Water for Life:

Research priorities for sustaining freshwater biodiversity

Report of an electronic conference, December 2007

EXECUTIVE SUMMARY

CEH Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

BIOSTRAT
Developing the EU Biodiversity Research Strategy

REPUBLIC OF SLOVENIA

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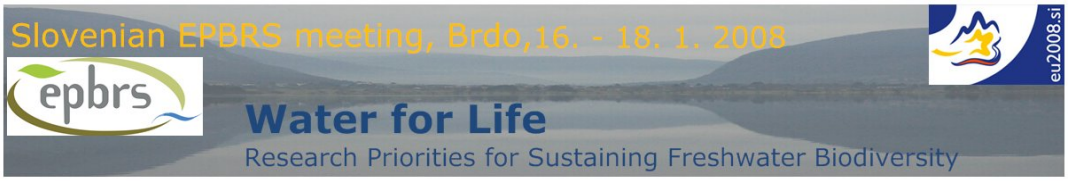
The publication should be cited as follows:
Young, J., Balian, E., Skoberne, P. and Watt, A.D. (Eds.). 2007. Water for life: Research priorities for sustaining freshwater biodiversity. Report of an e-conference.



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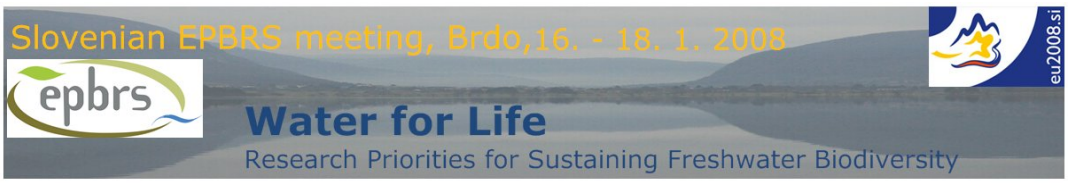
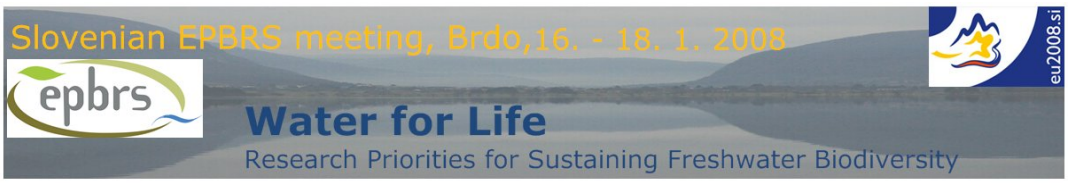


Preface

Research on biodiversity is essential to help the European Union and EU Member States to implement the Convention on Biological Diversity as well as reach the target of halting the loss of biodiversity in Europe by 2010.

The need for co-ordination between researchers, the policy-makers that need research results and the organisations that fund research is reflected in the aims of the "European Platform for Biodiversity Research Strategy" (EPBRS), a forum of scientists and policy makers representing the EU countries, whose aims are to promote discussion of EU biodiversity research strategies and priorities, to exchange information on national biodiversity activities and to disseminate current best practices and information regarding the scientific understanding of biodiversity conservation.

This is a report of the E-Conference entitled "Water for Life: Research priorities for sustaining freshwater biodiversity" preceding the EPBRS meeting to be held under the Slovenian EU presidency in Brdo, Slovenia, from the 16th-18th January 2008.



Introduction

Estelle Balian, E-Conference Chair

As a freshwater ecologist, I feel that freshwater biodiversity has been the "poor child" in conservation and policy initiatives aiming at halting biodiversity loss. It is not a question of competition between the different habitats. Many marine and terrestrial systems are under stress from the same causes that threaten freshwater ecosystems (e.g. pollution and climate change). There is evidence, however, that biodiversity loss is becoming even greater and faster in freshwater systems. Given the increasing pressure on water resources the situation is not likely to improve in the next decades.

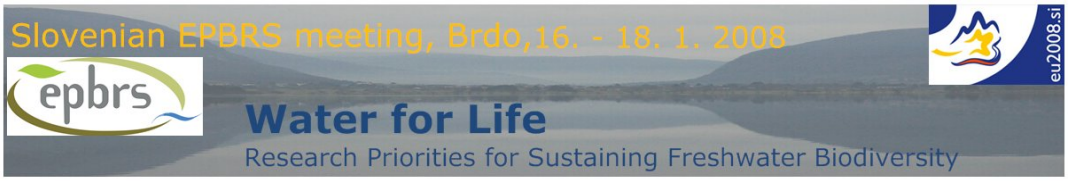
I might be preaching to the converted, but just a few facts on freshwater biodiversity: 9.5% of the described animal species, including almost half of the fish species in the world, are restricted to freshwater habitats, which represent only a very small fraction of the earth surface (0.8%). There are around 130000 described species of freshwater animals and macrophytes, but this is certainly far from the real number and our knowledge of fungal and microbial diversity is even more restricted. In addition, the vulnerability of freshwater biodiversity has a lot to do with its specificities: The supporting resource, water, is itself subject to increasing demands; most freshwater ecosystems can be compared to islands in the sense that they are disconnected from each other, rendering each system more vulnerable to degradation; freshwater ecosystem functioning is a critical component of almost all human activities but is also strongly impacted by these activities as they modify water flow or use the systems for waste disposal. But these are only some aspects related to freshwater biodiversity, and I am sure more issues will be raised during this e-conference.

