CORE
Metadata, citation and similar papers at core.ac.uk
Provided by NERC Open Research Archive

Water for Life:

Research priorities for sustaining freshwater biodiversity

Report of an electronic conference, December 2007

COMPLETE REPORT

Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

BIOSTRAT
Developing the EU Biodiversity Research Strategy

REPUBLIC OF SLOVENIA

epbrs

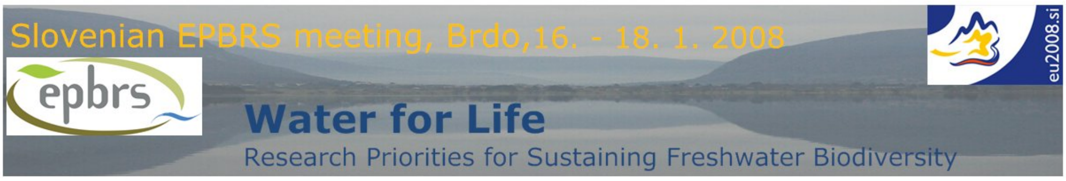
.be

E-Conference organisation:

Juliette Young and Allan Watt CEH Edinburgh Bush Estate Penicuik EH26 0QB UK	Centre for Ecology & Hydrology NATURAL ENVIRONMENT RESEARCH COUNCIL
Estelle Balian Royal Belgian Institute of Natural Sciences, Freshwater Biology- Belgian Biodiversity Platform	.be museum
Peter Skoberne Ministry of the Environment and Spatial Planning Dunajska cesta 48 SI-1000 Ljubljana Slovenia	REPUBLIC OF SLOVENIA

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.

Contents



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 16^{th}-18^{th} 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.

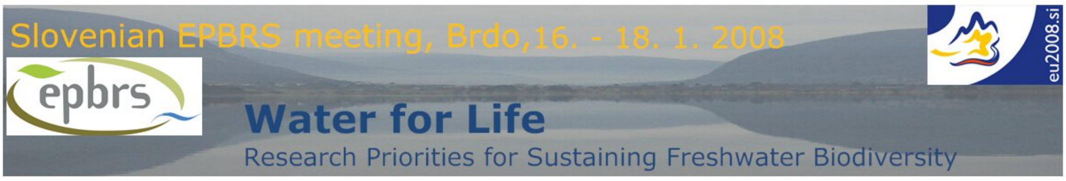
I might be preaching to the converted, but just a few facts on freshwater biodiversity: 9.5% of the described animal species, including almost half of the fish species in the world, are restricted to freshwater habitats, which represent only a very small fraction of the earth surface (0.8%). There are 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).

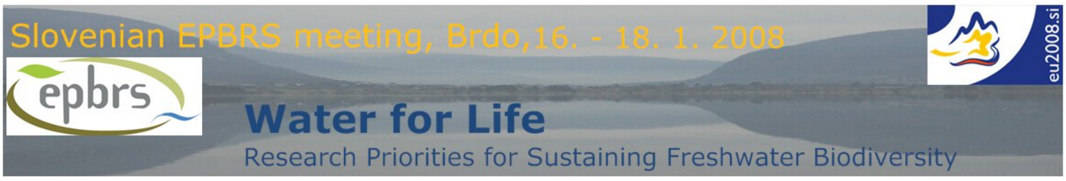
The topic of valuation of goods and services provided by freshwater biodiversity was discussed, starting with a contribution by Jay O'Keeffe, who identified a number of key research questions and priorities in this area, including: determining the relationship between biodiversity and the functioning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

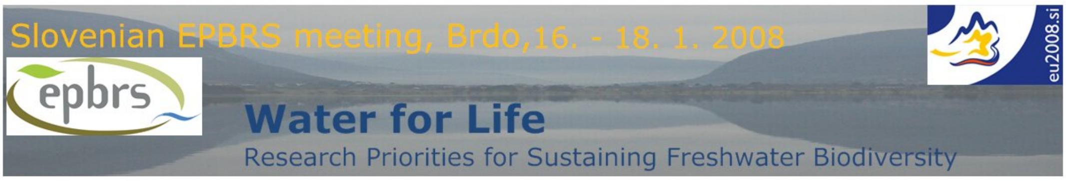
- Support and develop national taxonomic and systematics expertise and capacity, including the training of a new generation of taxonomists and ecologists;
- Integrate social, ecological and hydrological aspects into a transdisciplinary understanding;
- Develop a freshwater knowledge portal that could 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

Session I: Research needs for conserving above- and below-ground freshwater biodiversity

Session II: Research needs for coordinated implementation of EU Directives and the ecosystem approach in aquatic habitats

Session III: National perspectives



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 J. Naiman, University of Washington, Chair DIVERSITAS Freshwater Committee, Chair UNESCO-IHP Ecohydrology Programme

Freshwater organisms are severely threatened globally. Sustained leadership in freshwater assessment and monitoring, as well as disciplinary integration, are needed; establishing 'environmental flows' may be one solution.

This is a critical time for organisms living in continental waters. Even with the environmental vitality of freshwater ecosystems and their inherent biodiversity at the heart of social and economic sustainability, they are under severe threat because of expanding human demands for water. This is despite the fact that biodiversity underpins many freshwater processes (e.g., self-purification, protein production) that are of crucial importance for sustaining goods and services for human populations (Naiman et al. 2006). Fresh water is essential for nearly any form of human activity, including industrial production, navigation, domestic water requirements, waste assimilation, health, and food production.

Fortunately, the central importance of freshwater for human activities is now better recognized. In December 2003, the United Nations General Assembly adopted resolution 58/217 proclaiming 2005 to 2015 as an International Decade for Action – 'Water for Life'. The resolution calls for a greater focus on water issues and development efforts, and recommits countries to achieving the human-centric water-related goals of the 2000 Millennium Declaration and of Agenda 21. The goals are highly important matters for humanity, yet this should not obscure the fact that the 'Water for Life' resolution comes at a time when biodiversity and the biological resources of inland waters are facing unprecedented and growing threats from human activities (MEA 2005). The general nature of these changes is known, and they are manifest in all regions of the Earth – although their relative magnitude varies significantly from place to place (see www.gwsp.org). Identifying changes to water regimes and the inherent consequences of those changes to aquatic organisms and human societies has done little, however, to mitigate or alleviate them. The fact remains that, at a global scale, there are grand challenges facing all aspects of freshwater, from development, governance and health to biodiversity.

Quite literally, the hydrological regimes of the Earth are being fundamentally altered to meet the needs of rapidly expanding societies (Vörösmarty et al. 2004). The water regimes that helped shape the evolution of freshwater diversity and the life history adaptations of individual species are different than in the past and will be much different in the future. These major changes, to one of the Earth's most basic biophysical systems, is taking place with only a rudimentary understanding of the organisms being affected or the larger-scale consequences of those changes (Dudgeon et al. 2006, Balian et al. 2007). Unfortunately, despite centuries of investigations of the Earth's biota, the taxonomy of freshwater organisms and their distributional patterns are just beginning to become clear – and therein lies a great concern as we begin to quantify the immense diversity of the freshwater world.

Against this background, I have two major concerns and a suggestion. One concern relates to the state of knowledge about freshwater assessment and monitoring and the other relates to addressing biodiversity at a scale (or, more precisely, a level of integration) commensurate with the issue. The suggestion is to use 'environmental flows' as a tool for better assessment and monitoring – and management – of freshwaters and their diversity.

Assessment and Monitoring: One of the most telling graphics about the state of freshwater is from the Millennium Ecosystem Assessment (2005; Figure 1).

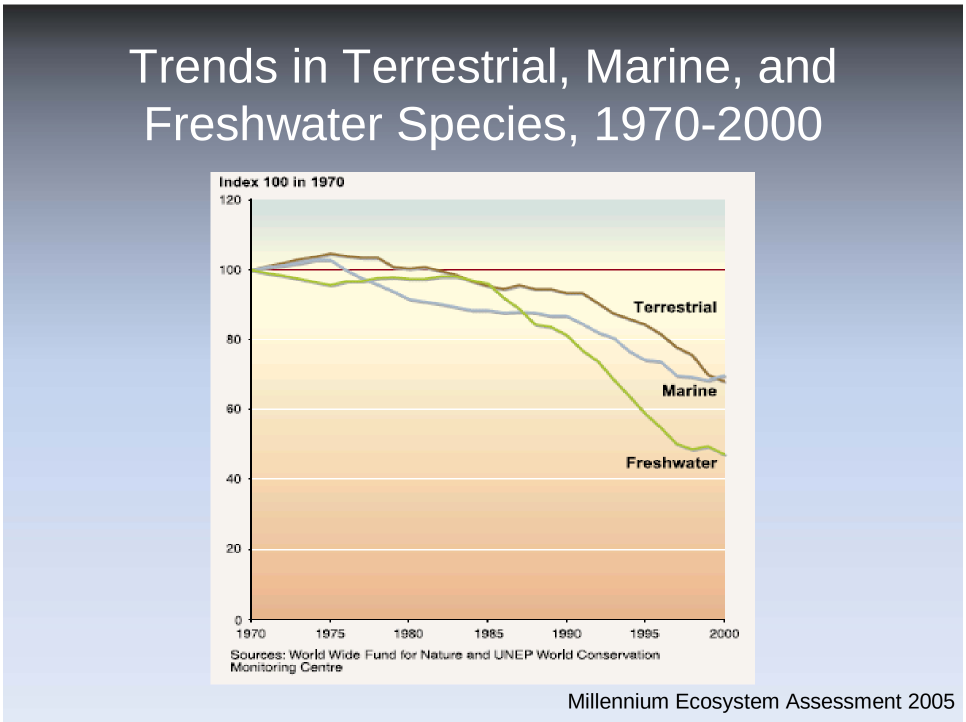


Figure 1. Trends in Terrestrial, marine and freshwater species 1970-2000 (MEA, 2005)

Between 1970 and 2002 – a mere 30 years, freshwater biodiversity declined ~55% while that of terrestrial systems and marine systems each declined ~32%. One must suspect that the actual value for freshwater was considerably higher considering the severe incompleteness of the taxonomic database on freshwater biodiversity. I find this to be a sobering statistic as well as a call to action for freshwater-related sciences and for conservation. As a consequence, I feel that it is critical that existing and emerging databases on species and distributions be compiled in a manner making them interactive and integrated so that the broader research community can have access. This will require a coordinated effort among countries, institutions and researchers – at a level commensurate with that of the IPCC – to effectively address the issues at hand. Complementary to these activities is the need to train a new generation of taxonomists and ecologists, with the most up-to-date techniques, in order to answer questions related to the distribution, monitoring and environmental requirements of freshwater organisms. These and other key needs underpin my deep concerns that assessment and monitoring of freshwater organisms needs a ‘fresh’ start – and better coordination – if it is to effectively contribute to global concerns and policy decisions.

Environmental Flows: A major effort to assess vulnerability of aquatic ecosystems – and maintain biodiversity – is embedded in the concept of “environmental flows”: the quality and quantity of water necessary to protect aquatic ecosystems and their dependent species and processes (Poff et al. 1997, Arthington et al. 2006). It is essential to quantify environmental flows in order to ensure ecologically sustainable development of water resources. However, water requirements of aquatic ecosystems have never been estimated globally. A major challenge is to evaluate their relative merits and provide regionally-relevant, hydro-ecological models (Poff et al. 2008). Likewise, these environmental requirements have not been globally compared to the water required to provide “goods and services” to society such as water supply for municipalities, electrical production, manufacturing and irrigation nor have the connections to social systems (culture, traditions) been made. A key task for researchers is to identify where hot spots of competition for water will occur, how they can be minimized, and how they can be integrated with existing social systems. While major efforts have been devoted to evaluating these vulnerabilities on the local to river basin scale comparatively little effort has been invested in global scale vulnerability research, apart from studies of climate change impacts on water resources. An Environmental flows perspective has the potential to provide a focal tool for the assessment and monitoring, the integration of disciplines (see below), and the resolution of many freshwater biodiversity issues.

Integration: The scale of alterations requires the integration of social and ecological sciences for the long term maintenance of biodiversity. This has been widely recognized for a long time, yet it remains a grand research challenge for the professional community to discover ways to provide effective leadership. Looking toward the future, a major advance would be to integrate social, ecological and hydrological aspects into a transdisciplinary understanding (sensu Max-Neef 2005). Transdisciplinarity is not just the bringing together of people from different perspectives to examine a common issue, but rather developing the entire perspective within each of us (Figure 2).

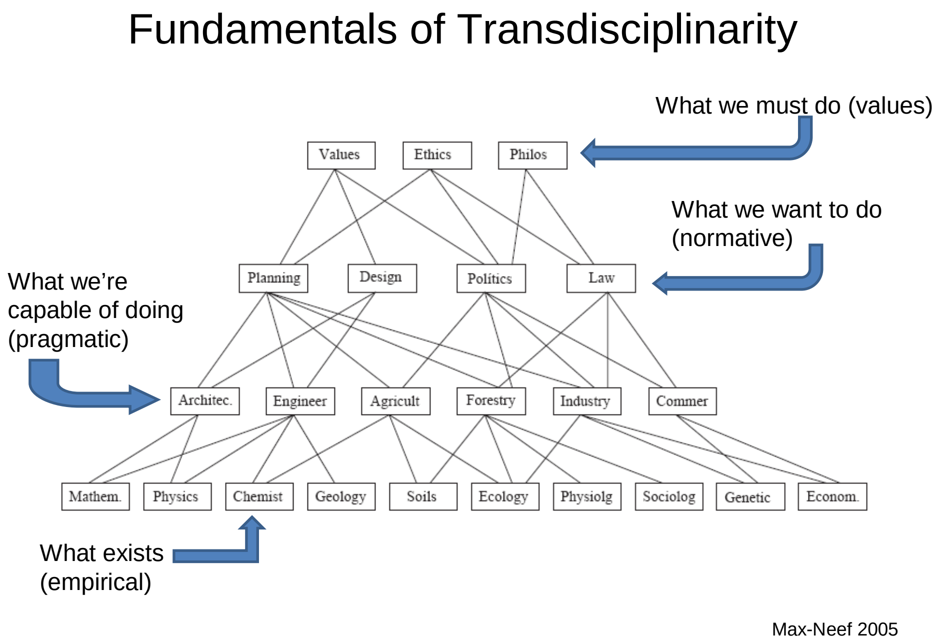


Figure 2. Fundamentals of transdisciplinarity

This means adopting approaches – and a philosophy – that integrates professional disciplines and social cultures. This quest conforms to the principles established in previous work aimed at providing generalisable and adaptable analyses of basin management issues (e.g. Holling 1979, Naiman 1992, Gunderson et al. 1995) – but it also builds on this work, and more fully integrates human aspects in effectively engaging freshwater biodiversity. This is not a traditional research frontier but rather one that prepares us for the future world.

Specific Topics of Vital Importance: In addition to the main themes outlined above, there are many knowledge gaps and strategically important research directions to be identified and worked toward on this topic. Chief among these, in my opinion, are the following:

- Unequivocally demonstrating a fundamental relation between biodiversity and the maintenance of important ecosystem processes in freshwaters (e.g. water purification, system resilience, food production)
- Determining if there are important relationships between freshwater biodiversity and health of human and wild organisms (e.g. disease transmission and prevention, production of nutritional and healthy fishes)
- Developing of realistic scenarios outlining the probable effects of climate changes (e.g. altered precipitation and temperature patterns, melting of snowpacks and glaciers) 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 (e.g., researchers, decision-makers, users) capable of viewing the Earth's freshwater system as an integrated system and, at the same time, addressing issues related to political borders

Freshwaters integrate all processes on the landscape and in the atmosphere. On one hand, they are complicated but on the other they offer a framework, or even a model, for the resolution of biodiversity issues on land and in the oceans. Nevertheless, the discussions are just beginning. My hope is that this initial opening remark acts as a catalyst for a creative, provocative, and fruitful process.

RE: Introduction to Session I

Ferdinando Boero, DiSTeBA, University of Salento, Lecce, Italy

As a marine scientist, I should keep my mouth shut. My little contribution might highlight the importance of freshwater ecology for marine ecology by adding: many species (e.g. salmon, eel and others) use both environments. The criticality for their life cycles is often at the level of the freshwater systems they inhabit at some time of their cycle.

Most of the impacts of human activities on marine systems, furthermore, use freshwater systems as carriers and, thus, freshwater have great impacts on marine biodiversity too. There are, then, transitional environments, where marine and freshwater systems meet. They are very important for humans too.

It is very important that aquatic biology (i.e. the biology of both marine and fresh waters) utilizes a common background, so preventing the re-invention of the wheel. Compartimentalization of approaches, in this framework, brings a lack of coherence of aquatic sciences, with duplication of intellectual efforts due to lack of communication. That's why the new journal 'Aquatic Biology' has been launched.

It is right to focus on our own specific problems, but the connections also have to be considered. And there are many. Surely, the flow goes from freshwater to the sea and the way back is through the atmosphere, so marine ecologists should be more concerned about freshwater ecology than vice versa. But there are organisms that go upstream, as I remarked above. The deadly jellyfish of Australia, the cubozoa, for instance, go upstream and reproduce in freshwater (their polyps have been found there). Then they flow to the sea to kill people. But then go back to freshwater. The source of marine stingers, in Australia, is in freshwater or, at least, in transitional waters! We probably have more in common than we think.

Current efforts to collate existing data on freshwater biodiversity

Hendrik Segers, Belgian Biodiversity Platform, Freshwater Laboratory, Royal Belgian Institute of Natural Sciences, Brussels, Belgium.

The ongoing efforts to collate existing data on freshwater biodiversity by creating data portals through which access can be gained to distributed databases, can only be welcomed. However, issues exist regarding interoperability between databases containing information of different nature and origin, and on the lack of incentives for research producing such databases. In conjunction, a scientific analysis of the effect of the present reliance on impact factors in the evaluation of scientific achievement, and, possibly, development of an alternative, is in order.

Recently, initiatives like GBIF, FishBase, Catalogue of Life, GENEBANK and many others, are increasingly providing unprecedented easy access to biodiversity information, through open, web-based portals linking distributed resources. Indeed, there is an overwhelming quantity of valuable biodiversity-related information, resulting from centuries of research on taxonomy and ecology, and of more recent molecular studies. This evolution of facilitating access to basic information in an almost unrestricted way, is very much to the benefit of managers and conservationists, and, ultimately, to society. It can therefore only be welcomed.

However, most relevant efforts to date appear to have focussed on marine and/or terrestrial ecosystems, and much less on freshwater ecosystems. This is probably a consequence of the fragmented nature of freshwater habitats, and of the complex internal and external interactions that determine the functioning of freshwater ecosystems. This specificity, in combination with the severity of the threats to, and vital significance of the services supplied to society by freshwater ecosystems, are strong arguments in favour of a concerted effort to open up existing information sources. Such an effort could lead to a freshwater knowledge portal that links data resources containing information of various types, over different levels of system integration, and including information on the physical and chemical environment. Only a focussed and comprehensive effort can produce the resource that is needed to effectively contribute to sustainable management and conservation of freshwater biodiversity.

There are, however, constraints hindering the development of a knowledge portal as described above. First, there still are technical issues hindering the construction of a knowledge portal that links information repositories containing data of diverse nature and origin. The experience gained in the development of similar initiatives, (see above), may be pivotal to overcome this technical impediment; hence cooperation with, and promotion of such facilitators should be enhanced.

Second, there is a lack of incentives for scientists to produce, and provide free and open access to, databases containing basic biodiversity and environmental information. Presently, the evaluation of scientific achievement appears to be disproportionately based on the analysis of the impact of publications or, even worse, of the journals in which papers are published. To be successful as a scientist, researchers have to publish in high-level, international journals, and it is unlikely that persons focussing on building a scientific career in a competitive environment can spare the effort to produce outcomes that are hardly considered in the evaluation of scientific achievement. This is particularly the case for, but is not restricted to, ecologists involved in monitoring, or taxonomists, who are expected to document diversity and produce the taxonomic backbone and tools needed by ecologists. It would be interesting to know if, and to which extent, the reliance on impact factors drives scientific research. A less biased, universally acceptable indicator may be needed as one element to promoting research activities that produces the databases underpinning sustainable management and conservation.

