrates are less affected than the fish from all these hydrotechnical works, such as molluscs (Sîrbu 2005; Gheoca 2005) plecopterans, ephemeropterans, trichopterans and chironomids (Curtean-Bănăduc 2005a, b; Robert and Curetan-Bănăduc 2005). The diversity of plecopterans decreases downstream of the dam (S4) in comparison with the upstream studied river sector (S3), from 6 to 4 species. The plecopterans weight in the studied macroinvertebrate communities do not fluctuate considerably between the two studied areas (1.58% upstream the lake—S3, 1.65% downstream the dam—S4).

In the Târnava Mare River, arround 1 km downstream of the Zetea Lake, a large number of planktonic organisms—copepods, cladocerans, and ostracods were found these organisms are not characteristic for the river sectors with a mountainous aspect like this (571 m altitude, 6‰ average slope) and probably drifted from the upstream dam lake (Curtean-Bănăduc 2005a).

3 Nonpoint and Point Waste Water Sources

The household sewage uninterrupted discharges happen in many sectors of the researched basin, being an evident human impact type in the researched area. All the human settlements are affected by a shortage of initiative, financial support, knowhow and/or decisional will in this general context, proper efforts being mandatory to clean the wastewater which comes from residential different local sources, which can contain including body wastes containing intestinal disease organisms. The nonpoint sewage runoffs effects are combined with the agriculture and industrial sewage runoffs. The wastewater produced by industry is also discharged in the research area; the processed wastewater can include acids, plating metals and different other substances which are toxic for aquatic systems. The pollutants of the research area replacement is not enough after a long term pollution history in the researched area, the aquatic biocoenosis structure revealing the need for ecological reconstructions.

Aquatic communities modifications, determined by the lotic sectors water quality decreasing due to the waste water presence almost everywhere exist starting with the first upstream locality, e.g. Vârşag locality on the upper Târnava Mare River, Praid locality on the upper Târnava Mică River (Curtean-Bănăduc 2005a), and on some tributaries such as Valchid locality on the upper Valchid Stream, Nou Săsesc locality on the upper Laslea Stream, Mălâncrav locality on the upper Mălâncrav Stream, Criş locality on the upper Criş Stream, Stejăreni locality upstream of the Stejăreni Stream, Daia locality on the upper Şaeş Stream, etc. (Curtean-Bănăduc and Bănăduc 2007).

In the reference area, the Târnava Mare sector, between the locality of Odorheiu Secuiesc and the confluence with Târnava Mică (S6–S12, 195 km) is the most affected by pollution, along this sector being recorded various successive pollutions, the most significant from a quantitative point of view being the organic one, due to discharges of domestic waste waters, animal husbandry waste waters, food industry and light industry waste waters. The Plecopterans, a taxa which is sensitive to organic pollution, was found in the benthic macroinvertebrates communities only upstream of this sector, in the upper river course (S1–S4) (Curtean-Bănăduc 2005b, 2015). The sector between 182 and 187 km (4 km upstream and 3 km downstream of Copşa Mică), is severely affected by historical heavy metals pollution (Pb, Zn, Cu, Cd) generated by the industrial park of Copşa Mică and adding to the organic pollution (Curtean-Bănăduc 2005a). On the river sector downstream of Copşa Mică (S11) the benthic macroinvertebrates association has the lowest density recorded for the entire river, and the only fish species captured here was *Barbus meridionalis*, the collected individuals coming, most probably, from the upstream sectors, so that we cannot speak of a stable population in the area.

It is certainly a fact that the self-cleaning capacity of this basin's rivers and streams is unable to rebalance 100% the human impact in this respect, as far as the confluence of Târnava River with the Mureş River.