The objective of this e-conference was to identify gaps in knowledge that currently hinder our efforts to conserve and manage freshwater biodiversity and ecosystems. What are the urgent research needs? How can science effectively contribute to a better understanding of the crisis faced by freshwater biodiversity and to adequate conservation strategies and environmental policies?

We asked scientists to write keynote contributions to stimulate the discussion. These keynote contributions were organised in two sessions:

- The first session on "Research needs for conserving above and below ground freshwater biodiversity" focuses on the status and trends of freshwater biodiversity, including drivers of change and threats: what is the current knowledge, what research is still needed. This session also includes topics related to the sustainability and valuation of goods and services provided by freshwater biodiversity, and to current and emerging conservation strategies.

- The second session on "Research needs for co-ordinated implementation of EU directives and the ecosystem approach in aquatic habitats" addresses the research and management priorities for sustaining freshwater biodiversity with a special focus on the role of European and International water and environmental policies. Some contributions address the implementation of the European Water Framework Directive in relation to freshwater biodiversity, and the international policies related to environmental flows.



Summary of contributions

Juliette Young and Estelle Balian

Summary of contributions: Week 1

In her introduction to the e-conference, Estelle Balian set out the main aims of the e-conference, namely to identify gaps in knowledge and urgent research needs necessary to address the crisis faced by freshwater biodiversity. This first week of the e-conference focussed mainly on "Research needs for conserving above and below ground freshwater biodiversity", i.e. research needs relating to the understanding of status and trends of freshwater biodiversity, including drivers of change and threats.

Bob Naiman started the session off with a very comprehensive contribution, in which he emphasised the need for continued assessment and monitoring of freshwater biodiversity. In his view, this required a coordinated approach in order to ensure that existing and emerging databases on species and distributions be compiled in order to make them interactive, integrated and accessible to all scientists, and for a new generation of taxonomists and ecologists to be trained in the most up-to-date techniques, in order to answer questions related to the distribution, monitoring and environmental requirements of freshwater organisms. In addition, he called for the need to quantify environmental flows (i.e. the quality and quantity of water necessary to protect aquatic ecosystems and their dependent species and processes) in order to ensure ecologically sustainable development of water resources. A first step towards using environmental flows as a way of assessing vulnerability of aquatic ecosystems and ensure their conservation is to estimate water requirements of aquatic ecosystems globally, evaluating their relative merits and providing regionally-relevant, hydro-ecological models. In addition, research needs to focus on identifying hot spots of competition for water will, how they can be minimized, and how they can be integrated with existing social systems. In order to achieve the above, he called for the better integration of social, ecological and hydrological aspects into a transdisciplinary understanding. In addition to these three broad needs, he also called for more research on the following aspects:

- Research to demonstrate a fundamental relation between biodiversity and the maintenance of important ecosystem processes in freshwaters
- Determining if there are important relationships between freshwater biodiversity and health of human and wild organisms
- Developing of realistic scenarios outlining the probable effects of climate changes on freshwater biodiversity and the distribution of species
- Linking conservation theory and social processes to the development of freshwater reserves and refugia in a rapidly changing world – in a manner 'harmonious' with human cultures and demands for water
- Developing a cadre of people capable of viewing the Earth's freshwater system as an integrated system and, at the same time, addressing issues related to political borders.

In response to Bob Naiman's contribution, Ferdinando Boero pointed out the importance of freshwater ecology for marine ecology and vice-versa. He called for the connections between both fields to be considered, in order to avoid replicating efforts.

Following on from Bob Naiman's first point, Hendrik Segers commended current efforts through initiatives like GBIF, FishBase, GENEBANK and the Catalogue of Life to collate existing data on biodiversity. He did, however, emphasise that many such initiatives

had a marine/terrestrial focus, with freshwater often being neglected. He therefore called for the need to develop a freshwater knowledge portal that could link different types of data resources. In order to achieve this, not only would certain technical issues relating to inoperability between databases need to be overcome, but the scientists contributing to such an initiative would need stronger incentives to do so. As an example of a current database on freshwater biodiversity, Jurgen Tack and his colleagues described the VIS database on freshwater fish in Flanders developed by INBO.

Christian Lévêque and Jean-Nicolas Beisel wrote a very interesting contribution on invasive species. They argued that most research on invasive species had so far focussed on the negative impacts of invasion, with studies usually focussing on the impacts of individual species on native species, often overlooking other factors that may be contributing to biodiversity loss. An initial research need would therefore be to determine the relative importance of invasion on the functioning of freshwater ecosystems, as well as better understanding synergies between invasions and other anthropogenic threats. In addition, they called for more research on the possible differences between human-caused invasions and natural biotic interchange, as well as research on the differences between so-called invasive and native species. Finally, they called for more research on the potential positive impacts of species introductions in order to gain a more balanced view of invasions. Following on from this contribution, Svetislav Krstić agreed that more research on these issues was needed, and called for the application of the ecosystem approach in any scientific guidelines on invasive species.