RE: Current efforts to collate existing data on freshwater biodiversity

Hugo Verreyken, Claude Belpaire & Jurgen Tack, Research Institute for Nature and Forest, Research Institute of the Flemish Community, Brussels, Belgium

The Flemish Research Institute for Nature and Forest (INBO) manages the 'Vis Informatie Systeem' (Fish Information System) or VIS. This is a new online database (in Dutch) on freshwater fishes in Flanders. Data from the INBO monitoring network on freshwater fishes and the INBO eel pollutant monitoring network were centralized in one information system and made available online to a wide range of users.

At present, VIS is a central database with individual lengths and weights of over 200000 freshwater fishes collected during fish stock assessments at over 800 locations all over Flanders since the mid 1990s. The Index of Biotic Integrity (IBI) is calculated based on these monitoring data and can be consulted in a table or as a graph. VIS also includes pollutant data (PCBs, heavy metals, pesticides, BFRs...) in eel tissue from over 350 sites in rivers, canals and standing waters in Flanders. Over 80000 results of contaminant analyses are now available through VIS.

Aimed user groups are scientists (scientific institutions, universities, consulting agencies...), policy makers (Flemish Authority), stakeholders (fisheries managers, anglers' organisations) and the wider public (anglers...).

Visitors can consult VIS at http://vis.milieuinfo.be/ without having to register. They can view fixed reports like (1) the number of specimens for a certain (or all) species of a specific site, river or basin, (2) the IBI per site, (3) pollutants in eel and other (piscivorous) species or (4) can have a length-frequency distribution drawn. Registered users, depending on the assigned privileges, can create new projects and import their data and, besides viewing the fixed reports, they can also export all the required data in txt-format.

Future plans for VIS consist of (1) improving the operational reliability, (2) translation in English to enhance the distribution of the data, (3) possibility to create maps (GIS-based) and (4) to convince more universities, fisheries managers, agencies... to import their data in VIS.

The Institute welcomes the ongoing efforts to collate existing data on freshwater biodiversity by creating data portals through which access can be gained to distributed databases and wishes to collaborate to make more monitoring data on freshwater biodiversity accessible. Initiatives such as VIS are an important part of this strategy. As mentioned, problems like interoperability between databases have to be overcome and for INBO one of these issues is translation of the information system from Dutch to English. Furthermore, important future applications will be the development of standardised reports enabling international reporting of ecological and chemical status within the Water Framework Directive (derived from fish based data from the database) and specific, location based consumption advice for anglers and fisheries managers. Other concerns are the desired connection with databases like FishBase and the further improvement of the user-friendliness.

Although the data in VIS are used by INBO scientists to produce manuscripts for publication in high-level, international journals, the data are also used to advise regional managers and policy makers. Besides that, the data are accessible online to all interested parties.

Is invasion necessarily a destructive process?

Christian Lévêque, Institut de Recherches pour le Développement, Muséum National d'Histoire Naturelle, Paris, France; and **Jean-Nicolas Beisel**, Université Paul Verlaine, Metz, France.

Ecologists faced with the quickening pace of human-aided species invasions have pointed out short-term consequences: community disassembly, extinction and global loss of biodiversity, homogenization of the world biota.

Most studies of biological invasions focus on the impacts of individual species. These leave the impression that a single colonizing species often causes or contributes to the extinction of multiple native species. Is it the general rule? Clearly the exotic species with large ecological and economic impacts receive a disproportionate attention by scientists whereas others go largely unstudied. Moreover, in habitats where extinctions have occurred, other human-caused changes may have contributed to the extinction of native species. The case of Lake Victoria is a good example: Nile perch is accused of being responsible for an ecological disaster, but the lake simultaneously experienced eutrophication that dramatically modified the aquatic system!

Do we have a clear idea of the relative importance of habitat disturbances and individual species introductions on the functioning of aquatic systems? What do we know about possible synergies between habitat disturbance and invasive?

What do we know about the role of disturbance in the success of species introductions? What is the role of the homogenization of habitats (in and between watersheds) as a result of human disturbances, in the homogenization of biodiversity observed at a large scale?

Species invasion is a phenomenon that is as old as the existence of species on earth and has been part of ecological history! The European freshwater fauna has been depauperated by the numerous glaciation - deglaciation cycles. The present species richness in most aquatic systems is the result of recolonisation from refuges zones (South Spain, South Italy, and the Danube and Ponto-Caspian area). For species like fish, large crustacean and molluscs, re-colonisation is usually possible through physical connections between rivers systems. But there are also many reasons to suspect that man also played a role. The well known example of carp which has been introduced everywhere in Europe is probably not unique. And there is evidence that man introduced (voluntarily or not…) several other species in systems where they had no chance of re-colonising on their own! That is to say that present species richness is just a matter of chance and challenge, as well as unknown human influences… The main conclusion is that European aquatic communities are largely stochastic. And certainly not "saturated". Any introduction upsets the status quo… and then? Do we have to adopt a "siege" mentality? What shall we do with global warming and migration of thermophilic species towards the north of Europe?

Are so-called invasive species so different from native species? Or is it the absence of regulation through predators and competitors that explains their success? Can we distinguish ecological or trophic groups with differential consequences on native ecosystems? Do human-caused invasions differ greatly from natural biotic interchange in their immediate and long term consequences?

Most attention so far has been given to the negative aspects of invasion. As scientists, shouldn't we also consider the positive ecological consequences of introductions? Such positive consequences of invasion may exist and should also be investigated. Field experience proves that after some time, introduced species can become part of the biological system; to the point that some introduced species are now considered as native, and even deserve a status of protected species!

Can we develop some scientific guidelines about introduction with a more balanced view of their usefulness and consequences?

Re: Is invasion necessarily a destructive process?

Svetislav Krstić, Faculty of Natural Sciences, Institute of Biology, Macedonia

In line with the comments by Christian Lévêque, I felt the need to add some comments using the example of the invasion of algae in freshwaters.

The notorious effect of *Caulerpa taxifolia* is probably the best known negative consequence of the introduction of invasive species in a new marine environment. But there are other examples, such as the impact of the diatom *Didymosphenia geminata* in the North Hemisphere freshwater environments (Gretz et al., 2006).

Amid my full agreement that we still do not know the answers to the questions posed by Christian Lévêque, especially regarding environmental evolution and human impacts on habitat disturbances, in the case of invasive algae, the standpoint is that they actually greatly modify the new environment either through their massive development or by nuisance production of metabolites, toxins in particular. And yes, in the case of algae, the invasive species ARE very different from the native ones and can create a completely new ecosystem in a very short time period, thus leaving very little space for adaptive processes of other biota that usually die.

In case of algae, the human-caused invasions (ballast waters, rapid eutrophication, even perhaps global warming!) can be differentiated from the naturally induced successions at least in their speed that can only be compared to that of massive catastrophes in the history of evolution on this planet.

As a conclusion, I fully agree that we need more evidence, research and knowledge to post any scientifically sound judgment on invasive species, but we must introduce the complex ecosystem approach in any scientific guidelines as an 'early warning system' that an ecosystem is on the 'point of no return' with vast consequences. Also for monitoring purposes, the first disturbances are to be expected among the primary producers including the occurrence of the invasive species.

RE: Is invasion necessarily a destructive process?

François Bonhomme, Département Biologie Intégrative, Institut des Sciences de l'Evolution, Université de Montpellier, France

I think that Christian Lévêque has clearly made the point that invasion is a natural process, and that "re"-colonisation or colonisation (alone) after glacial episodes has been a powerful mean to replenish most European ecosystems. In the same time, it may well have selected those species having "invasive" possibilities, and left aside other less mobile species, so our biocenoses may well be made of a bunch of invasive species!

The role of man behind this is of course the question at hand. If we have to make use of the precautionary principle, we should not at the same time adopt a rigid attitude that would ask, for instance, for the eradication of well installed species having found their place in the ecosystem, under the fallacious pretext that they are "non native". The claim for nativeness and all sorts of aboriginality has for me a very negative ideological flavour, and all that this discussion demonstrates is that science cannot be completely freed of ideological imprints when the question of the relationships between mankind and "nature" is set forth...

Biodiversity in subterranean habitats

Boris Sket, University of Ljubljana, Slovenia

Subterranean fauna is particularly diverse in southern Europe. It is scientifically interesting, and is an indicator of healthy underground water resources. To protect it, it is necessary to prevent changes in its environment and to encourage its scientific study.

Subterranean habitats are mainly voids in rocks (i.e. 'caves and cave waters') and interstitial waters in sandy or gravely deposits. Approximately 8% of European aquatic animal species are troglobionts (obligate subterranean dwellers) (Sket 1999). Troglobiotic fauna is rich in unaltered subterranean habitats. Therefore, it is an indicator of healthy subterranean environment. Its protection may be a by-product of high quality water resources protection for human needs (Sket 1972). Troglobionts are also interesting as the subjects of adaptation and speciation processes. For their small distribution areas they are often endemic for small countries and therefore an important part of national natural heritage.

The first scientifically described (Laurenti 1768) troglobiont was the salamander *Proteus anguinus*, the second was the beetle *Leptodirus hochenwartii* (Schmidt 1832), both found in Slovenia. The southern European countries are particularly rich in subterranean habitats (including ground waters) and we know today that the biodiversity here is the richest in the world (tropical countries are very modest in terms of subterranean biodiversity). Within it, the western Balkan area alone is approximately as rich as the whole of the USA plus Canada; in the aquatic part of the subterranean fauna it is even richer (Sket, Paragamian & Trontelj 2004). Many subterranean species are morphologically difficult to distinguish since they evolutionarily converged in morphological adaptation to their special environment. Therefore, molecular analyses show an additional degree of diversification, unrecognised till now. Although the Dinaric countries are comparatively small, ca 50% of subterranean species are 'national' endemics; there are only few with distribution areas longer than 100 km and very many are known to be found in single localities (Trontelj et al. in print). The most attractive species, like the cave shrimp *Troglocaris anophthalmus* or the cave salamander *Proteus anguinus*, which are present along nearly all the Dinaric karst, appeared to be in fact groups of genetically separate entities (Zakšek et al. 2006; Gorièki 2006). Also the faunas of individual cave systems seem to be the richest in fauna in southern Europe. Of 20 of the richest systems in the world six are in the Dinaric karst, mainly in Slovenia (Culver & Sket 2000); the richest ones are inhabited by approximately 80 troglobiotic species, up to 50 of them may be aquatic.

Troglobionts are highly endangered, particularly for their small distribution areas. Even in the case of slight organic pollution of groundwaters, surface species may invade underground and outcompete troglobionts (Sket 1977). Some countries are preventing biodiversity protection by hindering sampling, even for scientific purposes. But subterranean biodiversity is not endangered by collectors, let alone by researchers. It is mainly threatened by the destruction of its habitats, directly or indirectly caused by activities on the surface: pollution and construction activities. The research of the not-easily accessible subterranean fauna should be encouraged in order to shape appropriate protection measures.

Diversity and dynamics of aquatic bacterial communities

Hans-Peter Grossart, IGB-Neuglobsow, Dept. Limnology of Stratified Lakes, Stechlin, Germany

I still find it surprising that microbial diversity is greatly neglected in any European program on biodiversity. I guess that this fact is mainly linked to a) the enormous diversity of microorganisms, b) methodological restrictions, and c) to the invisibility of these organisms.

By using molecular techniques, however, we are starting to get a glimpse of the diversity and importance of microbial life in aquatic systems. Although there is a bunch of sequence information on microorganisms from various aquatic systems available, there are no systematic studies on global scale distribution of microorganisms. Microorganisms (Eubacteria and Archaea) contribute to most of the world's genetic diversity and due to their short generation time rapidly react to environmental perturbations. Hence, one should expect that microbial communities are nice indicators of the state (health) of a given aquatic environment.

Better knowledge of the microbial community has large implications for the sustainable management of limnetic resources and their efficient protection. Microbial communities can be seen as the integral of multiple factors acting on aquatic systems. For example, changes in quality and quantity will give a hint on environmental changes, e.g. anthropogenic factors such as land use and pollution. To improve water quality it is necessary to monitor and control anthropogenic activities, to study their effects on limnetic bacteria, and to undertake activities to increase the water quality, such as restoration and intelligent management. Better knowledge of microbial processes will lead to a better understanding of the functioning of the whole food web. Besides primary producers, heterotrophic bacteria form the trophic basis of limnetic food webs and are responsible for energy and nutrient cycling. Changes of either the catchment basin or the lake itself will lead to changes in microbial population structure. Hence by monitoring microbial (including algae and zooplankton) communities it will be possible to follow short-term as well as long-term environmental changes.

Specific research needs to assess microbial diversity in aquatic systems are:

a) Systematic qualitative and quantitative determination of the bacterial community structure.

b) Seasonal and long-term dynamics of bacterial community structure in relation to limnological parameters such as primary production, dissolved organic carbon (DOC), nutrients, zooplankton, and phytoplankton communities.

c) Optimisation of cultivation techniques to isolate and cultivate the key players which have been characterized by molecular techniques.

d) Physiological characterization and description of new species and/or clusters.

e) Development of specific detection methods for the key players through clone libraries and DGGE analysis (16S rDNA sequences).

f) Specific detection systems are needed to characterize and quantify key players in the field.

g) Combination of molecular, analytical as well limnological data will enable the study of the ecological role of specific bacterial species or groups.

h) Collection and storage of 16S rDNA sequences with high temporal and spatial resolution in a data base and further development of microarrays for DNA chip development for each studied system.

Freshwater biodiversity: the time perspective

Rick Battarbee, Gavin Simpson, Tom Davidson, Carl Sayer, Roger Flower, Don Monteith, Mike Hughes, Ben Goldsmith, Martin Kernan and Helen Bennion; Environmental Change Research Centre, University College London, UK.

Today there is increasing concern that biodiversity is being lost through human activity with respect especially to pollution and habitat disturbance, and that future global warming may cause rapid species migration and invasions on the one hand and range reductions and extinctions on the other, the consequences of which, in terms of ecosystem function and human livelihoods, are unknown. The starting point for most biodiversity research is the examination of present-day patterns and distributions.

However, contemporary biodiversity patterns are only a snapshot in time, the outcome of many processes acting and interacting dynamically on different time-scales. Understanding the present therefore also needs insights into the past. Our ability to reconstruct the past using direct observations is compromised for many ecosystems by the rarity and brevity of long-term ecological records. For some ecosystems, on the other hand, it is possible to embrace the potential of palaeoecological techniques as an additional or alternative approach.

Palaeoecological methods continue to improve and can be used not only to record species occurrences through time (for those taxa that leave a fossil record), but also to calculate rates of change, infer the causes of change and identify the ecological importance of biodiversity change in terms of habitat loss, community change and ecosystem functioning.

The approach is especially powerful for lake ecosystems as lake sediments contain an exceptionally rich fossil record and accumulate rapidly. Already the methodology is well developed as a means of reconstructing water quality change in response to human activity. In Europe we now have extensive palaeo data-sets for lakes that enable the extent of water quality change as a result of 19th and 20th century pollution to be assessed at the continental scale.

Palaeoecological methods now need further development to address specifically questions more relevant to biodiversity and ecosystem functioning issues rather than water quality. Such questions include:

1. What is the history (e.g. over the Holocene, over the Anthropocene etc) of taxa that are well preserved and identifiable?
2. Are trends in biodiversity between groups (e.g. diatoms, cladocera, chironomids) congruent in time?
3. How useful are diatoms as indicators of biodiversity?
4. Can the fossil record be used to indicate changes in biodiversity of communities that do not leave remains?
5. Can the palaeoecological record be used to track changes in genetic diversity, e.g. from the analysis of diapausing bodies?
6. What processes (natural climate change and variability, ecological succession, human activity e.g. related to soil erosion, eutrophication, acidification, salinisation) have been responsible for biodiversity change through time.
7. Has human activity in the past caused a loss of biodiversity either at a site or amongst a population of sites on a landscape scale (beta-diversity) and do we see convergence of naturally diverse ecosystems towards more homogenous species-poor states?
8. Can we use palaeoecological records to identify the impact of different stresses on ecosystem functioning e.g. in terms of loss of resilience, early warning of approaching thresholds etc?
9. Can observations of biodiversity change amongst sites along environmental gradients (e.g. nutrients, acidity) in space be observed within a site in time and can space and time approaches be combined to develop better predictions of response to a pressure in future, e.g. in response to climate change?.

10. With respect to climate change have there been changes in the past that we can use to evaluate threats for the future?
11. How can the palaeoecological record be used to inform nature conservation and is there any evidence from the recent palaeoecological record that current restoration practices are leading to an increase in diversity or a return to good ecological status?
12. How can we use sediment records to evaluate the role of other drivers of biodiversity loss to identify systems that are more vulnerable to climate change (especially relevant to shallow eutrophic lakes)?

In order to address these questions we need:

1. Further development of palaeo-databases (including surface sediments) both for meta and primary data;
2. To identify availability of existing contemporary data-sets e.g. mountain lakes, shallow lakes, that can be used for congruence analysis
3. To assess relative usefulness of different groups that leave high quality remains (e.g. diatoms, cladocera, chironomids, aquatic plants) as indicators of biodiversity change.
4. To assess how representative surface sediment records are of contemporary populations and distributions
5. To apply and test methodologies to address questions above on a case study basis.

Groundwater contamination and impact on human health

Mohammed Messouli, University of Marrakech, Chair DIVERSITAS NC Morocco

Moroccan Groundwater (GW) Systems in most Oases are experiencing dras-tic changes due both to global scale stresses, and the cumulative effects of local and regional scale changes. The adaptive capacity and resilience of GW are severely deformed because of the high magnitude of drivers. Many of the driving forces, in Moroccan oases, are leading to irreversible changes in the subsurface environment. The trend is that the subsurface is being used more and more for different functions. Pressures are due to the presence of pollutants but also to changes in the natural physico-chemical conditions.

In the Tafilalt Oasis, part of UNESCO Biosphere Reserve (SE Morocco), water for irrigation canals has, since the late-14th century, been provided by khettara (subterranean channels draining perched water tables). Since the construction of Hassan Eddakhil dam, in the early 1970s, the remaining active khettaras began to experience reduced flow, and over the next two decades many more khettaras dried up and were abandoned.

While construction of potable water facilities has been accelerated along the Tafilalt Oasis, thanks to assistance from Japan (ODA) and other donors, development of sewage infrastructure has received but little attention. The valley's population growth has resulted in the setting up of numerous latrine systems very close to drinking-water wells. As a result, the septic wastes have kept seeping into these wells on almost every "Kasbah".

An impressive number of chemical and biological substances, mainly produced by human activities, accumulate in GW impairing the pristine quality of the water, producing changes in the structure and function of ecosystems and, very important, creating threats to human health.. Water-related diseases that are exacerbated by the degradation of GW include those caused by the ingestion of water contaminated by human or animal faeces or urine containing pathogenic bacteria or viruses, including cholera, typhoid, amoebic and bacillary dysentery, and other diarrhoeal diseases.

Comparative sampling of pristine and sewage-polluted GW showed that the contamination induced the disappearance of stygobites, promoted the colonisation of the aquifer by invasive stygoxenes. This finding highlights the importance of integrating faunal investigations into the framework of interdisciplinary research programmes on groundwater contamination.

Assessment of the impact of contaminants on biodiversity and ecosystem integrity is preferably based on system specific information on exposure, species sensitivity, population and community effects, and ecological recovery. This information is hardly available and no signs exist that applicable data and methods become available in nearby future.

Against this alarming situation, Biosphere Reserve areas fail to meet standards and commitments set in both international agreements and national government policy, and little is being done to remedy the situation. The ongoing degradation of GW ecosystem services is a significant barrier to achieving the Millennium Development Goals and the harmful consequences of this degradation could grow significantly worse in the near future. Urgent action is needed to reduce anthropogenic threats to GW systems and policy makers should tackle this problem at grassroot level.

