Momir Paunović

Environmental Aspects of Floods

The objective of this document is to shortly present the current up-to-date knowledge in relation to floods and environment and thus provide basic information for course attendants on this complex issue.

The course covers general considerations on the topic, discussion on the collection of data on the influence of flooding to the environment, relation of flooding events and aquatic and riparian biota, relation of flooding and pollution and genetoxicological aspect of floods. Basic terms related to the environment are considered, as well. Having in mind that we discussed the collection of data on floods, which comprise field work activities, the document comprises the discussion on safety measures on field.

Terms and definitions

Here we explain the meaning of terms used in the text, but also the terms that should be properly understood by the academic community in order to be able to fully address this important topic.

Biota means aquatic organisms in general.

Ecology is a scientific discipline; the term originates from the Greek root Oikos, "at home", and ology, "the study of"; Haeckle (1870): "By ecology we mean the body of knowledge concerning the economy of Nature – the investigation of the total relations of the animal to its inorganic and organic environment;" Andrewartha (1961): "The scientific study of the distribution and abundance of organisms;" Odum (1963): "The structure and function of Nature." Ecology is also a biological discipline which involves the scientific study of mutual relations of organisms and their interactions with the environment. It is extremely important to use this term in its right meaning and not to mix it with "environmentally friendly" meaning. At least in the academic community, we have to be precise and use the right terminology.

Environment – in general, it means: "The surroundings or conditions in which a person, animal, or plant lives or operates." Here, we consider the environment as: "The natural world, as a whole or in a particular geographical area." The term is often wrongly used as synonym, or surrogate for ecology, or vice versa. Thus, it is important to use this term in its right meaning. Repeatedly, you can hear statements such as "ecological products", or "eco-product", which is the wrong use of the term ecology. It simply means that the product is not harmful to the environment, or that it is produced with the best available technology that reduces harmful effects to the environment.

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Ecosystem functioning – is defined as "the joint effects of all processes (fluxes of energy and matter) that sustain an ecosystem" over time and space through biological activities [25].

Ecosystem services – are usually defined as "the benefits that humans receive from nature", our work shows that most services are actually co-produced by a mixture of natural capital and various forms of social, human, financial and technological capital.

Community – here the term is used in sense of biological assemblages.

Flood risk is defined as the combination of the probability of a flood event and of the potential adverse consequences for human health, the environment, cultural heritage and economic activity associated with a flood event [3].

General consideration of the topic

The influence of floods to the environment are diverse and could be generally considered "negative" and harmful (to native ecosystems, ecosystem functioning and native biodiversity, human health and society in general), or natural and "positive" (to ecosystem functioning, native biodiversity) – Figure 1.

Floods are one of the most devastating disasters and they can seriously endanger human life, damage living infrastructure, destroy industrial facilities and agricultural production. Flooding is also connected to the occurrence of different diseases that can often spread rapidly, even becoming an epidemic. Flooding accounts for one-third of natural disasters and affects more people than any other type of disaster [21].

In addition to well-known physical destruction, harmful effects are connected to different other stressors. Interactions of flow regime, including so-called "key hydrological events" (flooding and draughts), and environment (which is also a complex concept in itself) is a complex topic that involves many items that are connected in diverse ways.

Flooding, as a natural event, is an important phenomenon for the normal functioning of aquatic ecosystems and this influence is considered native and "positive".

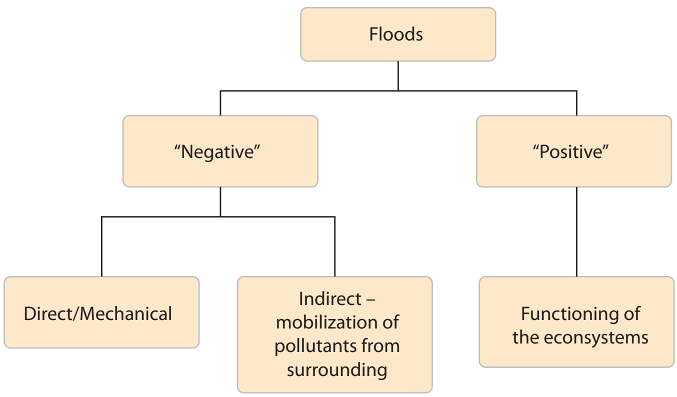

Figure 1. Schematic expression of influence of flooding to aquatic ecosystems (compiled by the author)