On a more habitat-specific level, Boris Sket described the high biodiversity value of subterranean habitats in countries such as Slovenia, as well as the threats currently facing these habitats. He called for more research on subterranean fauna, in order to implement appropriate conservation measures.

Describing freshwater biodiversity and current threats facing freshwater habitats in Malta, Adriana Vella and her colleagues made a number of recommendations for future directions in freshwater research and policy, including the creation of a register of wetlands cataloguing the location and characteristics of each, the development of predictive population and metapopulation models, and hydrological models for the principal wetland areas of the Maltese Islands to better understand the ecological dynamics within them. Meanwhile, Ivančica Ternjej, Zlatko Mihaljević, Sanja Gottstein and Milorad Mrakovčić called for more research on biodiversity in karstic lakes and rivers, as well as brackish coastal springs and on Adriatic anchialine caves. In addition, they called for research on endemic fish species, including life histories and conservation measures. Finally, Maria José Costa called for more research on freshwater biodiversity in Portugal, specifically the study of biodiversity in high altitude intermittent streams, with special emphasis on the macroinvertebrate community; research on biodiversity of freshwater tidal areas of estuaries; and research on the impact of exotic species on autochthonous freshwater fauna. In terms of more species-specific research, she argued for more research on diadromous fishes, as well as research on the threatened lamprey *Lampetra fluviatilis*, the development of methods to evaluate and increase silver eel (*Anguilla anguilla*) and research on Portuguese populations of the three-spined-stickleback *Gasterosteus gymnurus*.

Summary of contributions: Week 2

Status and trends in freshwater biodiversity:

As a first step to assessing the current state and trends of freshwater biodiversity, Louise Scally and her colleagues highlighted the basic need to inventory and survey freshwater habitats and species. In order to achieve this, a number of contributors (including Irish, Ukrainian and Slovenian scientists) called for the support and development of national taxonomic and systematics expertise and capacity.

Laurence Carvalho and Iain Sime remarked that our understanding of the functional role of freshwater biodiversity needed to be improved. On a similar topic, Louise Scally and colleagues emphasised the need to better understand the relationships between diversity and

ecosystem functioning. Odd Terje Sandlund echoed this in his contribution, in which he stressed that this sort of research should also be carried out in small water bodies that are currently not well protected by the WFD and are disappearing rapidly despite them being common across Europe and potentially important for biodiversity. Carten Neßhöver and Petr Petřík and his colleagues also highlighted the need to undertake comprehensive valuations of the goods and services provided by freshwater ecosystems.

The issue of better understanding long-term changes in biodiversity was discussed in a number of contributions. Laurence Carvalho and Iain Sime stressed the importance of being able to quantify or understand trends from natural variability. In order to do this, they called for a better understanding of the ecological requirements of freshwater biodiversity and the identification of the processes driving current changes, potentially through the analysis of long-term datasets (LTER sites). Ingmar Ott also called for more long-term studies on changes in land use and other human impacts and their impacts on biodiversity and ecosystem functioning. Linked to this point was the issue highlighted by participants including Vladimir Vershinin of developing and maintaining long-term, regular monitoring studies in freshwater ecosystems. This, however, as mentioned by contributors from Ireland, required the urgent filling in of knowledge gaps relating to baseline information, indicators of biodiversity and ecosystem health (also highlighted by Jari Niemelä and his colleagues, as well as Laurence Carvalho and Iain Sime), as well as a better understanding of community dynamics and biogeographic distribution patterns (see contribution by Odd Terje Sandlund and his colleagues).

Rick Battarbee and his colleagues discussed the current merits of palaeoecological methods as a means of reconstructing water quality changes, and called for further development of these methods to better understand current changes in biodiversity and ecosystem functioning. In order to develop these methods, research needs included the continued development of palaeo-databases both for meta and primary data; the identification of availability of existing contemporary data-sets that can be used for congruence analysis; the assessment of the relative usefulness of different groups that leave high quality remains as indicators of biodiversity change; the assessment of how representative surface sediment records are of contemporary populations and distributions and finally the application and testing of methodologies to address questions relevant to biodiversity and ecosystem functioning rather than water quality on a case study basis.

In terms of adapting to environmental change, a key need for the conservation of freshwater biodiversity was highlighted by Laurence Carvalho and Iain Sime as being the improved understanding of the factors that alter a freshwater site's resilience to environmental change.

Threats to freshwater biodiversity:

A number of contributors (e.g. from Finland, the Czech Republic and Hungary) highlighted that little was known on the impacts of climate change on freshwater species, or on the role of freshwater diversity in the fluxes and storage of both greenhouse gases and plant nutrients (see contribution by Laurence Carvalho and Iain Sime). Mohammed Messouli explored this topic in greater detail in his contribution, in which he called for a better understanding of the role of freshwater biodiversity in earth and climate systems, the impacts of climate change on freshwater biodiversity and human populations, and their interlinkages, feedback mechanisms and cross-scale effects. Although he acknowledged that more research was needed, he also emphasised that we already had a sound basis on which to implement mitigation and adaptation strategies.