Freshwater biodiversity and climate change

Mohammed Messouli, University of Marrakech, Chair DIVERSITAS NC Morocco

Aquatic ecosystems are critical components of the global environment. In addition to being essential contributors to biodiversity and ecological productivity, they also provide a variety of services for human populations (see www.diversitas-international.org/?page=cross_freshwater_pub). However, aquatic systems have been increasingly threatened, directly and indirectly, by human activities. In addition to the challenges posed by land-use change, environmental pollution, and water diversion, aquatic systems are expected to soon begin experiencing the added stress of global climate change.

Key Messages and research priorities

- Aquatic and wetland ecosystems are very vulnerable to climate change. The metabolic rates of organisms and the overall productivity of ecosystems are directly regulated by temperature. Projected increases in temperature are expected to disrupt present patterns of plant and animal distribution in aquatic ecosystems. Human alteration of potential migratory corridors may limit the ability of species to relocate, increasing the likelihood of species extinction and loss of biodiversity.
- Aquatic ecosystems have a limited ability to adapt to climate change. Reducing the likelihood of significant impacts to these systems will be critically dependent on human activities that reduce other sources of ecosystem stress and enhance adaptive capacity. These include maintaining riparian forests, reducing nutrient loading, restoring damaged ecosystems, minimizing groundwater withdrawal, and strategically placing any new reservoirs to minimize adverse effects.
- The continuing, accelerating loss of biodiversity could compromise the long-term ability of ecosystems to regulate the climate, may accelerate or amplify climate warming and could lead to additional, unforeseen, and potentially irreversible shifts in the earth system. Urgent action now to halt further loss or degradation of biodiversity could help to maintain future options for tackling climate change and managing its impacts.
- Both mitigation and adaptation are urgently required if we are to reduce climate change and its impacts over coming decades. Many of the people most vulnerable to climate change are those who depend most on biodiversity.
- A significant new research effort is required to improve understanding of the role of freshwater biodiversity in earth and climate systems, the impacts of climate change on biodiversity and human populations, and their interlinkages, feedback mechanisms and cross-scale effects.
- We need a follow up biodiversity ecosystem assessment to keep the focus, keep the IMOSEB momentum (= IPCC equivalent for biodiversity), and engage practitioners and policy makers.

Though more scientific knowledge is needed, there is a sound basis to begin policy application. Successful adaptation strategies must cover measures in all water-related sectors, particularly those which strongly depend on the availability of clean and sufficient water. Implementing adaptation rules is a challenging task: it has to deliver benefits in a cost effective way while accounting for many significant scientific, technical, planning, administrative and economic implications.

Adaptation of freshwater to climate change needs further development to address specifically questions more relevant to biodiversity and ecosystem services. Such questions include: What is the role for freshwater research and policy in mitigation and adaptation strategies?

- How can freshwater research contribute to the development of climate change adaptation and mitigation strategies?
- How can we use climate change science to benefit freshwater, biodiversity dependent livelihoods and sustainable development?

Confounding factors in chemical risk assessment

Jayne Brian and John Sumpter, Institute for the Environment, Brunel University, West London, UK

There is now convincing evidence that mixtures of chemicals act together to affect the health and sustainability of wildlife populations, highlighting the need to move away from chemical-by-chemical risk assessments and towards a more holistic and integrative approach. This will require consideration of how confounding factors, such as fluctuations in temperature and/or oxygen levels, influence the way in which organisms respond to mixtures of chemicals in real exposure situations. Exploration of this issue will help to determine whether existing safety margins are sufficient to ensure the protection of aquatic wildlife.

The sustainable management of the aquatic ecosystem has been increasingly compromised by pressure from anthropogenic changes: the effects of multiple stressors, including toxic chemicals, habitat alterations, pathogens and climate change, pose a significant threat to biodiversity (See Figure 1). Regulatory agencies are required to assess the potential impacts of these stressors to support policy and management decisions (Munns 2006). However, scientific assessments tend to focus on the impact of individual stressors, which fails to consider the cumulative risks arising from their interactive effects. This issue is illustrated by current approaches in ecotoxicology.

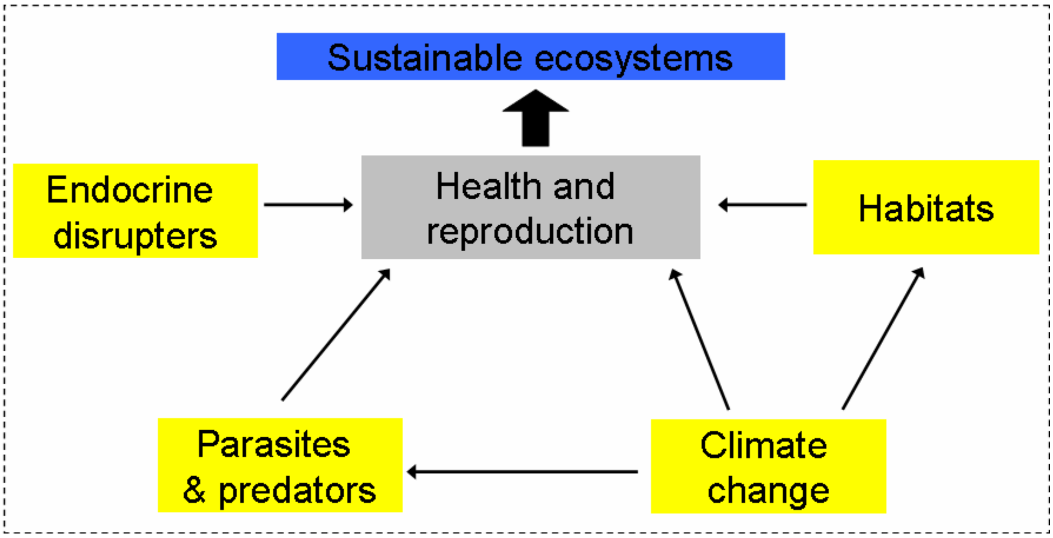


Figure 1. Schematic representation of the interactions between chemico-physical and biological factors that influence the response at the population level and beyond

Approaches for assessing the risk posed by chemicals in the environment assign a major role to standard toxicity tests, in which the response of a particular organism to a single substance is determined under otherwise constant and favourable conditions in the laboratory. However, the extrapolation of this type of data to real exposure situations is not straightforward because a wide range of chemical, biological and physical factors can influence the outcome of exposures in the environment (Heugens et al. 2001). As a result, the issue of whether existing risk assessment procedures can adequately protect humans and wildlife is clouded by uncertainty.

The implications of the single substance approach were considered, to some extent, in FP5/6, in which the effects of exposure to mixtures of chemicals were assessed. This revealed that endocrine disrupting chemicals have the capacity to act together to affect physiological and reproductive endpoints in fish (Brian et al. 2005; 2007). Significant mixture effects were detected, even when each component was present at a low concentration that was not sufficient to pose a threat on its own. These data demonstrate that current approaches may overlook risks that exist in real exposure situations and highlight one of the major limitations of existing environmental policy.

These data have also fuelled concerns that risk assessment procedures may further underestimate hazards by failing to consider how chemical toxicity may be influenced by the conditions of exposure. The use of laboratory-based toxicity data to determine risks that exist in real exposure situation fails to consider the potential influence of a wide range of environmental factors, which vary over spatial and temporal scales, on the response to chemical challenge. As yet, the relevance of confounding factors in the risk assessment of chemicals is an issue that has received little attention, despite the fact that a range of factors in the aquatic environment, including temperature, water quality and pH are known to modify chemical toxicity (Heugens et al. 2001).

The issue of confounding factors in the risk assessment of chemicals is extremely pertinent in view of climate change, which will undoubtedly lead to physico-chemical changes across a range of habitats, creating multiple stress situations (IPCC, 2007). Additional biological challenges may arise due to changes in ecosystem dynamics, such as the relationship between predator and prey or parasite and host. This may contribute to the way in which a population responds to contaminant-induced stress. The integrated nature of the hazards that exist within these dynamic and challenging exposure conditions highlights the urgent need to move towards methods that can achieve a more meaningful and holistic assessment of environmental risk.

In view of this need, further research is required to investigate the influence of these physico-chemical and biological interactions on the response to chemical challenge. This should focus on the integrated response to a well-defined group of chemicals, thus making it possible to differentiate between the effects of the different types of stressor. Endocrine disrupting chemicals offer an ideal candidate because their effects have been studied, both individually and in combination, across a range of assays. This existing knowledge base provides a strong basis for further research into interactive effects, which can be used to determine whether risk assessments should take more account of the confounding effects of environmental variability.

Taking a closer look at toxicants

Matthias Liess, UFZ, Germany

It is widely accepted that freshwater biodiversity is under pressure from a multitude of different stressors. However, there is great difference in the extent to which these different stressors are address by research. Toxicants especially are all too often ignored by researchers. I strongly feel that this is a shortfall, and due to the fact that (i) ecologists rarely recognise the importance of toxicants and (ii) toxicologists are often afraid of leaving the laboratory and to face the complexity of natural ecosystems.

To overcome this I suggest having a closer look at the effects of toxicants on freshwater biodiversity. As one example - pesticides strongly affect freshwater communities in streams within agricultural catchment areas (Liess M, Von der Ohe P. 2005), a problem relevant for most streams in Europe (Schriever C, Liess M. 2007).

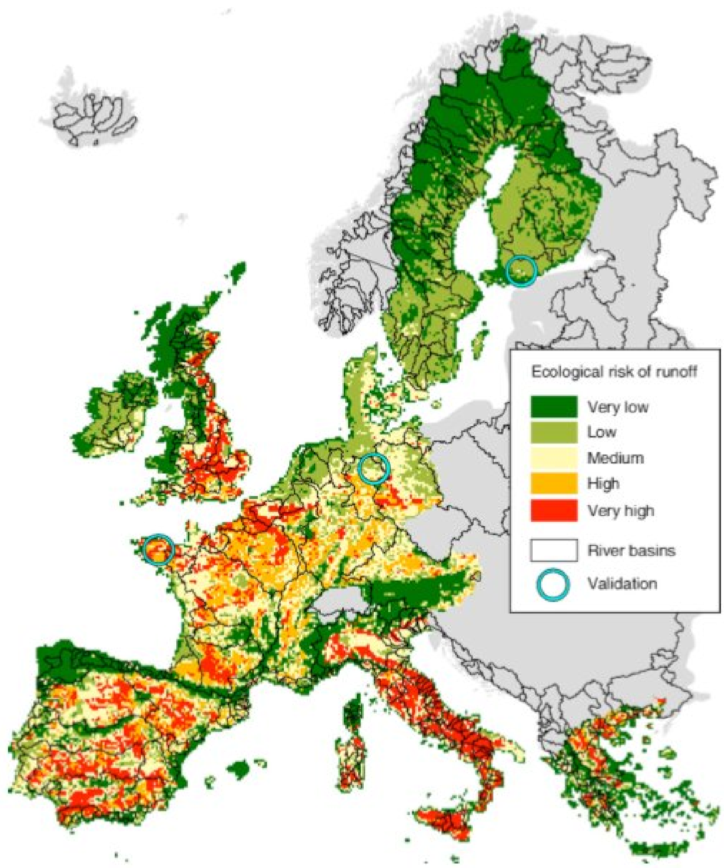


Fig. 4. Distribution of predicted ecological risk of runoff in the EU-15 countries (10-km raster). For details on the risk classification see Table 2.

Research on the hyporheic zone

Mohammed Messouli, University of Marrakech, Chair DIVERSITAS NC Morocco

With the growing demand for the sustainable management and utilization of natural resources, a better understanding of all components of the ecosystem, such as the linkage between groundwater and surface water, becomes imperative. This is even more relevant for arid regions where the impacts of environmental stresses tend to be more pronounced.

The hyporheic zone is a surface–subsurface hydrological exchange zone (i.e. an ecotone) along which stream water downwells into the sediment, travels for some distance beneath the stream, eventually mixes with ground water, and then returns to the stream. Important attributes of the hyporheic zone are: (1) the integration of groundwater (flow through porous medium) and channel water (free flow) and (2) the associated gradients in such variables as temperature, redox potential (Eh), pH, organic matter content, microbial numbers and activity, and availability of nutrients and light.

It is important for stream ecologists to consider the hyporheic zone when studying streams and rivers. One reason is that this zone is an important habitat for numerous aquatic organisms. Hyporheic zones contain a wide variety of subterranean fauna and zoobenthos, either at various stages of their lives or throughout their life histories.

A second reason for including the hyporheic zone in studies of stream and river ecosystems is the impact that hydrologic exchange with this zone has on surface stream biota. Hyporheic zone sediments and waters are metabolically active with complex patterns of nutrient cycling, which vary spatially and temporally. Upwelling waters from the hyporheic zone can deliver limiting nutrients to the stream channel that influence rates of algal primary production, the composition of benthic algal assemblages, and the recovery of stream reaches after disturbance.

A third reason for studying the hyporheic zone is the importance of this ecotone in the uptake of solutes and on ecosystem metabolism. For example, rates of both nitrogen and phosphorus cycling are strongly influenced in many streams by processes occurring in the hyporheic zone (Cirmo and McDonnell 1997, Hedin et al. 1998, Dahm et al. 1998, Dent et al. 2001, Thomas et al. 2003). Stream metabolism is also strongly affected by hydrologic exchange between surface waters and groundwaters and the residence time of water in the hyporheic zone.

Finally, landscape characteristics and scaling of exchange processes between streams and hyporheic zones are important to material storage and transport, stream biota, and ecosystem processes.

Below we outline four priority areas for research on the hyporheic ecotone:

- More interdisciplinary research and environmental management practices are needed to better understand, predict and manage processes at the interface of environmental compartments;
- The goal of environmental regulations to improve ecological health requires a holistic approach integrating our understanding of the ecological, hydrological, biogeochemical and physical processes;
- Upscaling spatially and temporally variable processes remains difficult and may hinder translation of research at micro-scales (molecular to grain size) into macro-scale (reach to catchment) decision-making;
- Scientists need to better communicate existing research to river managers, while managers must better communicate policy and regulatory-driven science requirements to researchers. Existing models, such as those that simulate stream-hyporheic exchange, are not widely known and rarely used by environmental managers.

Assessing the value of all waterbody types

Jeremy Biggs and Penny Williams, Pond Conservation: The Water Habitats Trust, Oxford Brookes University, Oxford, UK

There is a critical need for research that assesses the value of all waterbody types, large and small, in maintaining ecosystem functions.

Freshwater science has traditionally focused on the ecology of larger lakes and rivers, and has typically been concerned with the functioning of individual waterbodies. This has inevitably led to an underestimation of the value of the large numbers of smaller waterbodies - ponds, small lakes, ditches - which typify most catchments. Thus a recent estimate (Downing et al 2006) suggests that about 30% of standing surface water globally is in ponds and lakes of 10 ha or less in area. There is growing evidence that these small waterbodies play an essential role in catchment processes. Specifically: (i) they are critical biodiversity hotspot, with ponds, for example, contributing more to landscape, gamma diversity than rivers, lakes or streams (Williams et al 2004) (ii) they provide a wide range of ecosystem services from flood storage to carbon sinks (new Downing et al, in press).

All freshwaters, large and small, face uniquely wide-ranging challenges in the coming decades. They are threatened not only by local physical loss and damage, but also by threats far more remote in their catchments. This makes protecting freshwater uniquely challenging because adequate protection requires management of whole landscapes, not just the waterbodies themselves.

Taken together, these observations suggest the following major themes in freshwater biodiversity research:

1. A need to improve understanding of the whole network of habitats, both large and small, used by aquatic biota. Given the abundance and ubiquity of smaller waters, it is clear that their basic function and contribution to regional biodiversity needs to be better understood. In particular we need to understand: where freshwater biodiversity is located in semi-natural and anthropogenically modified landscapes, how freshwaters function as network of habitats, how biota exploit different types of water body at different times and how to manage systems to maintain or recreate these network functions. This has become particularly urgent requirement given the added stress of climate change.

2. The effects of agriculture. Given the current and likely future growth in agriculture, the need to develop techniques that effectively protect freshwaters has never been greater. Many different environmental technologies have been proposed to protect water from agriculture (buffer strips, no till agriculture, nutrient management) – and many billions of Euros are spent annually in applying these measures via agri-environment schemes and legislative enforcement. However, for most techniques there is very little evidence that their application is sufficient to make any on-the-ground difference to biodiversity. Research is needed both to properly assess the biodiversity benefits of different agricultural land management techniques, and to assess how to apply these measures strategically so that they have greatest value.

3. Protecting our highest quality ecosystems – large and small. There is clear evidence that it is possible to improve badly degraded freshwater ecosystems (for example, improving streams by installing effective sewage treatment plants). However, maintaining the quality of the top tier of sites (High status sites, in WFD terms) is more difficult. In the UK, for example, evidence suggests an onward decline in these top quality systems, which are the most important for biodiversity. Research to protect these high quality sites is urgent, and needs to focus on the multi-functional threats they face (land-use, climate, diffuse pollution) and the link between catchment management and the biotic response (not just the response of the physical and chemical environment).

4. Ecosystem services for biodiversity. In many parts of the world the main justification for protecting freshwater systems is the need to continue providing ecosystem services. Managing freshwaters to provide ecosystem services could be a major benefit for biodiversity: for example, waterbodies constructed to hold back water in upper catchments, or

to treat nutrient contaminated runoff have the potential to work effectively to enhance biodiversity. Research is needed to better understand the multifunctional benefits of such waterbodies.

Freshwater biodiversity: knowledge gaps and research needs for sustainable management

Alan Hildrew, School of Biological and Chemical Sciences, Queen Mary, University of London, UK

Previous contributors to this e-conference have effectively identified many key issues adding up to what is evidently a mounting 'biodiversity crisis' for freshwaters everywhere. I would like both to add to the 'list' but also to try to synthesise matters for a new research agenda within the EU. I will organise my remarks under four headings: i) priorities for the assessment of freshwater biodiversity, ii) new approaches and technologies, iii) climate change and freshwater biodiversity, and iv) providing information.

i) The assessment of freshwater biodiversity is presently very partial with respect to habitat (strong for larger water bodies, streams and rivers, poor for small, temporary and subsurface habitats), geography (uneven coverage within Europe and more so elsewhere) and taxonomy (good for larger organisms, less so for small, obscure or 'difficult' taxa). In particular, 'whole catchment' diversity often resides outside the main channel of rivers and streams, in off-channel drainage ditches, ponds and marshes in floodplains and elsewhere. In such small, more-or-less isolated water bodies, much diversity resides in between-habitat differences (i.e. in beta diversity). The overall 'population' of such small habitats is therefore necessary for effective conservation of overall species diversity, and the minimum density or number of local habitats necessary for particular tax is unknown.

ii) Assessing ecological status is mainly based on biological indicators, and for running waters is concentrated on sampling the main channel. We might ask how effectively assessments of in-stream communities can asses ecological quality at the whole-catchment scale – including the less well characterised habitats mentioned in i), above? Assessment of such habitats may be required for effective management. Evidently, molecular techniques are becoming more and more important, in characterising microbial diversity at the base of food webs, in assessing the genetic population structure of larger organisms, and in revealing sibling species even of quite well known taxa. Clearly, further research using such techniques is required both to test them and to exploit them in the assessment and monitoring of freshwater biodiversity.

iii) Climate change can influence freshwater biodiversity profoundly, and research on required environmental flows in a drier world have been stressed by others. A drying climate (or increased abstraction) will also reduce the supply of 'off-river' habitats available and thus the number of habitable patches for freshwater organisms living as metapopulations or in source-sink systems. This threatens local extinction for some species and a general loss of biodiversity. We need to test these propositions, assess how a drier landscape might depress gene flow and dispersal in aquatic organisms, and to provide conservation strategies that would not concentrate just on single water bodies but on suites or systems of water-bodies at larger spatial scales.

iv) Several people have mentioned web-based information systems that give access to information about freshwater biodiversity. I might add that the Freshwater Biological Association has been developing such a system - FreshwaterLife - which is such a web-based portal and can be seen at www.freshwaterlife.org

Biodiversity and ecosystem functioning

Klement Tockner and Hans-Peter Grossart, IGB, Institute of Freshwater Ecology and Inland Fisheries, Berlin, Germany

The scientific community has come to a broad consensus on many aspects of the relationship between biodiversity sensu lato and ecosystem functioning (BD-EF), including points relevant to management of ecosystems (summarized by Hooper et al. 2005). However, most information is derived from terrestrial ecosystems and it remains questionable if these results can be transferred to aquatic and semi-terrestrial ecosystems (see Covich et al. 2004, Giller et al. 2004). Below, we briefly discuss selected research directions to better understanding BD-EF relationships in aquatic ecosystems.