The topic of the relations of floods and the environment is even more complex taking into consideration that human influence has altered the interaction between floods and ecosystems. Human activities alter flooding characteristics – change the frequency, intensity and other features of floods. It is well known that even slight modifications to the historic natural flow regime had significant consequences for the aquatic and riparian ecosystems [24].

Our knowledge on the interaction of floods (and generally key hydrological events) and the environment is still limited and we still cannot properly assess the relation of loss and benefit of floods to the e.g. ecosystems [13]. Thus, the assessment of the influence of future extreme hydrological events, like floods and droughts on the environment includes high uncertainty. Traditionally, much attention has been focused on the hazards associated with flooding and floodplains, while less attention has been directed towards presenting the natural, economic and cultural importance of flooding and natural "breathing" of rivers.

The importance of floods to biodiversity

Flooding is a natural event and it plays an important role in maintaining ecosystem functioning and consequently significantly influence native biodiversity [17]. Rivers need floods to create unique habitat and support biological productivity and biodiversity. Dynamic (normal, typical) flow regimes, including flooding events, are important for the "normal" functioning of aquatic and associated ecosystems [15] – riparian forests, wetlands, etc.

Predictable seasonal floods are beneficial for riverine systems and can influence biotic composition, nutrient transport and sediment distribution but unpredictable floods may be disruptive for aquatic organisms [8]. This postulate is the basis of the "flood pulse concept for river–floodplain systems". The natural fluctuation of water level is crucial for the existence of ecosystems and habitats that depends on water. For example, riverine fish need floods for completing their life cycle [19] and many fish species find spawning areas in floodplains. Here we intentionally mention the importance of flooding for fish, since fish are considered a "flag" group for rising public attention. Flooding is also important to all other groups of aquatic organisms. Not only the frequency and intensity of flooding, but also the period of the year when high water levels usually occur is extremely important for aquatic biota, due to the seasonality of many life characteristics and processes in water ecosystems.

Additionally, many aquatic ecosystems have reduced resilience to extreme events including flooding due to diverse human activities (huge urban development, intensive farming on floodplains, river flow disruptions caused by different hydrotechnical constructions and pollution). These activities increase the likelihood that floods become catastrophic events especially from the perspective of "benefits" obtained from ecosystems [22]. The specific effects of flooding on aquatic ecosystems and their services are not well understood, but the importance of flooding for maintaining ecological functions in rivers has been recognised [15].

The negative influence of flooding on the environment

There is general consensus that extreme hydrological events will occur more often and will be more intense. Following the future increase in air temperature, water temperature will most likely increase in the temperate regions. Due to changes to all temperature-dependent chemical and biological processes, as well as increasing flood and drought events, the pressure on water quality in rivers and lakes will increase.

Floods have the potential to cause fatalities, displacement of people and damage to the environment, to severely compromise economic development and to undermine the economic activities of the Community.

Legal framework

There are many directives and strategic documents that regulate the matter of flooding at the EU level. Here, we address two umbrella documents: the Water Framework Directive in 2000 (Directive 2000/60/EC) and the EU Floods Directive (2007/60/EC).