Invasive species and their impact on freshwater ecosystems were again discussed, including a contribution by François Bonhomme in response to Christian Lévêque and Jean-Nicolas Beisel's contribution last week. In addition, a number of country perspectives (including Ukraine, Finland, Hungary and Lithuania) mentioned the threat of invasive species and the need to better understand the impacts of such species on native biodiversity. Also on this issue, Louise Scally and colleagues in Ireland called for the development of early warning systems for the identification and detection of non-native species. Philip Boon explored the

topic of invasive species in the context of the WFD, calling for research to further develop risk assessments for freshwater species known to have invasive potential; more studies on the ecology of individual non-native species, including genetics, reproduction, population growth, competitive ability, and the responses of organisms to abiotic factors; the development of new techniques for survey and monitoring to enable the distribution of key invasive freshwater species to be mapped; studies on the potential effects of climate change on the distribution of non-native species; and finally work on developing new methods of eradication for particular non-native species.

Linking the above two threats was a call from researchers in Norway to examine in more detail the relationship between ecosystem function, invasive species and climate change and the development of predictive models to determine the impact of these trends on ecosystems, taking account of prior knowledge of the state of ecosystems.

With regards to other potential threats on freshwater biodiversity, scientists from Finland highlighted the importance of better understanding the impacts of forestry activities on freshwater ecosystems, especially in countries where forestry plays an important economic role. In Ireland, Ukraine and the Czech Republic, one research priority was felt to be the impact of intensification of agricultural systems, including eutrophication and water pollution, on freshwater habitats and species. Viktor Gasso and his colleagues from Ukraine emphasised the need to better understand the impacts of the fishing industry on freshwater ecosystems. Orieta Hulea highlighted navigation as being a major threat to rivers such as the Danube, and called for research to contribute to identifying the best solutions to balance or mitigate the negative effects of unsustainable navigation plans and projects on the Danube River.

In their contribution, Jayne Brian and John Sumpter emphasised the need to address the cumulative risks arising from interactive effects of multiple stressors on aquatic ecosystems. Focussing specifically on the risks from toxic chemicals, they called for more research to better integrate confounding factors such as temperature, water quality and pH in the risk assessment of chemicals, particularly in the current context of climate change. They recommended that such research should focus on the integrated response to a well-defined group of chemicals (such as endocrine disrupting chemicals), in order to differentiate between the effects of the different types of stressor. The issue of toxicant impact on freshwater ecosystems was also emphasised by Matthias Liess.

Species- and habitat-specific research recommendations:

Hans-Peter Grossart discussed the importance of aquatic microbial diversity, and called for a better assessment of their diversity and dynamics, in particular: the systematic investigation of the bacterial community structure (including the physiological characterization and description of new species and/or clusters); the investigation of seasonal and long-term dynamics of bacterial community structure; the development of detection methods to characterize and quantify key organisms, and techniques to isolate and cultivate these organisms; the study of the ecological role of specific bacterial species or groups through the analysis of molecular, analytical as well limnological data; and the collection and storage of 16S rDNA sequences with high temporal and spatial resolution and further development of microarrays for DNA chip development for each studied system. Odd Terje Sandlund discussed the issue of salmonids in Norway, and mentioned the need to improve the scientific basis for conservation and restoration of salmonid populations in streams by identifying life stage specific physical habitat requirements, determining the impacts of catchment area land use on salmonid habitats and possible lessons to learn for existing restoration efforts.

In Hungary, species and habitat-specific research needs included the need to: develop appropriate methods to sample macroinvertebrates in large river systems; carry out more research on the cyanobacteria and algae of small water bodies, and determine the distribution and population sizes of the may-fly.

Habitat-specific research included:

- Groundwater contamination and possible impacts of these contaminants on biodiversity, ecosystem integrity, and human health in Morocco (Mohammed Messouli);

- Karstic and alluvial groundwater biodiversity in Slovenia (Anton Bracelj);
- Freshwater spring communities, leading to their potential inclusion in Annex I of the Habitats Directive (Jan Jansen).
- High-mountain Alpine lakes (Anton Brancelj)
- Hydrobiological surveys of the sodic-alkaline ponds of the Pannon region (Hungarian contributors)
- Coastal lakes and their communities (Ingmar Ott)
- Hydrographical research, the assessment of water quality in view of new channels being constructed and research on phyto and zooplankton in the fluvio-marine part of the Danube Delta (Christian Kleps).