1. Habitat heterogeneity, biodiversity and ecosystem functioning: Embracing spatial heterogeneity is seen as the next frontier for ecosystem ecology (Lovett et al 2005). Ecosystems need to be considered as interacting mosaics rather than homogeneous entities, and the composition and the spatial configuration of patches, as well as the boundary properties (e.g. permeability), need to be used as variables for predicting biodiversity and ecosystem processes. Strayer et al. (2003) suggest that in order for fine-scale spatial heterogeneity to influence whole-system performance two conditions are necessary – strong differentiation among patches and variability in patch connectivity. For example, we need to understand which habitat types and habitat attributes are most strongly influencing the capacity of a system to transform nutrients and organic matter and to quantify how the spatial arrangement of individual patches and the nature of hydrologic linkages (source and pathway of water, frequency and duration of connection) influence the capacity of a system for nutrients and OM cycling.

2. Functional linkages across ecosystem boundaries: Aquatic and terrestrial systems are tightly linked by trophic fluxes across aquatic–terrestrial boundaries. The prominent direction of aquatic–terrestrial fluxes shifts from forested headwater streams, where terrestrial input dominates, to open braided rivers, which exhibit a net transfer of aquatic-derived energy into riparian food webs. Riparian land use and river regulation can affect the bidirectional flow of matter and organisms along river corridors (e.g. Marczak et al. 2007, Paetzold et al. 2008). Hence, major research questions include: (i) how does the diversity of aquatic and terrestrial consumers affect the transfer (amount and direction) between the two systems, (ii) how does the availability and diversity of spatial subsidies affect populations, communities, and ecosystem processes in donor and recipient habitats? (iii) How do environmental conditions (e.g. increase in temperature and flow variability) influence aquatic-terrestrial linkages? (iv) How are pulses of resources transferred through various trophic levels, and how will a future shift in the magnitude, frequency, and timing of such pulses affect the various trophic levels?

3. Terrestrial habitat requirements for aquatic insect life history functions: Aquatic insects only spend a short period in the terrestrial environment although key life-history functions (i.e. dispersal, mating, egg deposition) are restricted to this period. Mortality during this period is very high, most likely much higher than during the entire aquatic period. However, our knowledge about the habitat requirements of aquatic insects during the terrestrial phase, i.e. for different life history functions, remains very limited. Do we know what the spatial extent of the "airscape" used by terrestrial stages of aquatic insects is? Very recently, Becker et al. (2007) demonstrated that species with aquatic larvae may suffer from the habitat splitting during their terrestrial stage (and between the aquatic and the terrestrial habitats).

4. BD-EF relationship at multiple trophic levels: Multiple trophic levels are common in aquatic ecosystems but have been completely understudied in BD-EF research. The response of ecosystem properties to varying composition and diversity of consumer organisms is much more complex than responses in the diversity of primary producers or decomposers (question of functional relevance). And how will anthropogenic and natural stressors (single and in concert) influence BD-EF relationships?

5. Novel communities and BD-EF relationship: Rapid changes in land-use, temperature, flow conditions in concert with species invasions will lead to novel communities in aquatic ecosystems. It remains a challenge to predict the composition of future communities and to develop experiments to testing the underlying mechanism and, hence, functional consequences of such novel communities.

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 and Paula Antunes, CENSE (Centre for Environmental and Sustainability Research) Ecological Economics and Environmental Management Group, Faculty of Sciences and Technology, New University of Lisbon, Portugal

This short paper identifies some of the main research priorities for freshwater biodiversity conservation arising from the implementation of a new EU water governance regime, focusing in particular in multi-disciplinary research in the interface between natural and human systems.

EU water governance requirements have changed with the adoption of a new water management paradigm, implemented through the application of the Water Framework Directive (WFD). The WFD recognizes water as a life support resource, and for this reason the main goal of the European water policy is to achieve a good ecological quality status in the water bodies of all member countries. This new perspective implies the adoption of a multidisciplinary approach to water resources management, capturing multiple aspects and concerns, considering objectives, concepts and tools from diverse fields like hydrology, ecology, economics, political science and sociology. The WFD has brought new requirements in aspects such as monitoring, assessment of impacts of human activities, valuation of ecosystem goods and services, design of new pricing systems and stakeholder engagement.

The linkages between this new water management paradigm and biodiversity conservation are widely acknowledged. However, in order to address these linkages, policy development and implementation processes still need a significant contribution from theoretical and empirical research, and mainly the development of new multidisciplinary approaches capable of dealing with complex and uncertain situations/ scenarios/ problems in the presence of limited/scarce resources and multiple values. In this context, we propose some priority areas for the European research in the field, focused mainly in the interaction between human and natural systems, including:

- Long term monitoring of freshwater conditions and biodiversity, establishing the connection with human social systems. This means studying the relation between ecological status of water bodies and human drivers of change, as well as linking ecological monitoring activities and results with the analysis of human perceptions, attitudes and behaviours regarding freshwater ecosystems. The development of approaches to promote active public participation in freshwater ecosystems monitoring activities is also a major area of research in monitoring activities.
- Assessment of impacts of pressures in freshwater ecosystems, such as fragmentation of natural species rich habitats, construction of highly managed ecologically-poor habitats (such as waterways, channels and reservoirs), pollution and over-exploitation of resources, associated to human activities such as irrigation, energy production, industrial development, tourism and domestic consumption. The assessment of the resilience and adaptive capacity of freshwater ecosystems to human pressures plays a central role in this matter. The development of knowledge and approaches to deal with the uncertainty and complexity inherent to the study and anticipation of behaviour in human-environment interactions, as well as the development of appropriate indicators and assessment tools are also a priority.
- Closely related with the previous topic, the assessment and valuation of ecosystem goods and services is also a major area of concern. The relevance of providing decision-makers estimates of the value of ecosystem services linked to freshwater biodiversity (e.g. food provision, flow regulation, water purification…) is widely acknowledged. Although there have been many studies developed at the local level for very particular situations, there are still many open questions related with the underlying assumptions of valuation, methodological issues, development of ecosystem-based studies (as a complement to the single-species or single-resource valuation experiences that have been developed), up-scaling and generalization of these exercises and the analysis of distributional aspects.

- Development of research in constructive stakeholder engagement in planning and management of both natural and modified freshwater ecosystems, focusing particularly in policy formulation and implementation processes. It is important to develop additional research to demonstrate the value of involving stakeholders and of adopting cooperative strategies. Although there have been several studies using different approaches and tools for stakeholder participation (e.g. social multi-criteria assessment, citizen juries, expert panels, mediated modeling,…), there are still many interesting theoretical and applied research topics, namely related with multi-level governance aspects (e.g. linking stakeholders at different scales - local, regional, national, international), communication of information to different audiences, design of new institutions to enhance cooperation or to avoid the collapse of cooperative approaches in the presence of significant changes in the ecosystem goods and services flow.
- The development of knowledge to support the design and implementation of policy instruments is a key element to achieve a well succeeded freshwater biodiversity conservation strategy. Freshwater biodiversity conservation can have opportunity costs that should be taken into account in the design of new incentives. Managing freshwaters for multiple purposes requires taking into account potential trade-offs between protection and exploitation. Moreover, freshwater ecosystems, especially rivers, cannot usually be protected adopting traditional zoning instruments (e.g. nature reserves) because of existing interdependencies with their catchments, and the importance of longitudinal, lateral and surface/groundwater interactions, thus requiring the development of new approaches. It is also relevant to improve knowledge about the links to other policies (e.g. agriculture policy) since freshwater ecosystems are also shaped by regional and global influences such as extensive groundwater systems, atmospheric deposition and climate change. The consideration of stakeholder perceptions of ecosystem functions and the understanding of key aspects influencing their behaviour are also important issues to consider in the development of new instruments, for which further research is needed.

Biotic indicators and the European Water Framework Directive

Didier Pont, Cemagref, France

Based on recent developments on fish-based bio-indicator in rivers, this contribution highlights some priorities for future research, in relation with the development of a standardized assessment of water bodies at the European scale.

The European Union Water Framework Directive (WFD) requires the assessment of all European rivers and their classification into five predefined levels of ecological integrity, based on four biotic elements, of which one is fish. In general, freshwater fishes are very good indicators of the biotic integrity of freshwater ecosystems because they occupy the top of most aquatic food webs. A high level of fish diversity in a given aquatic ecosystem could be related to favorable status of other fauna elements in the river but also to good status of the whole drainage catchments. They are sensitive both to regional (climate change, lack of connectivity) and local disturbances (physical impoundments, water quality).

There is now a growing need for sensitive biological measures of aquatic ecosystem integrity that can be compared between eco regions or basins. One way to attain this goal is to develop a common assessment method at the European scale. This requires the ability to define metrics (based on biological and ecological traits) which remain insensitive to natural environmental variability for any unimpaired site, and secondly, for any impaired site, the ability to quantify metric deviation from a predicted value. Adapting such a multimetric index over a broad area requires a detailed understanding of the nature of the major environmental gradients that cause, or at least explain, patterns of assemblage composition within and among water bodies under natural conditions.

A first common European Fish Index (EFI) was published recently (Pont et al. 2006, Pont et al. 2007). The EFI is as accurate as existing regional methods, but is also able to consider and compare a much wider variety of eco-regions than other methods. Nevertheless, some limitations are obvious. New future research is needed to improve such an approach at the European scale, including:

- A better description of the responses of species to the various types of human pressures, considering both water quality alteration and hydromorphological modifications, will allow the improvement of the efficiency of functional metrics used in multi metric indices.
- Empirical models linking the intensity of different pressures (degradation), restoration (recovery), and ecological status in small and medium sized rivers, lakes, and selected coastal areas have to be developed. The uncertainty of the models must be assessed.
- The problem of multi-impacted sites is of first importance, as it is one of the most common features in Europe. Very few is known about interactions between pressures.
- The potential impact of climate change on the baseline used to define reference conditions, as well as on the thresholds used as ecological class boundaries need to be evaluate
- In the same way, any climate change can also modify the impact of a given pressure on the aquatic fauna
- Concerning impacts of toxic substances, new specific bio-indication tools have to be developed. In such a way, efficient collaborations between eco toxicologists and hydrobiologists have to be encouraged in the future
- On the long term, future bio-indicator tools must be more based on process-based models rather than statistical ones.

Freshwater research needs from the CBD

Carsten Neßhöver, Helmholtz Centre for Environmental Research, UFZ Leipzig-Halle GmbH

The contribution summarizes a survey of CBP-COP-decisions regarding research needs on inland waters. It shows that research needs for Europe might easily be linked to the ones from CBD decisions.

As I am not a freshwater expert, I will not get into the specific discussion, but rather draw your attention to an existing source on research needs: The COP-decisions of the CBD, in our case on inland waters. The German Federal Agency for Nature Conservation has commissioned a complete survey of all COP decisions on research needs (very informative). This database is available via the German Clearing-House-Mechanism: www.biodiv-chm.de/konvention/fol412327. The research needs identified for freshwater can be found in more detail at www.biodiv-chm.de/konvention/fol412327/doc116498

Most of the issues raised there are quite generic and already covered by contributions to the e-conference (e.g. the importance of monitoring, indicators, and taxonomy). I would like to bring to your attention only a few points from this list, which I think have been missing in the e-conference to some extent until now and rather refer to the discussion on WFD and management issues in Session II:

- Identify nationally priority candidate inland water ecosystems and/or sites for rehabilitation or restoration and proceed to undertake such works, as resources allow. In identifying potential candidate sites, consider the relative conservation status of the threatened species involved, and the potential gains for the overall ecosystem functioning, productivity and "health" within each drainage basin.

Restoration of inland waters might become more and more important, especially in Europe – there are certainly some success stories available (e.g., fish species in the river Rhine)- but are these measures, focussing on the chemical aspects of restoration enough? What about the physical conditions of the rivers?

- Promote research to improve the understanding of the social, economic, political and cultural drivers within civil society that are directly impacting on the conservation and sustainable use of the biological diversity of inland waters.
- Develop effective management strategies to maintain or improve the sustainability of inland water ecosystems, including those identified as most stressed and facilitate a minimum water allocations to the environment to maintain ecosystem functioning and integrity. In so doing, consideration should also be given to the likely impacts of climate change and desertification, and factor in suitable mitigation and adaptive management approaches.
- Review the range and effectiveness of national incentives, subsidies, regulations, and other relevant financial mechanisms, which can affect inland water ecosystems, whether adversely or beneficially.
- Undertake comprehensive valuations of the goods and services of inland water biodiversity and ecosystems, including their intrinsic, aesthetic, cultural, socio-economic and other values, in all relevant decision-making across the appropriate sectors.

From our experience at the river Elbe, these economic and social drivers are essential in addressing the conservation of intact river systems. How do we increase the abilities of societies towards a more integrated management in multi-stakeholder situations- as they are typical in wetland systems (see also contribution by Rui Santos)?

- Assess the linkages between inland water ecosystems and climate change and the management options for mitigation of and adaptation to climate change.

The WFD and its role in managing non-native invasive species in fresh waters

Philip Boon, Scottish Natural Heritage, Edinburgh, UK

Introduction

Invasive non-native species are not specifically mentioned in the text of the EC Water Framework Directive WFD. However, both Annex II and Annex V indicate that they do need to be assessed, both as environmental 'pressures' and because they undermine 'naturalness', a key principle of the WFD. The European Commission's ECOSTAT group is beginning to examine the issues surrounding non-native species with respect to the WFD, including the use of these species in ecological status classification, and the way that WFD 'programmes of measures' might be used to address some of the problems.

Principles in managing non-native invasive species

Some key principles behind successful non-native species management include:

- Preventing future problems – this involves detailed risk assessment on individual species
- Taking early and urgent action on new outbreaks, identifying and controlling external sources of potential recolonization
- Using appropriate tools and techniques as part of a long-term management approach, rather than 'one off' eradication of existing problems
- Linking funding to long-term management programmes
- Involving stakeholders and interested parties, defining clear roles and responsibilities
- Underpinning the process by monitoring, with appropriate systems for storing, analysing and retrieving data
- Raising the profile of non-native species issues by appropriate and targeted publicity
- Undertaking research in support of non-native species management programmes

Priorities for research

- Risk assessments for freshwater species known to have (or believed to have) invasive potential. These will be specific to individual countries, or individual regions within countries, but where relevant, opportunities must be taken for information sharing throughout Europe.
- Studies on the ecology of individual non-native species, including genetics, reproduction, population growth, competitive ability, and the responses of organisms to abiotic factors. These studies may also need to include native species which, when introduced into other water bodies outside their natural range, may become invasive and threaten native populations.
- New techniques for survey and monitoring to enable the distribution of key invasive freshwater species to be mapped. For some species, existing survey techniques may be inadequate for accurate and repeatable recording.
- Studies on the potential effects of climate change on the distribution of non-native species. As temperature and rainfall patterns change, some invasive species will extend their distribution, while other species not yet invasive may become so.
- Work on new methods of eradication for particular non-native species. These may include 'traditional' methods such as mechanical removal and chemical treatment control, but should also involve new techniques of biological control.

Conclusion

Using the EC Water Framework Directive to address problems caused by freshwater invasive species requires a better understanding of their ecology and distribution and their response to changing environments, an assessment of the risk they pose to native species and habitats, and the development of innovative techniques for their control or eradication.

International policy frameworks for managing environmental flows for biodiversity

David Katz, Porter School for Environmental Studies, Tel Aviv University, Israel

Increasingly national and international policy frameworks are being created or adapted to promote environmental flows for aquatic ecosystems, however, because the concept of environmental flows is relatively new in the policy world, serious gaps exist as to the effectiveness of such policies and as to the institutional and financial mechanisms necessary for successful policy implementation.

Flow has been identified as the "master variable" in determining aquatic ecosystem functioning (Poff et al, 1997; Postel & Richter, 2003). Increasingly governments and international organizations are recognizing the importance of securing and restoring flows to streams and wetlands and are developing national and international legal and policy frameworks to do so. In addition, many more national policies and international agreements provide general frameworks, which while not addressing environmental flows explicitly, can be utilized to secure such flows (for reviews of such policies see Dyson et al, 1997; Scalon & Iza, 2004; Katz, 2006). Because such policies are relatively new, however, there remain many gaps in knowledge regarding their effectiveness in preserving biodiversity and ecosystem services, their cost-effectiveness, and their generalizability and transferability across regions and across ecosystem types. Furthermore, although arguments as to the economic and social benefits of environmental flows are often used to support the adoption of flow related policies, scientific, economic, and policy analysis research regarding environmental flows have evolved largely separate from one another, rather than in an integrated fashion that would allow cross-disciplinary learning.

The following are some of the pressing research needs related to this field:

- As knowledge about environmental flows and flow policies is still limited, especially in developing countries (Moore, 2004), there is a need to develop policies to disseminate and exchange knowledge, and train personnel. In this respect, development of a searchable global database on environmental flow prescriptions would be a welcome contribution. One such database listing environmental flows identified in published literature is currently in the initial stages of development by the International Water Management Institute (IWMI) and could serve as the foundation for a more inclusive and interactive research oriented database of the type just described.
- There is a great need for comparative work regarding how environmental flow prescriptions and policies differ across regions, ecosystem types (e.g. streams, wetlands, lakes, groundwater), gradients of water quality (especially important as countries use reclaimed sewage for flow augmentation), and governance structures, as well as, how policies need to be modified based on whether the goal is preservation of healthy systems or restoration of already degraded systems.
- Cost of research necessary for policy prescriptions has been identified as an obstacle to implementation, therefore research is necessary to evaluate existing finance mechanisms and to develop new ones. At an international level, it is important to help develop guidelines for international financial institutions and monitor implementation of existing ones. The World Bank, for instance, has recently declared environmental flows as an important consideration in its Lending Policies (e.g. Davis & Hirji, 2003), while the Global Environment Facility (GEF) has designated transboundary waters as one of its six focal areas. Such commitments may offer a genuine opportunity to develop physical, human, and institutional capacity for environmental flow policies.
- While many international environmental protection and sustainable development frameworks are adopting some type of language to facilitate environmental flows, data is still needed regarding which of these are actually being utilized to secure environmental flows.
- Finally, because environmental flow policies tend to be new, there is little work done in monitoring their effectiveness. From the perspective of research agendas, however, this can

be seen as an opportunity, as it may allow for much needed collection of baseline data for "before and after" policy effectiveness studies.

Regional environmental flow standards needed to guide Integrated Water Resources Management

Angela Arthington, Australian Rivers Institute and Water Cooperative Research Centre, Griffith School of Environment, Griffith University, Queensland, Australia

Research to support environmental flow prescriptions for biodiversity protection should be focused on flow-ecological relationships in contrasting hydrological river classes, in order to fast-track sustainable and integrated water resources management.

Flow regime modifications are ubiquitous in running waters (Naiman et al., 2002; Postel & Richter, 2003; Nilsson et al. 2005) and are likely to be exacerbated by global climate change (Vörösmarty et al., 2004; Dudgeon et al., 2006). With increasing concern about the impact of dams and flow regulation on river biodiversity and ecosystem goods and services (EGS), the scientific field of "environmental flows" has prospered to produce more than 200 methods grouped into four categories: hydrological rules, hydraulic rating methods, habitat simulation methods and holistic methodologies (Tharme 2003). Holistic (ecosystem) approaches recognize that the structure and function of a riverine ecosystem and many adaptations of its biota are dictated by patterns of temporal variation in river flows - the "natural flow-regime paradigm" (Richter et al., 1996, Poff et al., 1997, Lytle and Poff, 2004). Unfortunately, translating general hydrologic-ecological principles (e.g. Bunn and Arthington, 2002; Nilsson and Svedmark, 2002) and knowledge into specific water management rules for particular river basins and species remains a daunting challenge (King et al., 2003; Arthington et al., 2006).