The adoption of the Water Framework Directive in 2000 (Directive 2000/60/EC) set a new framework for the management of European river basins. The main goal of the WFD is to ensure the achieving of the environmental objective of good ecological status/good ecological potential and good chemical status for all water bodies in the European Union (the initial target year was 2015). In that respect, the river basin approach was introduced, requiring Member States to manage water bodies not within administrative/political units but for a river catchment. The environmental objective of the WFD in Art. 4.4, besides the requirements for the achievement of a good status (good ecological potential for artificial and heavily modifies water bodies), also addresses the issue of the preservation of water status in the future. Each river basin district was required to analyse the main pressures and impacts on water bodies, analyse the economic aspect of uses of water bodies and how it affects the natural environment. Programmes of measures have to be developed to ensure that water bodies achieve the environmental objectives. Thus, the WFD should be considered the umbrella document that, between other issues, regulates the relations of flooding and flood management and environment.

The EU Floods Directive (2007/60/EC) establishes a legal framework for the assessment and management of flood risks, and aims at reducing the adverse consequences of floods to human health, the environment, cultural heritage and economic activity.

The EU Floods Directive promotes that it is feasible and desirable to reduce the risk of adverse consequences, especially for human health and life, the environment, cultural heritage, economic activity and infrastructure associated with floods. The purpose of this Directive is to establish a framework for the assessment and management of flood risks, aiming at the reduction of the adverse consequences for human health, the environment, cultural heritage and economic activity associated with floods in the Community.

Flood risk management plans should focus on prevention, protection and preparedness. With a view to giving rivers more space, they should consider where possible the maintenance and/or restoration of floodplains, as well as measures to prevent and reduce damage to human health, the environment, cultural heritage and economic activity. In particular, it seeks to promote the integration into Community policies of a high level of environmental protection in accordance with the principle of sustainable development as laid down in Article 37 of the Charter of Fundamental Rights of the European Union.

Two Directives are interconnected and regulate the relation between flood protection and general environmental objectives established by the WFD. Those documents are reflected in the national legislative of EU member states, but are also incorporated in the regulatory system of many other non EU countries, thus the variety of agreements and initiatives having legal influence beyond the Union. Requirements regulated in the WFD and Floods Directive provide the frame for better organised flood protection that is compliant with environmental protection principles. Good balance between flood protection and environmental protection, as well as careful planning in the future should minimise the influence of flood protection measures on the environment, including mitigation of the negative consequences to biodiversity.

There are a number of reasons why better coordination is required [4]. The integrated and coordinated planning under the WFD and Floods Directive has the potential to identify measures that can deliver on the objectives of both policies. Natural Water Retention Measures are viewed as one of such win–win measures. Those measures can address major causes of not achieving good ecological status, for example through river and floodplain restoration measures that re-establish flows. Natural flow regulation can significantly contribute to a reduction of flood risk.

The effects of floods to aquatic organisms, community and ecosystems

Although many studies have been written, the effects of floods to aquatic organisms are not yet properly addressed. Flooding is a major disturbance that impacts aquatic ecosystems and the ecosystem services that they provide.

There are two general types of influence – mechanical, direct and indirect, through mobilisation of pollutants. In practice, the influence is often mixed, characterised as "multistressor" influence [13].

Direct, mechanical influence of flooding to the environment

Floods mechanically disturb communities, affect the behaviour of organisms, feeding, breeding, etc. There are many research gaps in knowledge on the direct influence of extreme hydrological events to aquatic communities [16]. The same authors concluded that in case of macroinvertebrate and fish communities, it was demonstrated that the abundance, density, richness and diversity experienced statistically significant decreases following extreme events.

There are many separate conclusions about the direct influence of flooding to the particular aquatic communities. Thus, [20] discussed the issue of direct effects of flooding on the fish community. During flooding and high water levels in 2014, pelagic fish species were sampled in greater proportion than at lower water levels in 2015, when benthic fish species were more abundant. The pelagic fish species are more resistant to the stressful effect of flooding than benthic species [20].