Research on measures to conserve freshwater biodiversity:

The topic of environmental flows was again discussed in the second week of the -conference, with a couple of contribution focussing exclusively on this topic. David Katz called for a number of research needs in this field, including: the development of a searchable global database on environmental flow prescriptions; comparative work on how environmental flow prescriptions and policies differ across regions, ecosystem types, gradients of water quality, and governance structures, as well as, how policies need to be modified based on whether the goal is conservation or restoration; the evaluation of existing finance mechanisms and the development of new ones; and the monitoring of the effectiveness of environmental flow policies. In addition to these research priorities, Angela Arthington also highlighted the need to conduct research on: the relationships between flow, ecology and environmental goods and services (EGS) in unregulated rivers; the flow-alteration-ecological-EGS response relationships, thresholds and resilience effects in regulated rivers ; the ecological responses and EGS benefits resulting from the implementation of an environmental flow regime; and ecological responses to changes in river flow regimes brought about by the direct and indirect effects of climate change, and their interactions.

In their contribution on research priorities identified for Finnish freshwater communities, Jari Niemelä and his colleagues highlighted the fact that very few protected areas had been established specifically to protect freshwater biodiversity, and little was known on the extent to which existing protected areas also protected freshwater biodiversity, and how effective such protected areas may be in dealing with climate change. Taking the specific example of the Danube Delta Biosphere reserve, Christian Kleps drew attention to the fact that protected needed specific needs related to the need to balance environmental requirements with socio-economic needs of local communities.

Jari Niemelä and his colleagues also called for more research to support the restoration of freshwater ecosystems, a topic mentioned in Vladimir Vershinin's contribution, e.g. understanding the impact of food web structure on the success of restoration activities impacts, understanding the impacts various kinds of restoration operations have on biodiversity. This last point was mentioned in Carsten Neßhöver's contribution in which he emphasised the need to identify nationally important freshwater habitats that could be suitable for restoration.

The Water Framework Directive was discussed in great detail, starting with a contribution by Rui Santos and Paula Antunes, who identified a number of research needs associated with this new water management approach, including long term monitoring of freshwater conditions and biodiversity, establishing the connection with human social systems; the assessment of impacts of pressures in freshwater ecosystems (including the assessment of the resilience and adaptive capacity of freshwater ecosystems to human pressures); the assessment and valuation of ecosystem goods and services; the development of research in constructive stakeholder engagement in planning and management of both natural and modified freshwater ecosystems; and the development of knowledge to support the design and implementation of policy instruments.

Also in relation to the Water Framework Directive, Didier Pont's contribution focussed on the need for the development of a standardised assessment method for water

bodies across Europe. Basing the rest of his contribution on the new European Fish Index (EFI), he called for more research to improve such approaches, including the need for a better description of the responses of species to various types of human pressures in order to improve the efficiency of functional metrics used in multi metric indices; the need to develop empirical models linking the intensity of different pressures, restoration, and ecological status in freshwater habitats; establishing the potential impact of climate change on the baseline used to define reference conditions, as well as the evaluation of the thresholds used as ecological class boundaries; the development of new specific bio-indication tools (which requires the closer collaboration between ecotoxicologists and hydrobiologists); and the development of future bio-indicator tools based on process-based models rather than statistical ones.

Finally, Odd Terje Sandlund stressed that the implementation of the WFD would require the establishment of cost-effective monitoring and classification systems for assessing ecological status. In this respect they identified a number of relevant research topics including the development of biological indicators, the development of methods for defining reference conditions, the harmonization of sampling methods and tools for linking changes in biodiversity to various pressure types and combinations of known and unknown pressures, the development of efficient methodology on zoobenthos in northern/mountain streams where current methods are infeasible without excessive costs and the assessment of how fish community and population status may be better used as indicators of ecosystem quality.

Summary of contributions: Week 3

Mohammed Messouli started off the last week of the e-conference by highlighting the importance of considering the hyporheic zone in studies of stream and river ecosystems and called specifically for interdisciplinary research and environmental management practices to understand, predict and manage processes better at the interface of environmental compartments and well as more research on upscaling spatially and temporally variable processes. Finally he stressed that better two-way communication mechanisms were required between scientists and river managers.

A number of contributions (see full contributions by Alan Hildrew, Jeremy Biggs and Penny Williams, and Antonio Camacho) mentioned the current bias towards the assessment of larger water bodies, and the current lack of consideration of small water bodies under the WFD. They stressed the urgent need to assess the value of biodiversity in these small, more-or-less isolated water bodies such as ponds, small lakes, ditches, especially in view of their important role in catchment processes. In term of specific research needs, Jeremy Biggs and Penny Williams called for research to: improve understanding of the whole network of habitats, both large and small, used by aquatic biota, especially given the added stress of climate change; assess the biodiversity benefits of different agricultural land management techniques, and assess how to apply these measures strategically so that they have greatest value; research to protect these high status sites, focussing on the multi-functional threats they face and the link between catchment management and the biotic response ; understand the multifunctional benefits of waterbodies. In his contribution, Alan Hildrew called for research to determine how effective assessments of in-stream communities are at assessing ecological quality at the whole-catchment scale, including the less well characterised small waterbodies. He also highlighted the potential role of a drying climate on freshwater habitats and called for the assessment of how a drier landscape might depress gene flow and dispersal in aquatic organisms. Finally, in light of previous contributions calling for a web portal with information on freshwater habitats and species, he mentioned the Freshwater Biological Association's recent initiative of developing such a system (www.freshwaterlife.org).