4 Riverbed Mineral Exploitation

In the Târnava River basin riverbed minerals exploitation negative effects are significant. Such exploitations start beginning with the alpine lotic sectors of the main localities like Zetea (Târnava Mare River) and Praid (Târnava Mică River) till the confluence of the Târnava River with Mureş River. It is obvious that this human activity it is not enough controlled. Almost all the riverine localities of the studied watershed, requires bigger and bigger quantities of row materials for constructions, and the river ecosystems suffer significantly. The too often missing of the proper knowhow and the avoidance of the legal regulations are the main identified problems in the researched area. Involving proper qualified personnel in the teams which are working in this activities management and control, their continuous support by the involved state agencies and the enforcement of environmental laws are necessary.

Structural and functional modifications in structure of aquatic communities, induced by the lotic sectors water quality decreasing due to riverbed mineral over-exploitation appear everywhere such exploitation exists, because these are not correlated with the natural capacity of the lotic systems to recover the sediments. A few hotspots in this respect in which this activity has a negative influence upon different taxa were registered in the proximity of the following localities: Zetea, Sighişoara, Copşa Mică, Târnăveni, Micăsasa, Blaj, Praid, Sovata, Târnăveni, Mihalţ, etc. This type of human pressure start lately to move from the main studied rivers to their tributaries, small stream which are very easily to be destroyed such as Valchid, Laslea, Mălâncrav, Criş, Stejăreni, Şaeş, etc. (Curtean-Bănăduc 2005a). A mixture of taxa responds through structure and abundance changes in a negative way, revealing the connotation of this human impact category in the studied area: plecopterans, ephemeropterans, trichopterans, molluscs, amphibians and fish (Sîrbu 2005; Gheoca 2005; Curtean-Bănăduc 2005b, 2015; Robert and Curtean-Bănăduc 2005; Bănăduc 2005; Hartel and Demeter 2005).

5 Overall Human Impact on the Basin Aquatic and Semi-aquatic Biodiversity

The major human threats and pressures which were identified in the studied area of Târnava Mare River are: industry, urban sewage, households' sewage, hydrotechnical works, household waste, embankment, manure, intensive agriculture, ballast exploitation and artificial standing water.

All these human pressures have had at least a medium term significant variable impact on the aquatic and semi-aquatic habitats of Târnava Mare River, impact absence and/or presence being revealed based on a series of indicator taxa such as: Plecoptera, Ephemeroptera, Trichoptera, fish species—*Squalius cephalus, Gobio gobio, Salmo trutta* and *Cottus gobio*. These taxa and not only should be included in developing an integrated monitoring system for this river.

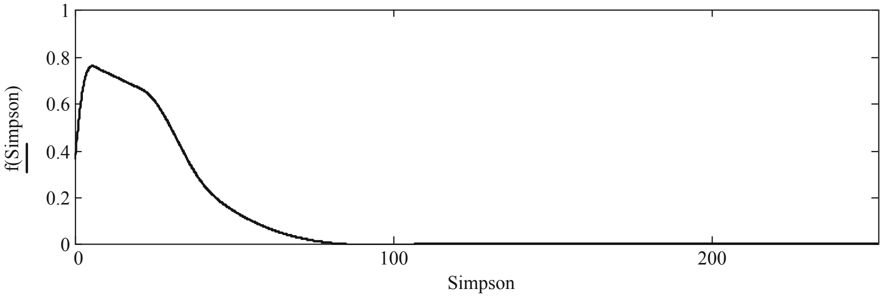

Fig. 4 The Gini-Simpson index for the Plecoptera larvae communities' dynamic, along (1–249 km) the Târnava Mare and Târnava rivers (cubic spline interpolation)

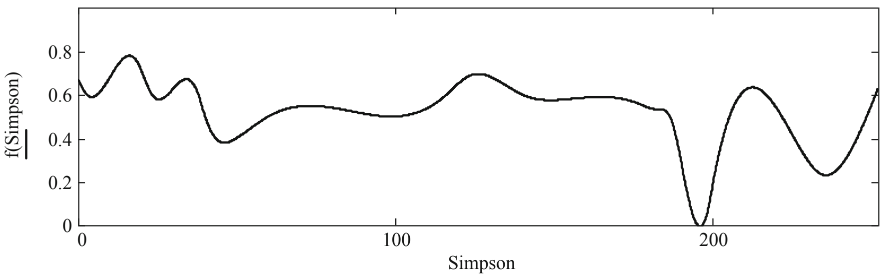

Fig. 5 The Gini-Simpson index for the Ephemeroptera larvae communities' dynamic, along (1–249 km) the Târnava Mare and Târnava rivers (cubic spline interpolation)