Influence through mobilised pollutants and multiple stressors – indirect influence

The other aspect, the effect of mobilised pollutants on aquatic biota during floods, especially in the case of large rivers, is still not properly addressed and remains an open issue. Pollutants in river water and river bed sediments, in particular in highly urbanised or industrialised regions, are still a concern in Europe. During the flooding event, water mobilises the bottom sediment and material from the flooded riparian ground and with this material different pollutants are mobilised, which is clearly illustrated at Figures 2 and 3. During the "regular" (e.g. mean water flow/level) water level, rivers carry a certain amount of sediment (Figure 2), while during flooding (Figure 3) the amount of mobilised sediment in water is considerably higher, which is visible based on lower transparency and higher turbidity. Urban pollutants such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and heavy metals may enter the rivers untreated via stormwater sewers or combined sewer overflows during intense rain events [13] [18].

Figure 2. River during "typical" medium flow. Photo – Paunović, Momir – the Sava River, upper stretch in Slovenia, 2015; Collection of the Institute for Biological Research "Siniša Stanković", National Institute of the Republic of Serbia, University of Belgrade

Suspended sediments represent a means of transport for particle related pollutants within river reaches and may represent a suitable proxy for average pollutant concentration estimation in a river reach or catchment [18]. Floods play an important role in the transport of pollutants associated with particulate matter. Generally, concentrations of suspended particulate matter and pollutant contents increase with increasing discharge, particularly in the early stage of floods. Based on our study on mussels, aquatic worms and two fish species, flooding had diverse effects on the level of DNA damage. DNA damage in the blood cells of fish specimens increased in summer 2014, one month after the flooding event [9].

The surface water quality at any given moment reflects the impact of both anthropogenic and natural pollution. Besides, extreme hydrological events which are related to a particular season, such as water scarcity and flooding, may further impair the already vulnerable state of freshwater bodies [1] [9].

It is proven that pollution related to flooding depends on many characteristics of the particular region, river type, historical pollution, distribution of point sources of pollution, etc. [18].

Recently, we worked intensively on genotoxical studies on the influence of flooding to aquatic biota [2] [1] [9].

Monitoring of the surface water quality based solely on the analysis of a limited number of xenobiotics cannot be considered reliable due to the presence of a large number of pollutants and lack of knowledge on their role in the environment. Generally, a mixture of different compounds (often in low concentrations) is the main reason for many harmful effects in aquatic biota [13]. In addition to the toxic influence, these agents can exert genotoxic effects, inducing damage in the DNA molecule, which, if not repaired, could lead to mutations and alterations in cells, tissues, organism of the whole population and the ecosystem. Biomarkers attract increasing attention in environmental studies, as a tool for detection of exposure and effects of pollution [2]. When examining surface water quality in situ approach and the use of aquatic biota are particularly valuable, since they provide a realistic insight into the consequences of exposure and bioavailability of a number of xenobiotics [2]. Fish may be exposed to harmful substances through water, sediment and food.

Figure 3. River during flooding. Paunović, Momir – the Sava River, upper stretch in Slovenia, 2014; Collection of the Institute for Biological Research "Siniša Stanković", National Institute of the Republic of Serbia, University of Belgrade

The level of DNA damage in specimens of mussels, fish and worms collected from the site situated on the Sava River was investigated in respect to the flooding event [1]. The selected site was found to be under the impact of two major sources of pollution: the coal processing power plant, with related fly ash disposal fields, and the wastewaters originating from the town Obrenovac. Extreme floods in May 2014 resulted in the evacuation of the entire town of Obrenovac, which resulted in the decrease of the amount and discharge rate of urban wastewaters. This was especially evident by the sudden decrease in the concentration of all indicators of faecal pollution. The results of correlation analyses indicated a negative correlation between the water level and faecal indicators, but on the other hand, a positive correlation was detected between the water level and concentrations of Ni, Cd, Co, Mn and Pb. In May and June 2014, with the peak of the flood wave, the highest concentrations of Mn, Pb, Cd, Co, As and B were recorded. It could be assumed that flooding of the fly ash disposal field and its intensive rinsing by rainfall could be the reason for increased concentrations of metals and metalloids and observed correlations with water level [1].