The topic of valuation of goods and services provided by freshwater biodiversity was discussed, starting with a contribution by Jay O'Keeffe, who identified a number of key research questions and priorities in this area, including: determining the relationship between biodiversity and the functioning of freshwater ecosystems on which the provision of goods and services depend; establishing how much of the ecological functions of freshwater

ecosystems are dependent on the natural biodiversity; developing methods for valuing water resources as a whole rather than focussing only components of the system; developing valuation systems that reflect the benefits of protecting biodiversity in the long-term; determining what the WFD classification of water bodies means for biodiversity and how this ecological classification can be related to human welfare; establishing the effects of water development/regulation projects on microbial biodiversity, and how this affects the provision of environmental goods and services. On the same issue, Mark Gessner highlighted a number of knowledge gaps relating to the relationship between freshwater biodiversity and ecosystem services and stressed the need to establish the extent to which, in addition to the physical features of ecosystems, species richness and other components of biodiversity contributed to the services provided by freshwaters.

Many contributions focussed on the Water Framework Directive (WFD) and other policy instruments. Thomas Dworak started off the session discussions on this topic with a comprehensive contribution on the overlaps between the WFD and biodiversity conservation. In terms of future action he suggested carrying out assessments on the detailed benefits of WFD implementation in terms of biodiversity protection and the interlinkages between the different authorities responsible for water management and biodiversity protection, in order justify the costs of the implementation on a wider basis. Also on the topic of implementation of the WFD, Petr Petřík highlighted the importance of having a national, integrated and comprehensive monitoring system, including monitoring of hydromorophological and biological components of surface waters in accordance with the WFD, and for better coordination between science and policy. Finally, Gorazd Urbanič discussed the (potential) inclusion of biodiversity in ecological assessment systems and current knowledge gaps related to this, including the extent to which member states use species level diversity in ecological assessment systems, whether we had sufficient knowledge of macrophytes, phytobenthos, fish (and phytoplankton) and benthic invertebrates, and whether we could sufficiently predict pressure-responses of the structure and functioning of our freshwaters with current levels of knowledge. He ended his contribution by questioning whether we were ready to deal with the current threat of climate change.

Stefan Schmultz discussed the potential benefits for biodiversity of activities resulting from the implementation of the Habitats Directive and the WFD, such as the provision of new data on the distribution of fish species, information on pressures affecting fish, methodologies to assess ecological status and the development of appropriate restoration and mitigation techniques that can improve the ecological status of freshwaters. In his view, further integration of the Habitats Directive and WFD required the establishment of European biodiversity databases integrating EU-databases and other sources that have recently become available; the revision of the list of protected fish species in annex 2 of the Habitats Directive; the identification of functional pathways of fish response to human pressures to enable development of more targeted restoration and mitigation programmes; the development of research on the large scale and aiming to sustain catchment restoration programmes instead of local habitat and fish population enhancements; and the comparison of pre- and post-restoration/mitigation in LIFE projects leading to research recommendations and reporting guidelines. Still on the topic of the WFD, Angelo Solimini and colleagues called for research on the relationship between biodiversity and the functioning of ecosystems, seen as fundamental for the development of suitable indicators and the management of freshwater goods and services.

Robin Abell's contribution focussed on protected areas. He identified some of reasons why freshwaters had until now been largely ignored in protected area accounting schemes and why the effective design and management of freshwater protection areas would require an interdisciplinary approach. Picking up on a research gap previously mentioned by Jari Niemelä and colleagues, he called for more research on the extent to which existing protected areas actually conserve the freshwater systems within them, and whether or not they were defined to protect freshwater biodiversity. He also called for the further development of monitoring systems and for research to identify which lands were the most critical for

protecting focal freshwater systems, the configuration of those lands to each other and to freshwaters, and the amount of land required for protection.

Turning now to country perspectives, Lithuanian scientists recommended more research on the spatial and temporal species distribution and monitoring of rare and endangered non-commercial freshwater species, as well as their population dynamics; the impacts of habitat destruction, pollution, genetic diversity loss and aquaculture on rare or endangered species; as well as the effects of invasive species and native populations' booms on local freshwater biodiversity. In Latvia, the current most important research issue related to climate change impacts of freshwater habitats and biodiversity. Specific research needs included a better understanding of the relationships between climate and biodiversity on various trophic levels in large river basins; the relationships between fluxes, climate and biota; and the assessment of species behaviour in order to better select potential water quality indicators under climate change stress. In Romania, general objectives for freshwater biodiversity research in included the need to assess the contribution to the mitigation of climate change of conservation of freshwater biodiversity and restoration schemes; understand the influence of extreme weather events in southern and south-eastern European countries on biodiversity, conservation and sustainable use; understand the contribution of freshwater biodiversity to ecosystem services; understand and evaluate the contribution of natural capital and freshwater ecosystem services to sustainable economies; improve methodologies and tools for freshwater ecosystem assessment and adaptive management and identify new measures, and modifications to existing land and water use systems to protect biodiversity from negative impacts of land abandonment or land use intensification. For a complete list of specific research needs identified by Romanian scientists please refer to their full contribution.