Four categories of ecological understanding and prediction are needed to support the development of environmental flow prescriptions and Integrated Water Resources Management for biodiversity protection, ecosystem resilience and societal benefit: (1) flow-ecology-EGS relationships in unregulated rivers (how does the natural flow regime drive the ecology of rivers in their natural states?); (2) flow-alteration-ecological-EGS response relationships, thresholds and resilience effects in regulated rivers (how do flow alterations from natural to modified states affect riverine ecology and resilience? Can we recognize ecological and EGS thresholds and tipping points?); (3) ecological responses and EGS benefits resulting from the implementation of an environmental flow regime (do environmental flows deliver the anticipated ecological and societal benefits?); and, (4) ecological responses to changes in river flow regimes brought about by the direct (e.g. more frequent and extreme flooding and droughts) and indirect (e.g. accelerated dam construction, interbasin transfers, complex, large scale, inter-linked water distribution systems) effects of climate change, and their interactions.

These knowledge gaps and predictive capabilities need to be addressed in all types of rivers, yet the task of building this comprehensive flow-ecology-EGS knowledge base appears near impossible. One way to fast-track the development of flow-ecological relationships and models is to classify the rivers of a bioregion, province or country according to flow regime (hydrological) characteristics, and then to build the required knowledge base and models for each contrasting type of flow regime (Arthington et al., 2006). If ecological responses to natural and modified flow characteristics and regimes prove to be consistent within each hydrological class, then environmental flow "standards" can be developed that typify that river class, and therefore, not all rivers within the class need to be studied in detail. The development of scientifically credible flow management guidelines in distinctive hydrological and ecological regions of the world would make a major contribution to the resolution of conflicts over shared water resources, and help to protect riverine biodiversity and the ecological goods and services provided by river ecosystems.

Danube: a lifeline or just a navigation corridor?

Orieta Hulea, WWF Danube-Carpathian Programme, Romania

The Danube River is the subject of conflicting EU policies, like plans and programmes to improve navigation by deepening and straightening the river on one hand and environment protection regulations on the other. The challenge is to shape the Danube navigation policies and contribute to solutions that will promote the competitiveness of inland navigation and improve the Danube's ecological status.

Despite many man-made changes and technological impacts, the Danube, the world's most international river and the second largest river in Europe, still preserves significant natural stretches with unique biodiversity. WWF considers the Danube as one of the Earth's 200 most valuable ecoregions, with great potential for ecological improvements and additional socio-economic benefits.

The Danube is the major waterway of Europe, with large potential for transporting goods promoted by the shipping industry and supported by the European Union plans within the framework of Trans-European Transport Networks (TEN-T) and NAIADES Programmes. TEN-T revised guidelines promote the Danube, the so called "Pan - European Transport Corridor" as the "backbone of the east-west waterway connection". At the same time, the Danube River is affected by many environmental legislative frameworks, including the EU Water Framework Directive (WFD) and Natura 2000 Directives (EU-FFH Directive and Birds Directive). According to the Roof Report of the International Commission for the Protection of Danube River, large parts of the Danube (86%) are "at risk" or "possibly at risk" of failing to meet the objectives of the EU WFD, especially due to hydromorphological alterations. The three main driving forces for these alterations are: hydropower generation, flood protection and navigation. Of these three, navigation has the most important impact on the Danube River.

In 2003, the EU and the navigation lobby of the Danube countries defined river stretches as "bottlenecks" - shallow river stretches- with a combined length of about 1000 km where river engineering measures are to be carried out over the next 15 years. However, these bottleneck also happen to be places with some of the highest ecological value, so called ecological hotspots. There are projects planned to eliminate these bottlenecks by artificial dredging and other hydraulic measures to reach a minimum draught of 2.5 meters in all seasons along the entire length of the waterway from the North Sea to the Black Sea. The negative impact of these projects has only been evaluated and/or understood to a limited extent, and much more information derived from detailed research is necessary in order to put strong arguments on the table against the planned measures. We would like to suggest several priority topics which can contribute to identifying the best solutions to balance/mitigate the negative effects of unsustainable navigation plans and projects on the Danube River:

1. Comprehensive studies on the Danube's sturgeons population (population size, distribution, behaviour – especially in relation to hydromorphological alterations and ecological requirements for migration and spawning) given that the sturgeon is an indicator species for implementing the WFD at the Danube basin level and the lower Danube is the last river sector where natural reproduction still occurs;

2. Detailed analysis of critical points (bottlenecks) from different perspectives: navigation (economic pressure), environmental protection and biodiversity conservation, preservation of key natural processes (sediment transport, erosion, deposition processes) and a detailed evaluation of the costs associated with the losses/benefits of removing these bottlenecks, integrating environmental costs;

3. Promote research on new innovation technologies which can compensate for existing hydraulic river constructions through restoration and compensation measures for river morphology and ecology (e.g. reverse engineering of obsolete constructions, opening side channels/arms, removing shore reinforcements and obsolete dams, restoring rivers sections that are not problematic for navigation).

More information on these topics would support a shift from the old strategy of canalising rivers to a new strategy which integrates other needs of the Danube with its "multi-use" services, including sustaining freshwater biodiversity.

Good ecological status in the Water Framework: What does it mean for freshwater biodiversity?

Thomas Dworak, Ecologic (Institut für Internationale und Europäische Umweltpolitik gemeinnützige), Vienna, Austria

Implementing the Water Framework Directive will indirectly bring also benefits to biodiversity. However the magnitude of these benefits is currently unknown and should be assessed in more detail.

The Water Framework Directive (WFD, 2000/60/EC) is the most substantial piece of water legislation ever produced by the European Community. It requires that all inland and coastal waters within defined river basin districts must reach at least good status by 2015 and defines how this should be achieved through the establishment of environmental objectives and ecological targets. Further objectives of the WFD are to protect and enhance the status of aquatic ecosystems (and terrestrial ecosystems and wetlands directly dependent on aquatic ecosystems) and to mitigate flooding events.

Even if the issue of biodiversity is not directly mentioned in the Directive, there are several overlaps between implementing the WFD and protecting biodiversity:

- Biodiversity is (implicitly) included in the definition of the water status due to biological quality elements. There are four biological quality elements specified in the WFD: i) phytoplankton, ii) macrophytes, iii) invertebrates and, iv) fish. The status of each of the biological elements for natural water bodies is determined by measuring the extent of the deviation of the sample taken from that established for that element in the absence of pollution or disturbance, referred to as the reference condition.

- The WFD requires protection of areas under the Natura 2000 network of sites (Habitats Directive and Birds Directive) but also species are not covered under existing biodiversity legislation; however they represent an important factor in natural habitats. For example groundwater is often considered as an abiotic environment. But this is an underestimation of the value of groundwater systems for biodiversity. Groundwater is the substrate for numerous microorganisms and animals. There are several hundred species of metazoan animals (animals larger than bacteria and protozoans), such as worms, shrimps or even amphibians, which fulfil an important role in the groundwater ecosystem.

- Finally and most important achieving the environmental objectives requires that the key pressures are addressed, which are also key pressures driving biodiversity loss. In particular the following pressures for biodiversity and water have been identified:

- eutrophication/organic pollution
- hydromorphological changes
- habitat fragmentation
- acidification
- toxic pollution
- effects of alien species
- water abstraction

Art 11 of the WFD requires that Member States take specific measures to tackle the pressures mentioned above and to outline these measures in river basin management plans. In many cases these measures have to follow a more holistic approach which requires taking action also in water related sectors, such as agriculture, forestry or industry. If measures are implemented properly, also benefits for biodiversity if measures can be expected. For example designing and restoring wetlands as part of flood management schemes is an opportunity to reverse the decline, and achieve targets for national biodiversity action plans. The restoration of floodplains will provide habitat for vulnerable species and contribute to flood attenuation.

However, even if there is a large overlap between implementing the WFD and protecting biodiversity from a legal point of view, the success of achieving both, protecting water and biodiversity will strongly depend on the implementation practice in the different EU Member States. The first river basin management plans have to be prepared in 2009 and will show the efforts made. Assessments such as analysing the detailed benefits of WFD implementation for protecting biodiversity would than be useful in order justify the costs of the implementation on a wider basis. Such an assessment should also focus on the interlinkages between the different responsible authorities for water management and biodiversity protection.

Valuation of the goods and services provided by freshwater biodiversity

Jay O'Keeffe, UNESCO-IHE (Institute for Water Education)

Research should concentrate on improving the quantification of ecological goods and services (EGS) obtained from biodiversity, and on developing economic models which provide holistic valuations of natural resources, and reflect the long-term benefits of sustainable resource management.

Despite the wave of policy and legislation (e.g. the South African water Act of 1998) that has followed the Rio convention of 1992, global biodiversity continues to deteriorate. Freshwater biodiversity is deteriorating faster than in any other ecosystems (Living Planet Index, 2004). The question is: Why is there such a mismatch between the good intentions of the policy and legislation, and its implementation? Reasons for this appear to be:

- That the way that people value short-term economic profits almost always overrides the long-term environmental costs
- That ecologists are still not very good at predicting and quantifying the losses of EGS consequent on natural resource development. (e.g. if 50% of the flow is to be abstracted from a river, what EGS will be depleted, and by how much?)
- That present economic models provide only component evaluations of natural resources, and treat these as if they were the value of the resource. (e.g. rivers are often evaluated in term of their commercial fish productivity, or pollution purification capacity, rather than holistically)
- That present economic models apply discount rates which reduce the value of long-term benefits in comparison with immediate benefits.

Key research questions/priorities:

- How is biodiversity related to the functioning of freshwater ecosystems on which the provision of goods and services depend? i.e. if the flow of a river is reduced by 50%, can we quantify the loss of biodiversity, and how much will this reduce the goods and services on which we depend?
- How much are the ecological functions of freshwater ecosystems dependent on the natural biodiversity?
- Current economic models for the evaluation of freshwater biodiversity concentrate on components of the system (fish production, recreation, reed cutting, medicinal plants, water-borne health issues) rather than valuing the whole resource (i.e. what would be the loss of value if a river were removed from the landscape?). Can we develop holistic methods for valuing water resources?
- Current economic models discount the value of benefits into the future, but the benefits of biodiversity are always long-term. How can we build into valuation systems a reflection of the benefits of protecting biodiversity for future generations?
- The EU Water Framework Directive classifies water bodies as Natural, Good, Moderate, Poor and Bad. What does this mean for biodiversity, and how can we connect this ecological classification to human welfare?
- Microbial processes and functions are essential for the provision of many of the goods and services on which we depend (e.g. water purification, decomposition) yet most species are not even named. What are the effects of water development/regulation projects on microbial biodiversity, and how does this affect the provision of EGS?

The WFD: research-policy interface needed

Petr Petřík, Institute of Botany, Academy of Sciences, Czech Republic

Based on a research review (Petřík et al. 2007) and interviews of water directors responsible for the implementation of the WFD, a lack of communication was identified. In addition, attention should be paid to the clear definition of ecological status/potential of freshwater ecosystems.

Implementing the EC Water Framework Directive is not an easy task, as pointed out by Thomas Dworak, and should be solved through multidisciplinary research (see also contribution of Rui Santos). In addition, there are knowledge gaps regarding environmental policy frameworks for managing environmental flows (see contribution of David Katz). Last but not least, there are unclear interpretations of some very important terms in the WFD as I would like to point out based on an example from the Czech Republic.

We asked two questions related to the WFD to two representatives (water directors) from the Ministry of Agriculture and the Ministry of the Environment, respectively. The water directors are responsible for the implementations of the Directive in our country. Only one representative from the Department of Water Management Policy (Ministry of Agriculture) answered.

Q: What is the contribution of practitioners or policy makers that deal with the daily problems in implementing the directive? Where do you see knowledge/methodological gaps that hinder the proper implementation of the WFD?

A: Related to the biodiversity issue and nature and habitat conservation, the main problems in implementation of the WFD lie in a lack of information relating to the links between anthropogenic pressures , aims specific to target communities, indicators of community status and suitable measures. In the cultural landscape of Central Europe, a definition of “good ecological status of water bodies” (particularly in the area of biological measures describing the status) is very problematic. The definition of measures is even more difficult, because the monitoring has only just started and so far we lack quantifiable results.

Q: Where do you see the role of scientists contributing to the process of defining programmes of measures?

A: Until good ecological status, parameters and links between anthropogenic pressures and impacts of measures proposed in Plans of Catchment Areas (Plány oblasti povodí, see Catalogue on www.mze.cz) on the quality of communities or their biological parts are better known, there is no way we can propose a programme of measures for good ecological status. All the measures are so far based on expert judgement.

My comments and conclusions: Aquatic and wetland ecosystems have long been monitored in the CR (e.g. Straškrabová et al. 1998). A detailed survey of current conditions and trends has been supported by programmes and inventories performed in the framework of fulfilling the obligations of the Ramsar Convention and also habitat and species mapping for establishing the Natura 2000 network. Important results have already been obtained from a long-term hydro-biological study of lakes, artificial freshwater reservoirs and watercourses. Thus, we already have very good data with which to assess good ecological status of freshwater ecosystems. What we need is a national, integrated and comprehensive monitoring system, including monitoring of hydromorphological and biological components of surface waters in accordance with the Water Framework Directive (2000/60/EC).

I have to repeat what I already pointed in my last contribution: There is not enough demand for knowledge at responsible institutes (Ministry of the Environment and Ministry of Agriculture) related to the WFD. To avoid separation of basic research from application in water management, better coordination between science and policy is urgently needed.

Freshwater biodiversity, ecosystems and services

Mark Gessner, Department of Aquatic Ecology, Eawag/ETH, Switzerland

Freshwater ecosystems worldwide are under strong pressure caused by human activities. Stress levels will most certainly rise further given a growing world population and increasing per-capita use of water in households, for irrigation and in industry, even if water-use efficiency in all sectors is greatly improved. Effects of global climate change on the geographic and temporal distribution of precipitation and runoff, coupled with human responses to these changes, are likely to exacerbate the situation in many regions.

While these developments have been widely recognized, discussion about consequences and remedies centre on water quantity and quality issues, primarily in relation to human demands. Neglected by many is the fact that freshwaters are distinct ecosystems that harbour a sizeable fraction of the world's species and genetic diversity and that stream, river, lake, groundwater and inland wetland ecosystems are diverse themselves in their ecological structure and function.

The enormous richness in relation to the tiny global extent of surface waters (approximately 0.3% by area) is well documented. This is particularly true for vertebrates, most of which are fishes, of which about 40% are restricted to freshwaters, the rest occurring in the vast oceans. Due in part to the island character of many water bodies and drainage systems, the potential for adaptive radiation in freshwaters is tremendous. It is likely, therefore, that freshwater diversity is even appreciably higher than is currently known even for taxa and regions that have been well studied. Detailed genetic analyses aimed at uncovering cryptic diversity will show whether this prediction holds true.

The riches of freshwaters have been clearly articulated by freshwater ecologists and conservationists. Protecting it is an ethical imperative. Few, however, are convinced of the need to conserve biodiversity and ecosystems purely on ethical grounds and this has engendered arguments building on the utilitarian value of freshwaters. Which goods and services do freshwaters provide to humans? Flood protection, water purification and protein production are three evident examples. Others may seem more subtle, such as the retention and transformation of nutrients and organic matter. A key issue to address is to what extent, in addition to the physical features of ecosystems, do species richness and other components of biodiversity contribute to the services provided by freshwaters. Currently purported arguments tend to be vague and often lack rigour. Much painstaking work is needed to establish sound quantitative links.

In addition, many even general questions relating to the relationship between freshwater biodiversity and ecosystem services remain open. For example, do all depend on ecosystem processes as is often proclaimed? Are processes at other levels of ecological organization important? To what extent does ecosystem structure matter and what is the role of biodiversity in determining it? For which services does the vast diversity of micro-organisms matter? Is (public) health a key issue in this context? And, in view of freshwater biota being homogenized at large scale and ecosystems as a whole converging towards a standard character: is a diversity of ecosystems crucial for services, both the currently identified and so far unknown, to be fulfilled effectively?

Freshwater biodiversity: to what extent (could) we include it in ecological assessment systems?

Gorazd Urbanič, Institute for Water of the Republic of Slovenia, Ljubljana, Slovenia

The Water Framework Directive (WFD, Directive 2000/60/EC) obliges EU member states to use bio-indicators to assess ecological status. However, biodiversity is only indirectly mentioned in the WFD. Ecologists usually identify biodiversity at three levels: within species (genetic diversity), between species (species diversity) and of ecosystems (ecosystem diversity) (Heywood & Watson 1995). In the WFD (at least) two of these three biodiversity levels are covered. Member states are obliged to develop a typology of waters, which means recognising biodiversity at the ecosystem level.

All member states developed typologies, but different approaches were used. Some countries defined (only) geo-morphological types, which resulted in a relatively low number of types. Other countries (Slovenia included) developed community based typologies which enabled them to define type-specific reference conditions based on all four of the biological elements mentioned in the WFD: i) phytoplankton, ii) phytobenthos and macrophytes, c) benthic invertebrates and, iv) fish. Using the latter approach usually resulted in the identification of many more water types. Is the difference in numbers a result of freshwater ecosystem diversity? Nevertheless, in any case second level-species biodiversity has to be used in ecological status classification systems. But do member states really use species level diversity in ecological assessment systems? Comparison across the developed assessment systems revealed that species level determination is usually used for macrophytes, phytobenthos, fish (and phytoplankton). It seems that we know these groups well, do we? (For an opinion about fish see Kottelat and Freyhof, 2007). What about benthic invertebrates with insects as the most diverse freshwater group?

Countries usually develop assessment systems based on family and/or genus level, but rarely on the species level. Some studies (e.g. Schmidt-Kloiber & Nijboer 2004) have shown that species-based assessment systems give a better starting point in management issues but also AQEM assessment software developed at the European level is not applicable if data on higher taxonomic levels are used. In some European countries (especially in Southern Europe) too little information about species diversity of many groups of benthic invertebrates is available. To say nothing of autoecological information requested for the development of assessment systems. If countries reach a good ecological status of fresh waters in the future, biodiversity might be preserved, but how well can we predict pressure-specific responses of the structure and functioning of our freshwaters with current levels of knowledge? Good enough? Interest in freshwater is growing every day and managers want good predictions based on pressure-response curves.

Before we solve this first issue, there is another: Climate change. Are we ready?

Integrating water management and fish conservation

Stefan Schmutz, Institute of Hydrobiology and Aquatic Ecosystem Management, Vienna, Austria

Fish species belong to the most threatened species of the world. About 46% of the fish species evaluated by the IUCN are threatened. In Europe 200 freshwater fish species are listed by the IUCN as threatened, representing 38% of the native European fish fauna.

Integrating monitoring activities of the Habitat Directive (HD) and the Water Framework Directive (WFD) can help to achieve a more complete picture on species distribution, risk status, relevant drivers and pressures and required restoration measures.

Comparing HD annex II taxa list with relative frequency of occurrence of fish species in Europe represented by FIDES, the fish database of the EU FAME project (8228 sites across Europe, FAME-consortium 2005) revealed that some protected species were very common. Cottus gobio is the fourth most common species in FIDES found in nearly every second site (44%). However, FIDES contains 22 fish species that are found at only at one site and are not listed in annex 2 of the HD.

According to the Natura 2000 EUNIS database (EEA) fishes are protected in 2703 sites representing 16% of all 16491 Natura 2000 sites. For 66 annex II taxa (92%) Natura 2000 sites were established by the year 2006.

Based on the information presented at the official LIFE website, 70 LIFE projects were designated inter alia to fish between 1992 and 2006. In total €154 million were spent for fish related LIFE-projects with a EC contribution of €81 million. In total, 37 taxa have been targeted by LIFE projects, representing 51% of Annex II taxa. The main pressures identified by LIFE-projects are channelisation, migration barriers, land use and landscape fragmentation, and water use. Habitat improvement was the most frequently recorded objective of LIFE–projects followed by fish breeding, improving fish migration and establishment of lateral connectivity. However, almost half of the 29 finalised projects failed to clearly demonstrate if or how project objectives were achieved.