As a continuation of the study of [1], effects of water level fluctuation and related pollution to fish have been investigated by [9]. Authors applied the alkaline comet assay and histopathological alterations (biomarker of effect), as well as concentrations of metals and metalloids in gills, liver and muscle of selected fish species – freshwater bream Abramis brama (Linnaeus, 1758) to determine relations. Sampling of fish tissues was performed in 2014, during winter (January and February), spring (March and early June) and summer (late June, July and August). Significant seasonal difference in DNA damage was observed in analysed tissues. During spring and summer, the level of DNA damage in gills was significantly higher when compared to the liver. Histopathological analyses showed higher frequency of alterations in gills during spring and in liver during summer, but without a significant seasonal difference. Gills had the highest concentration of metals and metalloids during the spring and summer, and liver during winter. Muscle was the least affected tissue during all three seasons. This study highlighted the importance of the multiple biomarker approach and the use of different fish tissues in assessment of surface water pollution.

The conclusions on influence of pollutants carried along the river and water level change, including extreme events, could be drawn based on the investigation of heavy metals in riparian soil. Thus, [14] worked on the assessment the spatial distribution of arsenic and heavy metals (Cd, Cr, Cu Hg, Ni, Pb and Zn) in a riparian area influenced by periodical flooding along a considerable stretch of the Danube River (Figure 4).

This survey comprised analyses of soil and plant samples collected during the international Joint Danube Survey 3 expedition [10] from 43 sites along 2,386 km of the Danube River. The study revealed a significant correlation between the concentrations of analysed trace elements and three datasets (river sediment, riparian soil and riparian vegetation), which point to a close relationship between riparian wetland areas and adjacent waterways.

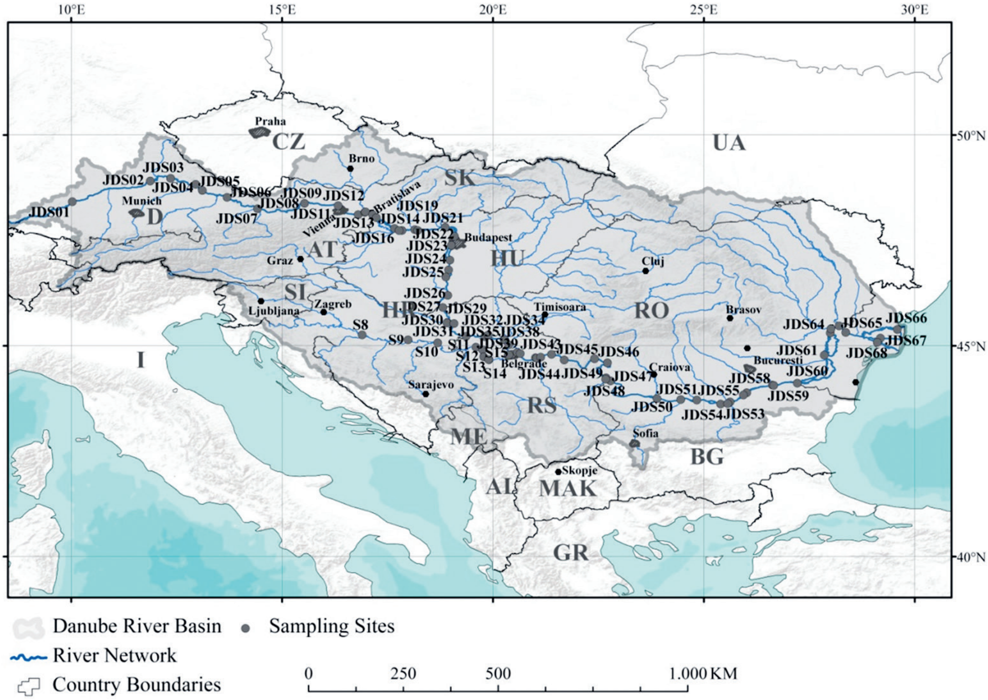

Figure 4. The area covered by the Joint Danube Survey. Paunović Momir – prepared for this publication