In the Târnava Mare River case, plecopterans are characterised by the highest specific diversity around 1 km upstream the Zetea Lake (Fig. 4). In the case of the Târnava Mică River, the highest plecopterans specific diversity (six species) was located in the sector upstream Praid, about 17 km downstream the springs. In these studied sectors, the human impact on the river is insignificant and the biotope characteristics favored the plecopterans. The plecopterans vanish from the benthic communities of Târnava Mare River downstream the Odorheiul Secuiesc locality, due to water pollution with organic substances. Also, on Târnava Mică River have not been fund plecopterans downstream the Praid locality (Curtean-Bănăduc 2005b, 2015).

The ephemeropterans present a high diversity and density in the Târnava Mare and Târnava Mică Rivers headwaters. The ephemeropterans are missing in the river sector of the Copşa Mică locality, severely affected by industrial pollution (Fig. 5) (Curtean-Bănăduc 2015).

In the case of Târnava Mare, caddisflies present the greatest diversity in the area laid 1 km downstream Zetea dam lake (Fig. 6). As regards Târnava Mică, the highest diversity of caddisflies occurs 0.5 km upstream Praid, at about 17 km downstream of the springs (Fig. 7). In these areas, the anthropic impact on the river is insignificant,

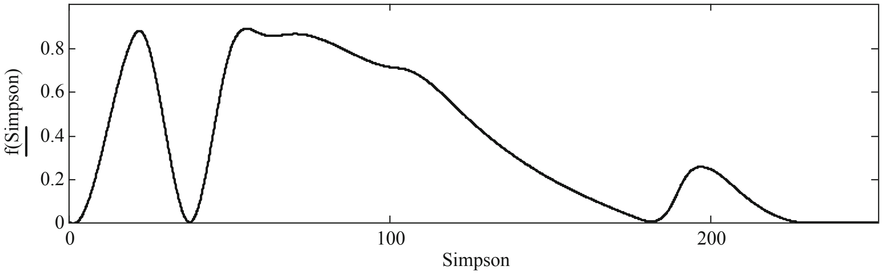

Fig. 6 The Gini-Simpson index for the Trichoptera larvae communities' dynamic, along (1–249 km) the Târnava Mare and Târnava rivers (cubic spline interpolation) (Curtean-Bănăduc and Olosutean 2013)

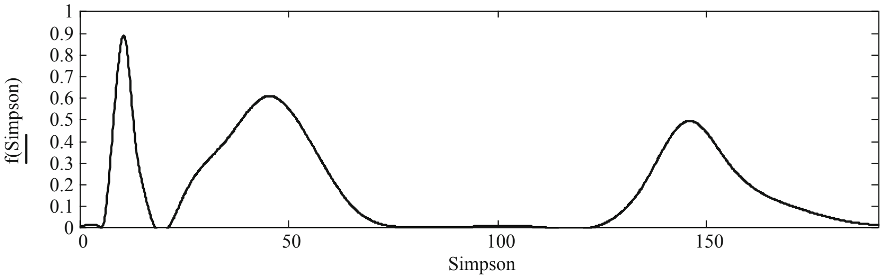

Fig. 7 The Gini-Simpson index for the Trichoptera larvae communities' dynamic, along (1–191 km) the Târnava Mică River (cubic spline interpolation) (Curtean-Bănăduc and Olosutean 2013)

and the biotope characteristics favoure the development of several species of caddisflies.