Activities resulting from HD and WFD implementation are of mutual benefit in protecting European fish species. WFD provides new data on the distribution of fish species, information on pressures affecting fish and methodologies to assess ecological status. Natura 2000 sites substantially support the main goal of the WFD to prevent further deterioration of aquatic ecosystems. LIFE-Nature projects play an important role in developing appropriate restoration and mitigation techniques that can improve the ecological status of freshwaters in a number of well recognised case studies.

Further requirements:

1. European biodiversity databases have to be established integrating EU-databases and other sources that have recently become available. This will be a valuable resource for a more quantitative assessment of biodiversity decline and recovery.
2. The list of protected fish species in annex 2 of the HD has to be thoroughly revised according to new information available across Europe.
3. Functional pathways of fish response to human pressures have to be identified to enable development of more targeted restoration and mitigation programmes.
4. Priority should be given to research on the large scale and sustaining catchment restoration programmes instead of local habitat and fish population enhancements.
5. Pre-post restoration/mitigation comparison should be an obligatory standard for LIFE projects. Research recommendations and reporting guidelines for LIFE projects should be developed.

Protected areas for conserving freshwater species and systems

Robin Abell, Conservation Science Program, World Wildlife Fund - United States

Declining trends in the integrity of freshwater systems demand exploration of all possible conservation solutions. Freshwater protected areas have received little attention, despite the prominence of protected areas as conservation interventions for terrestrial and more recently marine features. A dialogue on freshwater protected areas has been neglected both because few models of good protected area design exist, and because traditional notions of protected areas translate imperfectly to the freshwater realm. Partly as a result of this conceptual disconnect, freshwaters have been largely ignored in protected area accounting schemes, even though a number of existing freshwater conservation strategies could qualify according to general protected area definitions. Rather than impose terrestrially-motivated ideas about protected areas onto freshwaters, we propose new vocabulary – freshwater focal area, critical management zone, and catchment management zone – that can be used in conjunction with IUCN protected area categories and that recognize the special ecological dynamics of freshwaters, and in particular the critical role of fluvial processes. These terms, which attempt to diffuse concerns about locking away essential ecosystem goods and services, move us toward consideration of protected areas for freshwaters. This conceptual shift, which acknowledges that freshwater conservation may occur remotely from freshwater features, opens the door for improved integration of freshwater, terrestrial, and marine concerns in protected area design and management.

The effective design and management of freshwater protection areas will require that the most innovative ideas in conservation biology, freshwater ecology and biology, landscape planning, hydrology, environmental economics, and other social sciences be brought together. Combining these disciplines may also begin to bridge the sometimes artificial divide between freshwater, terrestrial, and marine planning, particularly when hydrologic processes are recognized as central to planning and management. Protected areas designed to achieve freshwater conservation goals will in many cases extend beyond the aquatic systems of interest to encompass some or all of the contributing catchment, and even downstream areas as well.

We presently have no satisfactory way of evaluating the extent to which the vast majority of existing protected areas actually conserve the freshwater systems within them, whether or not they were defined to protect freshwater biodiversity. In only a few cases do we have sufficient pre-establishment baseline data to evaluate trends. Monitoring systems should be put in place immediately, even if assessments must be based in the near term on biodiversity surrogates like landscape indicators. We cannot begin to fill gaps in protection until we know, even to some level of approximation, what those gaps actually are. Perhaps most important, we urgently need increased research into identifying which lands will be 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.

Diversity and ecosystem functioning under the WFD

Angelo Solimini, Joint Research Centre, Ispra and University of Milan, Italy; **Robert Ptacnik**, Norwegian Institute for Water Research, Oslo, Norway; **Leonard Sandin**, Swedish University of Agricultural Sciences, Uppsala, Sweden

We advocate that some fundamental research issues on the relationship between biodiversity and functioning of ecosystems should be urgently clarified in order to develop reliable indicators, useful for the management of goods and services provided by freshwaters.

There is an intuitive view in favour of stabilizing effects of biodiversity on ecosystem functioning, which is reflected in the current EU regulation (the widely cited WFD). Although not explicitly, the WFD assumes that biological diversity is closely related to functioning. Consequently, a healthy and functioning ecosystem, which is the ultimate target of management actions, holds higher diversity.

In view of globally increasing losses of freshwater species, the importance of diversity for freshwater ecosystem processes and the response to anthropogenic pressures have recently received considerable attention. General trends seen in diversity analysis indicate that a system's ability to buffer perturbations increases with increasing diversity. A number of recent studies combine information on diversity of communities and other state parameters in order to extract information directly related to system stability and ecosystem functioning/services. For example, resource use seems to provide an estimate for the system's susceptibility to species invasion. Regime shifts may be indicated by overall increasing variability of state parameters.

The WFD intends to use the biota of 'ecological status'. We argue here that we lack a better focus on processes. The problem can be illustrated by the current dilemma of defining reference conditions for water bodies. In spite of the lack of reliable information regarding the 'state' of our waterbodies in historical times, the information (if available) has limited value in times of changing environmental conditions (temperature), because historical baselines simply disappear. Thus, indicators focusing more on ecosystem functioning and services might be more 'objective', in case unequivocal descriptors of ES functioning can be defined.

Analysis of pan-european data sets revealed conspicuous meso- to large-scale gradients in species distribution and species richness, including fast spreading organisms like phyto- and zooplankton. Our current research relating diversity, trophic state and ecosystem function in European lakes suggests that, for a given level of available resource, phytoplankton diversity is correlated with the stability through time of an important ecosystem function, such as resource use efficiency and community turnover.

In running waters, the current approaches to study the relationship between community structure and ecosystem functioning and how this is related to the assessment of ecosystem health were recently explored in a special session organized by 2 of us (AGS and LS) at the European Symposium for European Sciences (see www.sefs5.it/welcome.htm). Recent advancements of ecological stoichiometry and metabolic theories, decomposition process, stable isotopes and size-based analysis of food webs, and nutrient spiralling (to nominate a few) provide different approaches to the study of lotic ecosystem functioning. Some indicators of ecological functioning (or surrogates for function) such as leaf litter breakdown rates, secondary production, functional feeding groups, traits, guilds, respiration and benthic metabolism has been used or suggested. However, one major conclusion of the symposium was that relatively few studies have linked these functional indicators to changes in community structure along gradient of anthropogenic pressures.

Do indicators of ecosystem functioning represent a useful complement to usual structural (community composition) metrics? It seems straightforward to tackle this issue by developing direct indicators of ecosystem functioning. Because they may provide a sounder ecological basis for obtaining an ecological quality classification and possibly increase the confidence and precision in classification of the ecological status of freshwaters. However, we first need to understand fully the complex and possibly non linear relationships between functioning, diversity and human pressures.

Inland Mediterranean wetlands and ponds and the implementation of the WFD and the Habitats Directive in Mediterranean countries

Antonio Camacho, Cavanilles Institute of Biodiversity and Evolutionary Biology, University of Valencia & Iberic Association for Limnology

The WFD opens a new opportunity for the conservation of aquatic ecosystems to be considered as priority users of environmental flows. This is essential since they cannot function without the key element, this is, water. However, to be considered under the umbrella of the WFD, aquatic ecosystems must be declared as "water masses" sensu WFD. In most Mediterranean countries, the implementation of the WFD is considering water masses as lakes having an open water area bigger than 0.5 Km2, which means that most wetlands and ponds in the Mediterranean Ecoregion are at the moment not under consideration of the WFD, at least, not as water masses (perhaps as protected areas according to point v from article 6 and annex IV). Coastal Mediterranean wetlands are often large, but in contrast most Mediterranean inland lakes, ponds and wetlands are small, and, of course, smaller than 0.5 Km2. For instance, in the case of Spain, the National Wetlands Inventory, which only includes the main wetlands, accounts for more than 2000 lakes, ponds and wetlands, but up to now just a few have been declared as water masses under the WFD because most of them have sa mall size or a temporal character (temporality and fluctuations are some of the main distinguishable features of many types of Mediterranean wetlands). At the regional level the inventories describe even more systems than these 2000, which means that the consideration of these under the WFD is actually even worse. It has been considered (Casado and Montes, 1995) that, for Spain, around 60% of the surface of wetlands has been lost, mostly during the 20th century, and the same pattern will probably be followed if a coordination of the nature conservation measures and water uses (regulated under the WFD) is not accomplished. This requires, at least partly, the consideration of wetlands as water masses under the WFD.

A clear example of the lack of consideration of all these small Mediterranean water masses at the Intermediterranean level is the intercalibration process for Mediterranean lakes (L-M GIG), which has been done for artificial reservoirs as representative of Mediterranean lakes. This shows that something is going wrong in the implementation of the WFD for the consideration of Mediterranean lakes, ponds and wetlands. This also means that something has to be done if we want to get Mediterranean wetlands under the umbrella of the WFD, which in my opinion is the only way to guarantee that they would get what they need, water, and the Water Authorities would then be requested to get their "good ecological status".

On other hand, the other European Directive related to the conservation of aquatic ecosystems is the Habitats Directive. When looking to the epicontinental aquatic habitats at the EUR-27 manual (EC-DGE, 2007), and specifically to the group of Habitats corresponding to "Standing Waters" (group 31), most of them are still defined by the macrophytic vegetation. Although vegetation is very important in aquatic habitats, since it can confer structure to them, few aquatic ecologists would use "Plant Associations" from the phyto-sociological point of view, as the Directive Manual do in this case, as the main argument to define ecologically any type of lake or pond. Instead they would integrate other structural and functional criteria. In my view, there is a need to integrate further, in a formal way, these additional criteria in the implementation of the Habitats Directive for standing waters (probably the same for rivers and streams, group 32), and this should be done from an integrated perspective of collaboration of nature managers and scientists.

Session III: National perspectives

Freshwater wetlands in the Maltese Islands: Characteristics and potential

Brief report compiled by **Adriana Vella** with the expert assistance of **Jonathan Henwood** and **Sandro Lanfranco**.

Characteristics of Maltese Freshwater Wetlands

Maltese freshwater wetlands are lacustrine or riverine. These are found inland from the coastal zone and include streams (running through valleys), pools (most notably rockpools), subterranean hydrological systems, open ponds and canals (Henwood, 2006). Given the Maltese climate, which is hot, semi-arid (Emberger Pluviothermic quotient is 92.5) and biseasonal with a warm dry summer and cool wet winter, these systems are characteristically seasonal, unless a permanent freshwater source is present. Their seasonality grants them a characteristic place in local natural landscape, owing to their ability to attract a world of life forms in ostensibly barren karstic areas.

The wet season is conducive to visible colonization patterns by micro and macro biota, thus having higher species richness. This is since the presence of water eliminates the major stress hurdle during the dry period. Notwithstanding the insular nature of freshwater wetlands, the species richness during the wet period is comparable to local coastal (and thus more saline) wetlands systems, which tend to be larger.

Floral Biota

Studies on biota of freshwater systems are sporadic, limited to rock pools and valley systems, both permanent and temporary (Henwood, 2004). Studies on macrophytic and algal flora are more numerous than studies on biota, with particular attention being given to rockpools.

The macrophytic biota of local freshwater systems comprises terrestrial, amphibious (both fluctuation tolerators and responders) and submerged species. Proportions of these components mix together throughout the seasons according to the physical characteristics of the pool or valley, namely temperature, duration and number of hydro periods, and seed bank. The major determining factor is the duration of the flood period, in which case if relatively short, the terrestrial component will prevail, whereas if intermittent or long, amphibious and submerged species will respectively take sway.

On the other hand, algal flora are found in all pools, even though a high surface area to volume ratio precludes prolonged flooding. Both macroalgae, namely characeans and microalgae (some with macroscopic populations) are present in differing quantities in pools and other wetlands. Amongst the algae one notes cyanobacteria, chlorophytes, clamydophytes, zygophyceans, bacillariophytes and others. Populations of algae differ throughout the flood season, having an initial and final community which differ, according to the physicochemical characteristics of the pools, mainly the length of the hydroperiod. Unlike macrophytes, they tolerate drying less and largely disappear when flooding ceases, but reappear once again during a consequent flood within the same hydroperiod. Therefore, during a one year cycle, various algal cycles may occur.

Threats to Freshwater Systems

Wetlands and their characteristic biota have long been studied in the Maltese Islands. Past records of wetlands and their characteristic flora are numerous, though incomplete, including records in Boccone (1674), Duthie (1875), Gulia (1871-1877) and others (vide. Haslam et al., 1977). Grech Delicata (1853) described the aquatic flora of the pre-drying age of the Maltese Islands, that is when valley systems were not overexploited for water, including the flora of inundantes (places flooded most of the year), uliginosus (marshes) and aquosis (watery places).

Although the local scientific community has long recognized the intrinsic importance of freshwater habitats, in particular due to their range of protected species, most systems are on the decline as originally indicated by Haslam (1999). The reasons behind this decrease in quantity of freshwater systems and their integrity are numerous, a few reasons of which are listed below:

1. Take up of land for development, most notably housing and industry. Given that valley systems are renowned for their visual and landscape attractiveness, housing in their vicinity

may be much sought after. Indeed, numerous local valley systems have either been encroached on or built in, with all consequent effects on both humans and environment. For example an area renowned for rock pools with numerous protected species, studied by Jonathan Henwood in 2004 were destroyed following the study, given that the land was given up to make way for an industrial estate;
2. Changes to topography and water catchments thus decreasing the quality and quantity of flood water;
3. Dumping of inert material in pools, smothering the substratum and living components, given that pools are the least appreciated of freshwater systems, merely described as accumulations of stagnant water by the local community;
4. Pollution of systems due to incidental runoff from agricultural land or deliberate pollution through introduction of chemicals such as pesticides.
5. Removal of species, most notably the painted frog, or plants such as the water iris for ornamental purposes;
6. Disturbance of pools due to offroading, hiking and other activities;
7. Water collection for irrigation of agricultural land and collection through boreholes, thus causing aridification of land; and
8. Flash flooding from roads and impermeable surfaces, which has been observed to wash pools clean of their substrata.

Due to these, there has been a steady decline in the number of freshwater systems, the flooding regime, and the quality of their water, with consequent effect on the typical biota.

Vertebrate fresh water fauna studies are limited and include short term research projects, such as research on the freshwater crab (*Potamon fluviatile lanfrancoi*) (Cachia,1997), which focused on the behavioural ecology of the crab inhabiting the San Martin Spring in Malta. 68% of all the crabs were found in sheltered places close to a water source. The crab had a varied diet in the wild, ranging from algae to amphibians. In captivity this was observed to change, having a preference to animal food rather then plant food. The Hayne's method was carried out to measure the population density: Summer: 350 crabs/ha & Winter: 125 crabs/ha. A total of 84 crabs were collected (86.5% of which were found to be right- handed). This species was showed to be vulnerable.

Potential of Freshwater Systems

Numerous studies such as Lanfranco, S. (1990), Henwood (2004), Camilleri (2006) and others have of late focused on freshwater systems, in each case yielding a wealth of information. This is notwithstanding the vulnerability of these pools to impoverishment and destruction.

Despite these late studies, the current scientific knowledge on Maltese freshwater systems and their biota is still in its early life. The following is a brief list of items which may be addressed in future studies:
1. Compilation of an algal species list for the various types of freshwater systems, taking into account seasonal and spatial variation. Collection of a species list should be the first step to better understand these systems and biotic interactions present. In addition, given that the species list may be compiled from each of the Maltese Islands, and different pool communities within each, metapopulation studies may be carried out, thus better understanding spatial relationships between systems;
2. Studies on taxonomic groups such as cryptophytes, picophytoplankton and others, given that these have never been studied;
3. Studies on the dynamics of macrophytes such as seeding and seedbank studies thus enabling a better understanding of the relationships of a pool within a population of pools with another;
4. Similar studies on the macro and micro fauna in pools, the latter of which have been largely overlooked. This may enable a better understanding of the relationships between the flora and fauna of pools, thus giving an in depth knowledge of pool ecology;
5. An examination of physicochemical characteristics of freshwater systems including aspects such as stratification, vertical mixing, clines and so on. In particular, the chemical species

such as nitrogen species, phosphate, sulfates, carbonates, organic ions and metal constituents other nutrients of these pools have been largely overlooked or rudimentarily examined;

6. Studies of impacts of increased aridity and precipitation on freshwater systems. This will enable identification of the response of pools to climate change, therefore indicating how these protected habitats will respond to future changes, whilst understanding their past;

7. Further work on the ecological role that pools and systems within the Maltese ecosystem play in terms of providing nutrients and water and its role as a sink for nutrients, carbon etc.

8. Studies on local subterranean hydrological systems, given that these have been rarely studied.

Recommendations:

The following are a number of recommendations for future directions in freshwater research and policy:

1. Register of wetlands: The establishment of a register of wetlands, cataloguing the location and characteristics of each, is a necessary first step. Protective measures cannot be implemented effectively unless the extent of the resource to be protected is not well-established. 2. Population models: An understanding of the dynamics of species in wetlands necessitates the construction of population and metapopulation models. Point studies are of course, valuable, but their predictive value is restricted. The construction of predictive models linked to abiotic models would provide an important conservation and restoration tool for such habitats. Such studies are time-intensive and would require a baseline of several years.

3. Hydrological models: The hydrological context within which colonists interact should also be well-defined. Few local studies have provided predictive information on the hydrodynamics of wetlands. The construction of hydrological models for the principal wetland areas of the Maltese Islands would be an invaluable tool in understanding the ecological dynamics within them.

Concluding remarks

As briefly noted, the wealth of local freshwater systems has been overlooked and therefore, an affluence of knowledge is waiting to be unlocked. However, given the lack of appreciation, the integrity of these systems is often compromised. This is a cause for concern given that a valuable resource is being lost and with it numerous species of importance, both a notable component of Maltese environment.

Selected research priorities regarding freshwater biodiversity in Croatia

Ivančica Ternjej, Zlatko Mihaljević, Sanja Gottstein and Milorad Mrakovčić; Faculty of Science, University of Zagreb, Croatia

1. Additional research and fauna investigations are needed in karstic lakes and rivers: Karstic lakes are a natural phenomenon of Croatia: one of the biggest of all is Lake Vrana on the island of Cres. Faunistically, the lake is very interesting because it is a type locality of an endemic copepod subspecies (*Cyclops abyssorum vranae*), whose presence in the lake has not been confirmed since its description. There are contradictory data on other copepod fauna in the lake. Other faunistically interesting karstic lakes are travertine barrage lakes, especially in the Plitvice NP area. Its hydrological regime makes it unique, with many microbiotopes which enables high diversity of species, among others microcrustaceans like copepods and cladocerans. Microcrustacean fauna of Plitvice Lakes was never fully investigated: indeed, former investigations were focused on trophic status of the lakes, while fauna was neglected.

Karstic rivers in Croatia: there are many micro biotopes with high diversity of species, especially water insects. In the past, research was focused on limnological and ecological studies. Insect fauna has been determined solely on the basis of larvae, so these data are somewhat questionable. Faunistical research was recently intensified, and numerous species of some insect groups (Diptera, Plecoptera, Trichoptera, Ephemeroptera) were recorded. Research on Trichoptera fauna has since resulted in the discovery of some 20 new species. There is a large amount of species that are rare elsewhere and some preliminary results show the biggest biodiversity of aquatic insects. Intensive research worldwide has been focused on studying Mediterranean rivers. Most Mediterranean rivers are subjected to high natural flow variability that imply temporality and allow the presence of seasonally different communities. However, Croatian Mediterranean karstic rivers differ in this respect: they never dry out (the only exception is Èikola River) and belong instead to permanent hydrological systems, making them particularly interesting at the global level.

2. Additional research and fauna investigation are needed in brackish coastal springs and on Adriatic anchialine caves: Significant coastal areas of high biodiversity value in Croatia are sites with permanent and intermittent coastal springs situated near the coastline or several kilometres away. The main characteristic of the springs is periodical salinity during the year with the highest value during the summer period. Many invertebrate species related to those habitats have a very restricted distribution range. Notable among the endemic and relict species are the epibentic isopod *Jaera nordmanni illyrica*, stygobiotic amphipod *Medigidiella dalmatina*, tubificid worm *Thalassodrilus modricensis*, etc. Negative environmental impact of tourism development and water pollution are the major factors affecting this kind of specific habitat and biodiversity of invertebrate communities.