Research priorities

Juliette Young, Estelle Balian & Allan Watt

1. Research needs to evaluate the current status and trends of freshwater biodiversity

Assessment and monitoring:

- Inventory and survey freshwater habitats and species;
- Survey and inventory biodiversity-rich but poorly known ecosystems including karstic lakes and rivers, brackish coastal springs, Adriatic anchialine caves, tidal areas of estuaries, high altitude intermittent streams, freshwater spring communities, high-mountain Alpine lakes, sodic-alkaline ponds of the Pannon region, coastal lakes, hyporheic zones;
- Survey and inventory freshwater species including endemic species, diadromous fishes, may-fly, macroinvertebrates, aquatic microbial diversity, cyanobacteria and algae of small water bodies;
- Establish the terrestrial habitat requirements for aquatic insect life history functions;
- Understand community dynamics and biogeographic distribution patterns;
- Develop a standardised assessment method for water bodies across Europe;
- Develop and maintain long-term, regular monitoring in freshwater ecosystems.

Trends in freshwater biodiversity:

- Develop palaeoecological methods to better understand current changes in biodiversity and ecosystem functioning;
- Quantify and understand current trends from natural variability;
- Develop predictive population and metapopulation models.

Baselines and indicators:

- Evaluate the thresholds used as ecological class boundaries;
- Develop new specific bio-indication tools and base future tools on process-based rather than statistical models;
- Develop methods for defining and gathering reference or baseline conditions;
- Assess how fish community and population status may be better used as indicators of ecosystem quality;
- Develop indicators of biodiversity and ecosystem health.

Goods and services:

- Understand the relationship between biodiversity and ecosystem functioning. This should be carried out at different trophic levels, and consider the role of habitat heterogeneity;
- Determine the functional linkages across ecosystem boundaries;
- Establish the extent to which ecological functions of freshwater ecosystems are dependent on the natural biodiversity;
- Assess and undertake holistic and long-term valuations of freshwater ecosystem goods and services;
- Assess the value of biodiversity in small, more-or-less isolated water bodies such as ponds, small lakes, ditches;

- Determine the role of freshwater diversity in the fluxes and storage of both greenhouse gases and plant nutrients;
- Establish the extent to which, in addition to the physical features of ecosystems, species richness and other components of biodiversity contribute to freshwater services.

2. Research needs to identify the drivers of change in freshwater habitats and quantify their impacts on freshwater biodiversity

General:
- Identify the processes currently driving changes in freshwater biodiversity;
- Assess the impacts of pressures in freshwater ecosystems, including the assessment of the resilience and adaptive capacity of freshwater ecosystems to human pressures;
- Harmonize sampling methods and tools for linking changes in biodiversity to various pressure types and combinations of known and unknown pressures;
- Develop hydrological models for principal wetland areas.

Cumulative threats:
- Examine the relationship between ecosystem function, invasive species and climate change, leading to the development of predictive models;
- Determine the synergies between invasions and other anthropogenic threats.

Climate change:
- Quantify the impacts of climate change (including extreme weather events and a drying climate) on freshwater habitats and species;
- Quantify the ecological responses to changes in river flow regimes brought about by the direct and indirect effects of climate change, and their interactions;
- Develop realistic scenarios of the probable effects of climate changes on freshwater biodiversity and the distribution of species;
- Establish the potential impact of climate change on the baseline used to define reference conditions.

Invasive species:
- Understand the impacts of invasive non-native species on freshwater biodiversity and ecosystem functioning;
- Develop early warning systems for the identification and detection of non-native species;
- Develop risk assessments for freshwater species known to have invasive potential;
- Study the ecology of individual non-native species, including genetics, reproduction, population growth, competitive ability, and the responses of organisms to abiotic factors;
- Develop new techniques for surveying and monitoring to map key invasive freshwater species;
- Determine the potential effects of climate change on the distribution of non-native species;
- Develop new methods of eradication for particular non-native species;
- Determine the differences between human-caused invasions and natural biotic interchange;
- Identify the potential positive impacts of species introductions.

Other threats:
- Quantify the impacts of forestry, intensification of agricultural systems, commercial fishing and navigation on freshwater habitats and species;
- Develop further the risk assessment of chemicals, integrating confounding factors such as temperature, water quality and pH;
- Determine the impacts of groundwater contamination on biodiversity, ecosystem integrity, and human health;

- Establish the effects of water development/regulation projects on biodiversity (including microbial biodiversity), and how this affects the provision of environmental goods and services;
- Assess the impact of native populations' booms on local freshwater biodiversity;
- Assess the impacts of habitat fragmentation on freshwater biodiversity.

3. Research needs for the conservation and management of freshwater habitats and species:

Conservation and restoration:

- Determine the extent to which existing protected areas protect freshwater biodiversity, and how effective such protected areas may be in dealing with climate change;
- Identify areas most critical for protecting focal freshwater systems, the configuration of those lands to each other and to freshwaters, and the amount of land required for protection;
- Identify nationally important freshwater habitats that could be suitable for restoration;
- Understand the impact of food web structure on the success of restoration activities impacts;
- Understand the impacts of various kinds of restoration operations on biodiversity;
- Develop empirical models linking the intensity of different pressures, restoration, and ecological status in freshwater habitats;
- Assess the biodiversity benefits of different agricultural land management approaches (e.g. buffer strips, no till agriculture, nutrient management);
- Develop research in constructive stakeholder engagement in planning and management of both natural and modified freshwater ecosystems.