This is related to the presence of naturally occurring elements found in metal ore deposits in the Danube River Basin, and anthropogenic metals released by mining and processing of metal ores, industrial facilities and other anthropogenic sources/activities. In general, elevated levels of trace metals were characteristic for the Middle and Lower Danube stretches, with Cd, Cr, Cu, Hg and Ni measured at sites along the Middle Danube sector (in Hungary and Serbia), whereas the Lower Danube (Romanian and Bulgarian) sector was particularly polluted with Pb and As. Our findings point to the necessity of further analyses of the physical and chemical characteristics of the soil and metal accumulation patterns in plant tissues. The obvious correlation between the metal content in the sediment and soil as compared to the correlation between the two datasets and measured metal contents in plant tissue shows that river sediments and riparian soils are influenced by similar environmental factors, whereas the distribution and accumulation of the same elements in different plant species is more complex and species-specific.

Riparian zones are unique and dynamic systems proportional to the main water body size and site topography, which can play a key role in the functioning of an aquatic ecosystem, affecting its chemical, physical and biological processes. Vegetated riverine riparian areas influence the chemical loads from diffuse industrial and agricultural sources, and reduce in-river pollution during floods, with the riparian soil acting as an important sink for pollutants, especially heavy metals [14].

Anthropogenic heavy metals are usually deposited in top soil, therefore riparian soil is a complex and dynamic component and an excellent medium for monitoring heavy metal pollution.

The influence of flooding to ecosystem services

As previously emphasised, because of their dramatic influence on human society, the effects of flooding on aquatic ecosystems are often viewed as negative; however, this is not always the case. Flooding can also provide considerable benefits, including creating conditions for normal ecosystem functioning, providing necessary water for wetlands, rising fertility of soil, recharging groundwater, increasing fish production, etc. [8]. Since the effects of flooding on aquatic ecosystems can be both negative and positive, the assessment of influence of flooding to ecosystem services should also include the study of a mix of negative and positive outcomes [23].

Flood events could be characterised based on magnitude, frequency, duration and volume and these characteristics are important for determining the effects of floods on both aquatic ecosystems and the people who benefit from them. For example, flood magnitude can determine the amount of groundwater recharge or the extent of home and infrastructure damage during flooding. Flood magnitude is only one aspect of predicting flood impacts on aquatic ecosystems and ecosystem services. Ecosystem conditions prior to flooding are potentially equally as important as flood characteristics for determining ecosystem response to a flood event [22].

[22] analysed the effects of flooding to the following ecosystem services addressed by the Millennium Ecosystem Assessment framework [11]: 1. Supporting services (primary production, soil formation); 2. Regulating services (water regulation, water quality, disease regulation, climate regulation); 3. Provisioning services (drinking water, food supply); and 4. Cultural services (aesthetic value, recreation and tourism). Authors find out that:

- the influence of flooding on ecosystem services depends on the flood size and service type
- extreme floods are more likely to be associated with a decline in ecosystem services
- small floods could provoke the decline of ecosystem services, but they also enhance many ecosystem services
- although the trends in ecosystem service availability following flooding were detected, many services responded in complicated ways
- the ratio of gains and losses of ecosystem services related to flooding depends on initial aquatic ecosystem conditions
- the ratio of gains and losses of ecosystem services related to flooding depends on the time of the year

Flood protection strategies should take into the consideration basic requirements that provide normal functioning of aquatic ecosystems. Aquatic ecosystems require flood protection strategies designed to dampen the undesired effects of extreme floods and enhance smaller beneficial floods to maximise ecosystem service provision [22].

The effects of flood protection measures on the environment

Flood protection measures are found to be one of the significant triggers that negatively influence the environment. Technical constructions built for flood protection may disrupt lateral and longitudinal connectivity of river systems, change basic characteristics of natural habitats (including those that depend on water), influence the hydrological character and sediment transport, etc.