Anchialine caves in Croatia are coastal caves with pools and without surface connection to the sea, containing salt or brackish water, which fluctuates with the tides. In pools, salinity increases with depth, from freshwater or brackish water near the surface to marine water at greater depths, often marked by a halocline. It is found in coastal limestones of continental plateaus. Specific community of numerous stygobiotic animals inhabit anchialine caves, mostly crustaceans where some rare species have an extremely limited distribution: Copepoda (*Acanthocyclops gordani*, *Badijella jalzici*, *Halicyclops dalmatinus*, *Speleohvarella gamulini*), Thermosbaenacea (*Tethysbaena halophila*) and Amphipoda (*Hadzia fragilis*, Melita spp, *Niphargus hebereri*, *N. pectencoronatae*, *N. salonitanus*, *Rhipidogammarus karamani*). Vertical salinity gradients determine spatial distribution patterns of stygobiont crustaceans. The species richness of crustaceans is strongly dependent on habitat morphology as well as on abiotic factors such as salinity and food supply. Crustacean diversity was higher in caves with steep salinity gradients. The reasons for the vulnerability of Adriatic anchialine caves are groundwater contamination from sewage discharge and degradation of habitats adjacent to urban areas due to dumping and litter accumulation. Nevertheless, the number of surveys of invertebrate biodiversity in anchialine caves on Adriatic islands is still low.

3. Research on endemic fish species: Over one in three freshwater fish species in Europe are threatened with extinction (IUCN 2007). These species are an important part of our heritage and are critical to the freshwater ecosystems upon which we depend for water purification and flood control. Areas subject to the highest levels of threat include the lower reaches of the Danube river, the Balkan Peninsula, and southwestern Spain. In Croatia, Dalmatia is a special ichthyological region of Croatia and it is one of the most important centers of ichthyological diversity in Europe. Unfortunately, specialized habitats of endemic fish species have been quickly changing under anthropogenic influences and it is questionable just how much longer this natural distribution of these species can survive. Life histories of most endemic species are poorly known and therefore new ecological investigations are essential for conservation. As such, research priorities in this field include research on:

- The ecology and habitats of endemic fish in Eastern Adriatic watershed
- Conservation measures for the endangered salmonid fishes of the Adriatic basin
- Conservation measures for the endangered fishes of the genus Phoxinellus and related genera in Eastern Adriatic watershed
- Distribution and taxonomy of endemic fish species in Mediterranean part of Croatia

Research priorities for Freshwater Biodiversity in Portugal

Maria José Costa, Faculdade de Ciências de Lisboa and Instituto de Oceanografia

The following are a few research priorities that need to be addressed in the specific context of Portuguese freshwater biodiversity:
- Study of the biodiversity of high altitude intermittent streams, with special emphasis on the macroinvertebrate community: these systems are rare in Portugal (they are only present in Serra da Estrela), are particularly vulnerable to climatic changes and remain largely unknown;
- Study of the biodiversity of freshwater tidal areas of estuaries: these ecotone areas are extremely vulnerable to human and climatic changes and to settlement of exotic species, are very important as migratory routes for diadromous fish species yet remain poorly understood;
- Study of the impact of exotic species on the autochthonous freshwater fauna: this is a major constraint in Portuguese continental waters due to habitat modifications (e.g. dams) that facilitate the establishment of exotic species;

Additional more species-specific studies include:
- Research on Diadromous fishes: screening for major constraints and developing management tools for rehabilitation of the Portuguese river basins;
- Research on *Lampetra fluviatilis*: This is the most threatened lamprey species in the Iberian Peninsula and should be studied in detail;
- Development of methods to evaluate and increase silver eel (*Anguilla anguilla*) at the river basin level to contribute to the recovery of this highly threatened species.
- Study of Portuguese populations of the three-spined-stickleback *Gasterosteus gymnurus*: there is some evidence of distinct ecological behaviour of this species in the southern limit of distribution, which may contribute to make this species more vulnerable in Portugal.

Re: Research priorities for Freshwater Biodiversity in Portugal

Jan Jansen, Department of Ecology, University of Nijmegen, The Netherlands

As an addition to the contribution by Maria José Costa, I would like to stress the need for the inventory and investigation of fresh water spring communities, especially of the non-calcareous ones which are very unfortunately not included in the annex I of the EU Habitat Directive and Natura 2000 manual. These habitats are extremely vulnerable and most of them are or are being transformed to fountains with public access and for mineral drinking water companies but most often without respecting the intrinsic value of the habitat.

I have voluntarily investigated about 80 different spring communities in Serra da Estrela (highest mountain area of continental Portugal) and was not able to publish the results because of lack of financial support. Some have affinities to Natura 2000 (7160 Fennoscandian mineral-rich springs and springfens). At least one bryophyte species new to science was discovered: *Fissidens jansenii* Sérgio & Pursell. For instance the off-spring of Portugal's largest river whose origin is in the country itself, Mondego River, is largely altered by human activity and has most probably lost its original character. With the aid of the Cecilia Sérgio and coll. from the Jardím Botanico, Lisbon we were able to detect about 125 different bryophyte species!

In my opinion priority should be given to the investigation, inventory and protection of spring and spring brook communities of Portugal, not only their flora but also their fauna. Most of the springs have an original character and the list of species that inhabit them is rather unpredictable.

For the whole of Europe I suggest to search for political solutions to include all spring communities to Annex I, not only non-calcareous and alkaline ones and the ones restricted to Scandinavia. Especially now that water has been acknowledged to be of vital importance to human well being. So why should the source of it all not be well protected?

Urgent issues of freshwater biodiversity research in Finland

Jari Niemelä and Jukka Horppila, University of Helsinki; and **Jani Heino and Timo Muotka**, University of Oulu, Finland

The following topics have been identified as urgent freshwater biodiversity research issues in Finland:

1. Protection of freshwater biodiversity. How well is freshwater biodiversity protected in the country? How representative are protected areas in terms of safeguarding freshwater biodiversity? As few protected areas have been established specifically to protect freshwater biodiversity, it is not clear how well protected areas designed to safeguard terrestrial biodiversity also protect freshwater biodiversity. For instance, many forest reserves include freshwaters but is their biodiversity protected through such reserves? Related to the above question is how the ability of protected areas to maintain freshwater biodiversity may change due to climate change.

2. Effects of climate change on the distribution of and abundance of species dwelling in freshwaters. We have poor understanding of how northern freshwater species are affected by climate change. Such species may be especially vulnerable to climate change (warming) as they are adapted to cold waters, and have nowhere to escape. However, a problem in this kind of research is that the current distribution patterns and ecological requirements of many freshwater species are poorly known.

3. Forests and freshwaters. Many freshwater bodies are located within forests in Finland, and forestry activities affect freshwater ecosystems. However, there is insufficient knowledge of exactly how such operations impact freshwater biodiversity. As Finland is a forested country and forestry is an important industry, this question is of great importance.

4. Invasions of introduced species. The effect of introduced species on native freshwater biodiversity is poorly known. Northern freshwater ecosystems are species-poor, and, therefore, they might be prone to invasions by exotics. Furthermore, climate change may increase the vulnerability of northern freshwater ecosystems to invasions. For instance, it seems that the expansion of the introduced rainbow trout has so far been limited by low summer temperatures of Scandinavian freshwaters, but if waters warm due to climate change, rainbow trout may be able to expand its range.

5. Restoration. There is lack of knowledge to support restoration of freshwater ecosystems. For instance, understanding is needed on the impact of food web structure on the success of restoration activities. In Finland, some 15-20% of small (running) freshwater bodies are in more or less natural condition, while in Central Europe the proportion is much lower. Thus, there is a huge need for restoration of freshwaters in Finland, and elsewhere in Europe. However, there is lack of knowledge of how to perform such activities for the benefit of biodiversity, and what kind of impacts various kinds of restoration operations have on biodiversity. Knowledge of the structure of the food web in the freshwater body to be targeted for restoration activities is essential for the success of such activities.

6. Indicators. Indicators to signal changes in freshwater biodiversity are needed. This is related to protection, restoration and climate change. We need biodiversity indicators to find out what kinds of changes are taking place and to guide management and mitigation actions.

Urgent issues of freshwater biodiversity research in Russia

Vladimir Vershinin, Institute of Plant and animal Ecology RAS, Ekaterinburg, Russia

The most pressing questions in freshwater biodiversity of Russia are connected to industrial water pollution, including mining industry impacts on water conditions directly through mining drainage water, and indirectly through the destruction of ecosystems and their components.

Another big problem is the overuse and waste of natural freshwater resources, ultimately bringing about their demise. The main reasons for this are poorly controlled fishing and bootleggers (Sovremennye... 2006; Vaisman, 2002).

The situation with Russian sturgeons is worrying, with an increase in temperature, salinity and eutrophication influencing freshwater communities' structure creating conditions for the invasion of alien species. For example the introduction of the fish species *Perccottus glenii* can unpredictably change the equilibrium in ecosystems of freshwater lakes and ponds. Now the number of species found outside their historical limits exceeds 115 in Russia (Bogutskaya & Naseka, 2002). The presence of hydro power stations with big water pools for example has significantly transformed the natural breeding sites of many fishes and other animals whose life cycles connect with fresh water.

It is also apparent that the cutting of forests and the oil industry in the North-East of Russia are negatively affecting freshwater biodiversity in this area. Unfortunately momentary profit in many cases overrides common sense and understanding of biodiversity conservation needs. Superimposing these pressures on existing ecological problems such as climate change leads to slightly unpredictable situations.

Surely that we need is restoration of freshwater biodiversity in many regions of Russia, but we're far from any decision regarding this issue, not only because of lack of knowledge, or lack of money, but also because of officials who wrongly presume that nature can sort everything out by itself. In addition, we need biodiversity indicators to understand what kinds of changes are taking place. However, this could be problematic in view of the current approach to methods of monitoring and indication.

Biodiversity research on Estonian fresh water communities

Ingmar Ott, Lake Võrtsjärv Limnological Station, Institute of Zoology and Botany of the Estonian Agricultural Academy (EAA), Estonia

The following research needs are identified as having a high priority in Estonia:

1. Long-term changes in land use and other human impacts as well as changes in biodiversity and ecosystems functioning should be studied in different types of inland waters.

2. More attention should be paid to coastal lakes and their communities: in particular to the study of bacterioplankton, phytoplankton, zooplankton, phytobenthos, macroinvertebrates and macrophytes and their interaction. Chemical regimes of the halotrophic lakes see great fluctuations. The metabolism of water bodies is dependent on sea water, prevailing sediment type and the age of the ecosystem. In the lakes close to pristine conditions, the primary producers are charophytic or phytobenthic species. These biotic groups have the greatest influence on the whole functioning of the ecosystem. The competition between phytobenthos and charophytes will be affected by water fluctuation and compactness of the sediments.

3. Complex monitoring is already in place and should be permanent in running waters, small and large lakes (Peipsi and Võrtsjärv). The goal is to estimate the ecological status of the ecosystems, of rare and protected species, and to better understand possible long-term changes.

Research needs: Freshwater in Ireland

The following contribution lists a number of research needs for freshwater from an Irish perspective. These are taken from a document entitled "Biodiversity Knowledge Programme for Ireland" published by the Irish Environmental Protection Agency and compiled by the Irish National Platform for Biodiversity Research. The editors are: **S. Clerkin, M. Emmerson, J. Finn, P. Giller, B. Naughton, G. Purvis, L. Scally and C. Spillane**.

Inventory and Survey

The support and development of national taxonomic and systematics expertise and capacity (especially for key groups), including the training of specialists in both traditional and new taxonomic methodologies and the dissemination of this specialist expertise amongst the wider research community is essential. Priorities identified in this area include:

- The status and distribution of rare or threatened freshwater species

Monitoring and Indicators

The development of usable, practical and effective indicator methods and survey protocols as tools for the assessment and regular monitoring of biodiversity in important habitats and ecosystems is a key priority. Specific research topics would include the filling in of knowledge gaps relating to baseline information, indicators of biodiversity and ecosystem health

- Early warning systems for the identification and detection of non-native freshwater species

Functions and Processes

Biodiversity and ecosystems processes

There is a need to improve our basic understanding of how genetic, species and ecosystem ecology and processes influence the development and maintenance of biodiversity across a gradient of managed and natural ecosystems; this should include the processes underpinning the relationship between biodiversity and ecosystem services e.g. food production, maintenance of soil fertility, pollination, and natural pest control.

- Relationships between diversity and ecosystem functioning in freshwater ecosystems

Protection of ecological services

Management of biological resources

There is a need to acquire knowledge relating to the development of alternative production systems which have the capacity to maximise environmental protection and make wider use of genetics resources that best match local conditions in agricultural systems, forestry and fisheries, while simultaneously protecting and utilising natural ecosystem processes.

Specific areas to be researched include:

- Impact of intensification of agricultural systems, including eutrophication and water pollution effects.

Research priorities for freshwater biodiversity in Hungary

E. Ágoston-Szabó, M. Dinka, N. Oertel„ G. Guti, K.T. Kiss and É. Ács, Institute of Ecology and Botany, Hungarian Danube Research Station, Hungary; **B. Csányi, K. Zsuga, K. Bodolai, Z. Szalóky**, VITUKI (Environmental and Water Management Institute), Budapest, Hungary; **B. Kiss, P. Juhász, Z. Müller**, BIOAQUAPRO (Environmental Service and Consultancy, SME), Debrecen, Hungary

The following are a few research priorities identified by freshwater biologists in Hungary:

1. Better understand fundamental processes such as organic matter mineralization, plant litter decomposition, sediment, water chemistry and the biogeochemical cycle of nutrients in shallow lakes.

Sustainable use of natural resources with special emphasis on sustainable water use and preservation depends on our understanding of fundamental processes such as nutrient cycling in aquatic ecosystems. The rates and pathways of organic matter mineralization are of primary interest in understanding freshwater ecosystems. In shallow aquatic ecosystems characterized by high sediment area-to-water volume ratio the sediments may be the primary site for organic matter mineralization: the degradation of organic matter in sediments drives the release of nutrients from sediments to surface waters and can profoundly influence the biogeochemical cycling of nutrients (Wetzel 2001). Sediments serve as sinks, sources and transformers of nutrients and other chemical contaminants, and can have a significant impact on water quality. The primary driver of these processes is the ecosystem biogeochemistry, which includes chemical, biological and physical processes in the sediment and water column. The relationship between biodiversity and ecosystem functioning (nutrient cycling in the light of ecological stoichiometry) needs further research.

2. Develop appropriate methods for sampling of macroinvertebrate communities in large river systems (Danube)

Large river systems are difficult to sample, therefore further studies are required to find appropriate quantitative and standard methods for sampling of macroinveretebrates. In addition to the structure of the communities, steps must to be taken to explore their function in the material and energy fluxes of the river ecosystem. This is a prerequisite for understanding the changes in biodiversity and scientifically supporting the rehabilitation of rivers. To understand the riverine functions, the study of the material and energy fluxes in the detrital food chain must increase. Lacking spatial references in the case of large, canalised and over populated rivers long-term research is needed to find time-to-time reference situation. To elucidate the biodiversity of the main channel of a river includes the exploration of the side arms, inflowing waters, adjacent wetlands, etc.

3. Better understand the spread of invasive species in the integrated river system of the Rhine-Main-Danube

Alien species, often originating from biogeographically distant regions, come into our waters either by passive dispersal (e.g. transport by ships), by active migration, or are introduced by man. As a result of the lacking competition in the waters, they can disperse rapidly over wide areas. At present this phenomenon has become intensive in the case of many ponto-caspian macroinvertebrates and fish species in the River Danube. The faunal change needs intensive research, because of its ecological effects on natural river ecosystem and economic consequences on human society. The cause of invasion, the role of neozoa species in the riverine food chain network must be studied. Is there any cause and effect between the previous spreading of ponto-caspian macroinvertabrates as fish food and fish species recently spreading from the same region?

4. Determine the relationship between climate change and fresh water biota

In parallel with the detection of change in air temperature, we need to build a strong database of water temperature to detect the possible temporal changes in river and in shallow lake waters. This is a prerequisite to study the direct effect of climatic changes on the processes that happen in fresh waters (e.g. shifting habitat zones of different communities in consequences of changes in water temperature). Global warming impacts on carbon biogeochemistry need to be studied as well.

5. Develop understanding of the relationship between habitat and fish communities

Diversity of fish communities is directly related to the variety of habitats within a river basin and large river ecosystems have to have a complex habitat structure to maintain a diverse fish community. Large rivers have been subjected to modifications for centuries, however impacts on fish biodiversity from human activities can be difficult to assess in large rivers. Sampling and monitoring methods for representative and comparative fish community assessments have to be further developed. Long-term scientific surveys on the dynamics of river fish communities are essential to complement monitoring programs.

6. Investigate the cyanobacteria and algae of small water bodies

The algal flora of many important lakes and rivers is more or less well known, but more than half of Hungarian lakes (including e.g. small permanent or temporary lakes of National Parks or protected area), reservoirs, gravel-pit lakes, oxbows and small rivers and creeks are not yet studied. The aim is to discover the "whole" algal flora, to know and understand the biodiversity of algae and to understand the ecological reason for their distribution. New methods in their investigation (electron microscope, techniques of molecular biology) have to be applied to determine their taxonomy and to describe new species.

7. Evaluate the ecological status of large rivers using the methodology of the EU WFD

Based on the experiences of international framework projects (AQEM, STAR, FAME) only wadeable sized rivers are well known in terms of the Water Framework Directive (WFD) compliant ecological status evaluation. Large fluvial systems like the River Danube and its main tributaries are difficult targets of the trans-national monitoring activity, even in the present days, due to several methodological gaps:

- Lack of appropriate quantitative sampling methods used along the entire length of the river;
- Lack of knowledge on water body delineation and the internationally accepted typology
- Lack of the type (section-type) referential conditions;
- Lack of knowledge on the connection between Biological Quality Elements (BQE) and different anthropogenic stressors (organic pollution, specific pollution, nutrient load, river morphological stresses, etc);

The most important consequence of these gaps is the lack of biotic data along the entire Danube and tributaries. Therefore the WFD compliant data collection that includes all of the mentioned problems is crucially important in the Danube basin context as one of the main research priorities.

8. Determine type-specific referential conditions of water bodies with special emphasis on lowland and large rivers

The determination of the environmental quality ratio (EQR) is highly dependent on the correct basis of comparison (type specific referential conditions). Although this comparative basis has a crucial role, the correct determination of the referential conditions is especially difficult in case of large rivers and lowland conditions due to the enormous amount of anthropogenic impacts. Therefore, extended data collection is necessary for revealing the referential taxon lists for different BQEs together with the development of generated indices and metrics. The application of the best available status could be an appropriate method in certain cases.

9. Determine the biological validation of running and stagnant water types using different BQEs

Faunistic and floristic data collection has to be carried out in water bodies having closed hydrographic connections in order to use the syn-biological results for validation (or falsification) of their present typological classification. The survey is extended to seasonal frequency and to large (country) scale in order to cover both seasonal aspects and watersheds representing increasing size classes. Special attention should be paid to revealing within-type variation and between-type differences referring to a given river in order to clarify the length of representative stretches and territory of the running and stagnant water bodies, respectively.

10. Evaluate the ecological status of stagnant waters (lakes) based on different biological quality elements

Generally, phytoplankton and macrophytes as primary producers are used for quality assessment in the case of lakes in order to describe the effect of nutrient load as the main stressor. Methods for the ecological status determination is mainly based on algae - macrophytes require more research for their appropriate use in the assessment procedure. Similarly, the indication of effects of other stressors requires the detailed analysis of other biological quality elements. There are no available and generally accepted methods for this purpose that use aquatic macroinvertebrates yet. Detailed study is necessary for the clarification of the appropriate sampling methods and strategy in the lakes concerning the pelagial and littoral regions. The development of biological metrics for status evaluation is crucially important.

11. Assess the effects of hydrolomorphological interventions on the composition and ecological state of the taxonomic groups specified in the WFD

The ecological state of running water bodies is largely influenced by human hydromorphological interventions. There is a need to do further research on the relationship between the Water Framework Directive components, biological quality elements (BQEs) and such human impacts. Small rivulets and vulnerable wild areas are the least understood in this respect.