The longitudinal dynamic of caddisfly larval communities structure in the two studied streams shows that in the upper courses these communities present a large specific diversity, and characteristic species of these communities are litho-reo-oxyphilous, the communities of the middle and lower flows are characterized by a low specific diversity, the numerically prevalent species being the eurivalente ones.

Comparatively analyzing the diversity of caddisflies communities of the rivers Târnava Mare and Târnava Mică, basing on Jost gamma diversity index, we remarked that the caddisflies exhibit the greatest diversity in Târnava Mare (γ Târnava Mare = 9.622, γ Târnava Mică = 8.480). The values of Jost beta biodiversity index values show that the structural variability of the caddisfly communities of the River Târnava Mare ($\beta = 2703$) is higher than that of the caddisfly communities of the River Târnava Mică ($\beta = 1973$).

Based on the variations of trichopterans communities, it is obvious (Figs. 6 and 7) that the Zetea Dam Lake and the localities Odorheiu Secuiesc, Mediaş, Copşa Mică and Blaj sectors on the Târnava Mare and Târnava rivers, and Praid, Târnăveni, and

Blaj sectors on the Târnava Mică River are under a constant and significant human impact pressure.

The rivers Şaeş, Stejăreni, Criş, Mlâncrav, Laslea and Valchid, southern tributaries of Târnava Mare River shelter communities of benthic macroinvertebrates and fish with a structure characteristic for small meandering watercourses, with low slope and predominant sedimentary substrate, and water rich in nutrients, with banks rich in hygrophile vegetation. In all these tributaries are relatively numerous fish species protected at national and international level such as: *Barbus meridionalis*, *Barbus barbus*, *Chondrostoma nasus*, *Alburnoides bipunctatus*, *Squalius cephalus, Sabanejewia balcanica* and *Alburnus alburnus*. The macroinvertebrates and fish communities structures, in conjunction with the specific local biotope characteristics, reveal the fact that the Stejăreni and Criş valleys present an ecological state close to that of the natural one. Average human impact is present in the Valchid and Mălâncrav valleys, and Şaeş downstream from the Apold locality, which is most affected by human impact.

It should be understand the fact that the spotted threats and pressures effects can be diminished only by collaborating with local community administrations.

6 Management and Conservation Issues, Based on Identifying the Major Contributors to the Târnava Basin Studied Lotic Systems Biodiversity

The aquatic and semi-aquatic biodiversity elements of the Târnava River watershed consist of a notable system in an area where species-rich animal communities have been heavily impacted, remedies to this situation being related to the need for an integrated applied basin management.

From the hydrotechnical works point of view there is a number of solutions which should be used, such as the lotic systems river assimilative capacity recovery, as well as land acquisition and wetland zones rehabilitation, and the hydrotechnical works management planning must rely on the reasonable distribution of water. As long as wetland areas may be devastated and ruined, the human impact can be diminished through rehabilitation, establishment, or improvement of other wetland areas. The protection and restoration of as many as possible typical lotic sectors should be a main activity (Curtean-Bănăduc et al. 2007).

From the point of view of waste water sources management there are some main elements which should be of concern: permanent enforcement of environmental laws, improving the water consumption efficiency, keeping hazardous waste sites isolated, the protected lotic sectors should be large and dense to admit a good river self cleaning capacity, managing strategically the river biocoenosis as biological capital (Curtean-Bănăduc et al. 2007).

In the circumstances of mineral over-exploitation of the riverbeds, the following elements are necessary for a good lotic systems management: wise gravel mining, based on the riverbed natural regeneration estimate, creation of policies for cultivation of permanent cultures (orchards, vineyards, forests), restoration of riverine forest vegetation, rotating non aggressive sylviculture and grazing activities, in relation to the seasonal conditions, especially in the proximity of the lotic systems (Curtean-Bănăduc et al. 2007).

As an comprehensive conclusion, based on the identified human impact negative effects upon the studied lotic ecosystems elements of the Târnava River basin, it is indisputable that an practical basin integrated management can be only a main goal for the future and not a reality of the present.

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