In case of the Danube River Basin, a large number of surface water bodies are failing good ecological status, largely due to pressures altering hydrological and morphological conditions and interrupting river continuity, which subsequently impact the aquatic fauna and flora [6]. Structural flood protection measures were identified to be one of the key drivers causing the failure of good ecological status/good ecological potential in river water bodies and new projects impacting water bodies are expected in the Danube River Basin by 2021 [7] [26]. The drivers causing hydromorphological alterations are in particular water supply, navigation (e.g. channelisation to improve ship ways), hydropower (e.g. dams interrupting river connectivity, ponding of rivers, changing flow regime in case of water abstraction or hydropeaking) and flood protection measures changing bed and bank structures. For example, the main key driving forces causing continuity interruption are hydropower generation (50%), flood protection (18%) and water supply (12%) [6]. The impacts of these activities on surface water bodies resulted in the designation of many European rivers as heavily modified according to Art. 4(3) WFD. Heavily modified water bodies (HMWBs) are considered being significantly changed in hydromorphological character due to specific uses.

Flood protection measures can cause a change in groundwater level which may threaten lowland forests, that are among the most complex, dense species-rich ecosystems, but also globally endangered ones.

The WFD include measures to ensure that the hydromorphological conditions provide circumstances within water bodies for the achievement of the good ecological status for water bodies, or good ecological potential in the case of artificial and heavily modified water bodies.

Safety measures

For the proper understanding of the influence of flooding to the environment, confident data is needed. Moreover, to increase the certainty of syntheses, large datasets are needed. In order to collect the data, often field activities are required. Collection of the field data always involves specific safety risk. It is specifically true if the field work is realised during floods. Conditions on field are often difficult and require specific skills and attention during the work (Figures 5 and 6).

Figure 5. Field work during floods. Paunović, Momir – the Sava River, upper stretch in Slovenia, 2014; Collection of the Institute for Biological Research "Siniša Stanković", National Institute of the Republic of Serbia, University of Belgrade

Figure 6. Field work during floods. Stefan Anđus – the Sava River, upper stretch in Slovenia, 2014; Collection of the Institute for Biological Research "Siniša Stanković", National Institute of the Republic of Serbia, University of Belgrade

Here we list same basic measures aimed to minimise safety risk during field work:

- never go alone to the field work
- you should always wear life jackets during the work on the river, or nearby the river
- it is desirable to wear a helmet during the field work
- in case of strong water current, use a rope to stay more stable in the water and to be secure
- in case you use a motorboat, be extremely careful in handling the boat, it is of specific importance if the water is not transparent
- it is necessary to provide the possibility of cell phones or radio communication for the field team

Conclusions

It is crucial to gain sound scientific information on interactions of flooding with other stressors in freshwater ecosystems, in order to understand its environmental and socio-economic consequences, and to convey this information to managers, stakeholders and policymakers, in order to minimise impacts, to adapt to oncoming changes, and to improve our management and policies.

The influence of floods to the environment could be generally considered "negative" and harmful or natural and "positive" (to ecosystem functioning and native biodiversity).

As a natural event, regular and seasonal flooding is important for the normal functioning of aquatic ecosystems and this influence is considered native and "positive".

There are two general types of "negative", "harmful" influence – mechanical, direct and indirect, through the mobilisation of pollutants. In practice, the influence is often mixed, characterised as "multistressor" influence.

Floods mechanically disturb communities, affect the behaviour of organisms, feeding, breeding, etc.

The effect of mobilised pollutants on aquatic biota during floods that could be considered an "indirect" influence is a complex topic. It is still an open issue.

The effect of mobilised pollutants could be assessed based on the measurement of selected parameters, or by using biomarkers.

In both cases, either if the measurements of physical and chemical parameters is applied, or if the biomarker approach is used, it is necessary to use the combination of several indicative parameters to be able to properly assess the influence of flooding to the environment.

Multiple biomarker approach and the use of different indicator organisms and tissues in assessment of the influence of pollution to aquatic ecosystems is required in order to gain a confident synthesis.

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