Environmental flows:

- Quantify environmental flows and develop a searchable global database on environmental flow prescriptions;
- Undertake comparative work on how environmental flow prescriptions and policies differ across regions, ecosystem types, gradients of water quality, and governance structures;
- Identify hotspots of competition for water, how they can be minimized, and how they can be integrated with existing social systems;
- Determine the relationships between environmental flow, ecology and environmental goods and services;
- Quantify the ecological responses and environmental goods and services benefits resulting from the implementation of an environmental flow regime;
- Monitor the effectiveness of environmental flow policies.

Implementation of the WFD and Habitats Directive:

- Assess the benefits of WFD implementation in terms of biodiversity protection, especially in High Status sites;
- Assess the impact on freshwater biodiversity of not including small waterbodies in the current WFD, and the potential for redefining "water mass";
- Determine what the WFD classification of water bodies means for biodiversity and how this ecological classification can be related to human welfare;
- Develop knowledge to support the design and implementation of policy instruments such as the WFD;
- Compare pre and post restoration/mitigation in LIFE projects in order to develop research recommendations and reporting guidelines.

4. In order to achieve the above research, the following enabling actions are necessary:

- Ensure that existing and emerging databases on species and distributions be compiled in order to make them interactive, integrated and accessible to all scientists;

- Support and develop national taxonomic and systematics expertise and capacity, including the training of a new generation of taxonomists and ecologists;
- Integrate social, ecological and hydrological aspects into a transdisciplinary understanding;
- Develop a freshwater knowledge portal that could link different types of data resources;
- Develop and encourage two-way communication mechanisms between scientists and river managers;
- Revise the list of protected freshwater species (including fish species) in the Habitats Directive annexes.

List of contributions

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Session I: Research needs for conserving above-and below-ground freshwater biodiversity	
Current trends and status of freshwater biodiversity and priorities for the future	Robert Naiman
RE: Introduction to Session I	Ferdinando Boero
Current efforts to collate existing data on freshwater biodiversity	Hendrik Segers
RE: Current efforts to collate existing data on freshwater biodiversity	Hugo Verreyken et al.
Is invasion necessarily a destructive process?	Christian Lévêque & Jean-Nicolas Beisel
RE: Is invasion necessarily a destructive process?	Svetislav Krstić
RE: Is invasion necessarily a destructive process?	François Bonhomme
Biodiversity in subterranean habitats	Boris Sket
Diversity and dynamics of aquatic bacterial communities	Hans-Peter Grossart
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Research on the hyporheic zone	Mohammed Messouli
Assessing the value of all waterbody types	Jeremy Biggs & Penny Williams
Freshwater biodiversity: knowledge gaps and research needs for sustainable management	Alan Hildrew
Biodiversity and ecosystem functioning	Klement Tockner & Hans-Peter Grossart
Session II: Research needs for coordinated implementation of EU Directives and the ecosystem approach in aquatic habitats	
European water governance and consequences for freshwater biodiversity conservation	Rui Santos & Paula Antunes
Biotic indicators and the European Water Framework Directive	Didier Pont
Freshwater research needs from the CBD	Carsten Neßhöver
The WFD and its role in managing non-native invasive species in fresh waters	Philip Boon
International policy frameworks for managing environmental flows for biodiversity	David Katz
Regional environmental flow standards needed to guide Integrated Water Resources Management	Angela Arthington

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Danube: a lifeline or just a navigation corridor?	Hulea Orieta
Good ecological status in the Water Framework: What does it mean for freshwater biodiversity?	Thomas Dworak
Valuation of the goods and services provided by freshwater biodiversity	Jay O'Keeffe
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Freshwater wetlands in the Maltese Islands: Characteristics and potential	Compiled by Adriana Vella
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Urgent issues of freshwater biodiversity research in Russia	Vladimir Vershinin
Biodiversity research on Estonian fresh water communities	Ingmar Ott
Research needs: Freshwater in Ireland	Compiled by Louise Scally
Research priorities for freshwater biodiversity in Hungary	Compiled by Katalin Török
Research priorities for freshwater biodiversity in Ukraine	Viktor Gasso et al.
Research needs regarding freshwater biodiversity in Norway	Compiled by Odd Terje Sandlund
Research priorities in Slovenia	Anton Brancelj
Specific research in the case of protected areas: the Danube Delta Biosphere Reserve	Christian Kleps
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Biodiversity research needs in the UK	Laurence Carvalho & Iain Sime
Freshwater biodiversity research needs in Latvia	Gunta Springe
Research priorities for sustaining freshwater biodiversity in Lithuania	Compiled by Eduardas Budrys
Research priorities for freshwater biodiversity in Romania	Compiled by Simona Mihailescu