12. Study may-fly (*Palingenia longicauda*) distribution and population sizes in Hungary, leading to the development of the species' conservation action plan

Palingenia longicauda used to occur in the whole of Europe, but has since disappeared from Northern-European rivers and is currently only present in the Tisza river and its tributaries in Hungary. Further studies on the population of may-fly require the use of GIS technology to detect the relationship between the location of the largest sub-populations and the different river-regulation methods used in the area. A thorough action plan has to be elaborated to recommend optimal river-regulation approaches for the conservation of may-fly assemblages.

13. Conduct hydrobiological surveys of the sodic-alkaline ponds of the Pannon region

Sodic-alkaline ponds are a characteristic of the Pannon region. These wetlands are among the most endangered habitats. Complex hydrobiological research on such water bodies and their catchment area is required to support the long-term survival of these ecosystems. Optimal land use and water use conditions have to be defined, possibly based on international cooperation, in order to conserve these precious habitats.

Research priorities for freshwater biodiversity in Ukraine

Viktor Gasso and Roman Novitsky, Dnipropetrovsk National University, Dnipropetrovsk, Ukraine; **Sergiy Afanasyev**, Institute of Hydrobiology of National Academy of Sciences of Ukraine (NASU), Kyiv, Ukraine; **Mikhail Son**, Odessa Branch Institute of Biology of the Southern Seas (NASU), Odessa, Ukraine

Ukraine, as a part of Europe on the one hand and of former Soviet Union on the other, has common (natural) and specific (mostly political) problems in freshwater biodiversity research and relevant policy determining the approaches to the research needs. National key researchers consider the most urgent needs as follows:

1. Research on the genetic diversity of common and vulnerable (especially threatened) species.

About 15 freshwater fish species are at the verge of extinction in Ukraine. Among them are *Eudontomyzon mariae, Zingel zingel, Anguilla anguilla, Acipenceridae* species and others. They are characterized by low numbers with a real threat of bottleneck pass (in the case of survival, of course) with the associated genetic consequences. It is necessary not only for research but for inevitable future needs to establish genetic banks of vanishing and significant species.

2. Long-term research-based prediction of possible threats of alien invasions to inland waters of Ukraine from the surrounding territories.

One of the biggest problems in Ukraine linked to this situation is fast-developing decorative aquaculture (aquariums and artificial ponds) with a wide spectrum of new species. However, the scientific community currently only establishes the facts of finding new alien species and nobody knows the possible threats of new invasions. As a result we tend only to react rather than prevent.

3. Influence of the fishing industry on biodiversity.

Industrial aquaculture of native and alien species has specific but little known impacts on biodiversity of freshwater ecosystems in Ukraine. Ukraine has no legislative basis for commercial and amateur fishery – a specific gap between research and policy. This results in considerable over-fishing (the real quantity of caught fish exceeds the reported data 8–9 times) and degradation of aquatic ecosystems.

4. Influence of environmental changes on biodiversity.

The high levels of industrialization and agricultural intensification has resulted in an intensive transformation of freshwater ecosystems through water pollution and regulated water flow. Together with the influence of climate change, escalating water consumption, invasions and other threats, a real transformation of freshwater organisms is occurring. The influence of water quality on homeostasis and sustainability of native populations is poorly known in Ukraine. In addition, anthropogenic pollution should be controlled to ensure the survival of fresh water ecosystems.

5. Lack of qualified taxonomists.

Within the next few years Ukraine will face a lack of qualified taxonomists for particular groups (e.g. protozoa and zooplankton) and general ageing of research staff. This is a result of protracted lack of financing, resulting in the lack of appeal of taxonomy for students.

Research needs regarding freshwater biodiversity in Norway

Odd Terje Sandlund, based on information compiled by **Erik Framstad** from a number of scientists.

Biodiversity research in freshwaters in Norway has had very low priority since the mid-1990s. Thus, a long list of issues are in need of research, in particular to create a sensible basis for implementation of the EU WFD. Some of the important issues are to:

- Improve understanding of community dynamics and biogeographic distribution patterns. Better understanding of species dispersal and natural community dynamics and their significance for aquatic ecosystem structure and function is needed as a basis for assessing effects of human-induced impacts like climate change, eutrophication, resource extraction and land use change. Habitat suitability modelling is a useful tool for predicting species potential distribution but needs to take species dispersal ability and migration history into account.

- Improve the scientific basis for conservation and restoration of salmonid populations in streams. With their strict environmental requirements, salmonids in streams are particularly vulnerable to various anthropogenic pressures, while also being among the most attractive target species for anglers. Research is needed to improve our understanding of the conservation biology of salmonids, and to develop effective approaches to restoration of salmonid populations and their riverine habitats.

Relevant topics are:

• Life stage specific physical habitat requirements in terms of habitat structure and water flow patterns.
• Impacts of catchment area land use on salmonid habitats.
• Possible lessons to learn for restoration efforts from northern river systems where several of the salmonids are still abundant.

- Improve understanding of ecosystem function, invasive species and climate change. Stability of communities, and thus predictability, generally increases with species richness. Less species-rich communities may be more susceptible to invasion of non-indigenous species, which may further impact biodiversity. The spread of opportunistic species, combined with global trends of decreasing species richness, requires predictive models for the impact of these trends on ecosystems, taking account of prior knowledge of the state of ecosystems. Climate change may affect biodiversity indirectly by increasing both the probabilities and the ecological consequences of species invasions. Large-scale climatic gradients from temperate lowland to high arctic mountain lakes may constitute appropriate a space-for-time framework for suitable field studies.

- Improve understanding of the biodiversity and ecosystem services of small water bodies

Water bodies below a certain size are not well protected by the WFD and are disappearing rapidly from the landscape in Europe. Small lakes may be important for biodiversity and are a common water body type in many European countries. More knowledge is needed about the biodiversity of small water bodies, their ecological functions, services, and threats.

- Improve the scientific basis for implementing the Water Framework Directive. Implementation of the WFD requires establishment of cost-efficient monitoring and classification systems for assessment of ecological status. This is especially challenging for biological quality elements and parameters. A number of research topics are relevant:

• Development of biological indicators (from pressure specific to general indicators),
• Methods for defining reference conditions (palaeolimnological methods, modelling, natural variation),
• Harmonization of sampling methods and tools for linking changes in biodiversity to various pressure types and combinations of pressures, either known or unknown
• Development of efficient methodology on zoobenthos in northern/mountain streams where current methods are infeasible without excessive costs

• Assessing how fish community and population status may be better used as indicators of ecosystem quality (since there is a rich source of fish data and there are many more experts on fish than other groups).

Research priorities in Slovenia

Anton Brancelj, National Institute of Biology, Ljubljana, Slovenia

The top research priorities for sustaining freshwater biodiversity in Slovenia should include:

- Research on fissured (karstic) and porous (alluvial) groundwater aquifers:

Results from the 5th FP EU project PASCALIS revealed that Slovenia is one of the biodiversity hotspots for groundwater fauna in Europe. However, only some parts are well surveyed, particularly saturated zones in karst. So far over 150 stygobitic taxa have been recorded in Slovenia. Unsaturated zones in karst and porous habitats in rivers (hyporheic and phreatic zone) still contains many unknown species (on average 1 new species per year in Copepoda alone over the last 10 years). Most of those taxa are endemic; some of them occur only in small areas (100–1000 km2).

Intensive exploitation of drinking water, pollution and climate change (effect on hydrology) are the main threats to these species. Further research, especially in porous aquifers, is needed not only on a theoretical aspect (biodiversity) but also in terms of practical needs (water quality control: good ecological status of GW is not included in WFD!)

- Research on remote and pristine surface headwaters

Several new species in remote and pristine surface streams have been discovered in the last few years in remote and pristine surface headwaters (in combination with new molecular techniques). Special attention should be focussed on high-mountain lakes. These habitats are very sensitive to climate change and direct human impacts and, as such, can serve as an early warning system. Slovenia has 14 high-mountain lakes (studied in the 4th FP EU projects MOLAR and EMERGE). These lakes are quite unique in the Alps and harbour a very specific group of fauna & flora.

- Monitoring of surface water bodies (lakes, rivers and reservoirs)

The introduction of new species (either as a result of climate change, transport or from aquariums) can severely affect local fauna, resulting in the deterioration of ecosystems through loss of local fauna, reduced biodiversity and a decrease of water quality. Another specific problem is fish stocking – either as "exotic" species (white amur) or the transfer from one river basin to another (arctic char). Although these introductions are now regulated by law, these were common in the past.

In addition, to echo the contribution of Viktor Gasso and colleagues, the lack of qualified taxonomists is also occurring in Slovenia, and needs to be addressed.

Specific research in the case of protected areas: the Danube Delta Biosphere Reserve

Christian Kleps, Romanian Academy of Agricultural and Forestry Sciences

The concept of biosphere reservation was promoted in 1971 by the Man and Biosphere (MAB) Programme under UNESCO auspices. This concept takes into account the conservation of some particular natural areas, including representative ecosystems with genetic resources able to maintain and extend endangered species of plants and animals. Unlike other protected areas, the biosphere reservation is not dedicated exclusively to protection, but has more purposes, namely: ecosystem conservation and balanced utilization of renewable natural resources; keeping all traditional forms of economic activity which do not contribute to the ecological imbalance; permanent surveillance of the protected ecosystems elements; population information and education on the scientific value and necessity to preserve and protect plants and animals species and landscape; integration and scientific cooperation in the frame of the world network of protected areas.

The Danube Delta Biosphere Reservation (DDBR), with a surface of 580,000 ha (2.5% of Romania's surface), was included in MAB Programme of UNESCO in 1990, and in the same year was listed as a wetland of international importance, especially as a waterfowl habitat under the Ramsar Convention, being included also among the strictly protected areas in the World Heritage List under the World Cultural and Natural Heritage Convention. At the same time as Romania acceding at the European Union, 80% of DDBR territory was put forward to be included in the European Network of Natura 2000 Protected Areas.

There are 4 types of functional areas in the frame of DDBR: (i) strictly protected areas, including 18 sites with excellent examples of terrestrial and wetland ecosystems and generally supporting the most sensitive species found in the DDBR; (ii) buffer areas, with 13 zones, including areas with biological characteristics like the previous ones, mitigating the impact of the human activities on the strictly protected areas; (iii) economic zones, including areas where traditionally allowed activities are undertaken, in the limits of the support capacity; (iv) areas of ecological restoration, where Danube Delta Biosphere Reservation Authority carries out activities of ecological restoration.

DDBR represents a real museum of biodiversity, with 30 types of ecosystems, 5,137 species, of which 1,689 flora species (4 protected under Bern Convention) and 3,448 fauna species (380 protected under Bern Convention): molluscs (86 species), insects (2,219 species), fish (125 species), amphibians (10 species), reptiles (11 species), birds (325 species) and mammals (42 species).

The research activities carried on in DDBR are mainly the responsibility of the Danube Delta National Institute (DDNI) in Tulcea, nominated as Centre of Excellence for Deltas and Wetlands within the European Commission's Centres of Excellence Programme launched in 1999 (DELWET Project). The institute carries out basic and applied research to scientifically support the management in the DDBR and other wetlands of national and international importance for the biodiversity conservation and sustainable development. Current topics of research include: monitoring the biological diversity and environmental factors; modeling the basic processes of ecosystem functioning; assessment and reduction of the anthropogenic impact; restoration of the ecosystems; strategies for biodiversity conservation and sustainable use of the natural resources.

In the future, more hydrographical research will be needed for the fluvial part of delta, developed in the former gulf of Danube river (258,100 ha), partly subjected to an intensive silting process. A real concern is the construction of the Bistroe channel in the Ukrainian part of the Danube Delta and new research will be necessary to evaluate water quality and biodiversity in this new context. For the fluvio-marine part of delta (180,000 ha), affected by major morphs-hydrographic changes in the contact zone with the Black Sea, specific research on the phyto- and zooplankton will be required.

Research priorities in freshwater ecosystems in the Czech Republic

Petřík P. (ed.)[1], **Květ J.**[2], **Pithart D.**[2], **Pokorný J.**[2], **Matěna J.**[3], **Elster J.**[4, 5], **Maršálek B.**[6, 7], **Ráb P.**[8], **Poštulka Z.**[9], **Ansorge L.**[10]

[1] Institute of Botany, Academy of Sciences of the CR (AS CR), Department of Geobotany, www.ibot.cas.cz, [2] Institute of Systems Biology and Ecology, Department of Wetlands Ecology, www.usbe.cas.cz, [3] Institute of Hydrobiology, AS CR, Biology Centre, www.hbu.cas.cz, [4] Institute of Botany, AS CR, Phycology Centre, Section of Plant Ecology, www.butbn.cas.cz, [5] University of South Bohemia, Faculty of Science, www.bf.jcu.cz, [6] Institute of Botany, AS CR, Centre for Cyanobacteria and their Toxins, www.cyanobacteria.net [7] Faculty of Science, Masaryk University, Research Centre for Environmental Chemistry and Ecotoxicology, www.recetox.muni.cz, [8] Institute of Animal Physiology and Genetics AS CR, Laboratory of Fish Genetics, www.iapg.cas.cz, [9] Friends of the Earth Czech Republic, www.hnutiduha.cz, [10] Ministry of Agriculture, Department of Water Management Policy, www.mze.cz

The forest-water ecotone, the riparian zone, and related groundwater are all understudied ecosystems in the Czech Republic (see EPBRS recommendations 2001). In addition, there is not enough intensive and widespread research dealing with forest and water ecosystems biodiversity. Scientists dealing with biology and landscape ecology do not usually get the opportunity to collaborate enough with those studying atmospheric deposition, soil science, soil, and water chemistry. There is no cooperation between academic natural science and so-called forest and agricultural science. The forest and agricultural sciences are usually oriented towards increasing production and benefits and biodiversity is not yet seen as an important goal for such research. There is also a huge gap between findings of natural scientists and industrial forestry and water management. Coordination of activities among the individual sectors is unsatisfactory and the competence is not clearly defined (e.g. amongst the administrators of watercourses, fishing organizations and private owners). Conservation and management of inland water biodiversity is inconsistent, extensive pollution is not tackled sufficiently, and there is no clear programme for remedying unsuitable hydrological regulation of watercourses, which contributes to the progressive destructive consequences of floods. There is a lack of attention to catchment area integrated management (i.e. in catchment area plans). Economic management of fishponds emphasizes production benefits and the management is in no way based on the ecosystem approach. There is not enough demand for knowledge at responsible institutes (Ministry of the Environment and Ministry of Agriculture) related to the WFD. Basic research should be better supported by these administrative bodies. To avoid the separation of basic and applied research in water management, better coordination between science and policy is urgently required. In the implementation of the WFD, attention should be paid to the definition of ecological state/potential of freshwater ecosystems.

According to the National review (see et Petřík al. 2007) two main actions are needed: (i) reduction of emission and deposition of nitrogen within the National Emission Ceiling Directive and (ii) changing the paradigm of strictly benefit-oriented forestry and agriculture toward sustainable management, aiming to increase or at least conserve existing biodiversity.

To fulfil these actions in general, the most important research needed is to:

• Determine wetlands' and shallow water bodies' responses to climate changes; mitigation of their impact on wetlands

• Determine wetlands' and shallow water bodies' response to eutrophication and pollution on system of effective measures preventing eutrophication, erosion and excessive transport of sediments in the cultural landscape

• Evaluate ecosystem services provided by wetlands (e.g. to estimate the water retention achievable by means of soft restoration methods, such as restoration of contour coppice woods combined with contour ditches, ponds, infiltration pits, wetlands, stream restoration, etc.)

• Applications of research results to different types of wetland and shallow water bodies in different regions

• Taxonomy and ecology of freshwater organisms such as, e.g., cyanobacteria (to prevent water blooms) or fish (determination of the driving factors responsible for their life cycle)
• Ecology of specific freshwater habitats such as, for example, periodical shallow wetlands created during floods
• Implication of present knowledge and future research into management of artificial water bodies, and in addition, their influence on water quality and biodiversity (on all trophic levels from bacteria to fish) of rivers.

There are also some specific technological research needs, including the need to determine:
• How to deactivate the old phosphorus ballasts in the sediments of water reservoirs without draining them off (as they are used for water supply)
• How to reduce water blooms in water reservoirs without using chemicals
• How to assess the potential of water retention in the landscape with respect to climate change
• How to influence the processes responsible for the denitrification process both in the soil and water

Biodiversity research needs in the UK

Laurence Carvalho, Centre for Ecology & Hydrology (CEH); and **Iain Sime**, Scottish Natural Heritage (SNH)

Below we outline four priority areas for research on freshwater biodiversity:

1. Confidence and understanding of biodiversity trends

In order to understand the pressures on biodiversity and, in turn, the effectiveness of measures to conserve and manage freshwater biodiversity, it is important not only to collect information on the spatial and temporal variability of biodiversity but also to be able to quantify or understand trends from natural variability. Therefore, beyond the continued need for maintaining adequate spatial and temporal datasets, there is a research need to understand the ecological requirements of freshwater biodiversity and identify what processes are driving changes. The analysis of long-term datasets (LTER sites) can be particularly useful in this respect.

2. Assessing the health of freshwater ecosystems

We need to better understand what constitutes significant functional shifts in our freshwater ecosystems, which can clearly have major implications for the species and habitats such ecosystems support. What are the consequences of shifting from benthic to planktonic production? From phosphorus to nitrogen limitation? There is a need to develop robust indicators of functional change, that may provide better targets for restoration than particular species recorded in the past.

3. The functional role of freshwater biodiversity

A high priority is given to the delivery of sustainable solutions to issues affecting the environment, particularly in freshwaters (e.g. WFD). This presents opportunities to further the conservation of freshwater biodiversity by making use of the functional role freshwater species and habitats can play. However our understanding of the functional role of freshwater biodiversity needs to be improved in order to maximise such opportunities. For example, a better understanding of the contribution wetlands can play in delivering sustainable flood management should provide more opportunity to restore and re-connect remnant wetlands within catchments. With respect to climate change and eutrophication, there is also an urgent need to better understand the role of freshwater microbial diversity in the fluxes and storage of both greenhouse gases and plant nutrients.

4. Connectivity and resilience to change

One reason that particular elements of freshwater biodiversity are vulnerable to environmental change is their lack of connectivity with other freshwaters. There can be little connectivity between catchments for many obligate freshwater species and some of the inherent conservation value of some freshwater sites lies in their historic lack of connectivity (e.g. remnant, isolated fish species). A key need for the conservation of freshwater biodiversity, in the face of environmental change, is to understand the factors that alter a site's resilience to environmental change.

Freshwater biodiversity research needs in Latvia

Gunta Springe, Faculty of Geography and Earth Science, University of Latvia

Climate change impacts on freshwater ecosystems and their biological diversity is currently regarded as the essential research topic in Latvia. Research in this field should provide a better understanding of:

1) The relationships between climate and biodiversity on various trophic levels in large river basins using the Salaca river basin as a model type;

2) The relationships between fluxes, climate and biota in order to describe changes in water quality (including dissolved organic carbon content) and their impact on the structure and functioning of the biotic communities;

3) Assessment of species behaviour in order to better select potential water quality indicators under climate change stress.

Additional knowledge is necessary on the biodiversity in the surface waters of Latvia, as well as the assessment of the trophic links and population dynamics for all groups of organisms. For appropriate and successful management strategies, potential developments of freshwater fish communities should be forecasted. Relatively large and not heavily modified waterbodies (e.g. the Salaca River and Lake Burtnieku) need to be chosen as a model types to assess the changes in species diversity, analyze alterations in composition and structure of the fish community in relation to climate change factors. Forecasting potential changes in water composition taking into account leaching, wash-out, absorption and biogeochemical cycles is of utmost importance, as well as projections of possible impacts on the structure and function of freshwater ecosystems. Water composition alterations should also include changes in organic carbon cycling where knowledge on the nature of these changes is still missing.

Research priorities for sustaining freshwater biodiversity in Lithuania

Compiled by **Eduardas Budrys**, Institute of Ecology of Vilnius University, Vilnius, Lithuania

1. Diversity of non-commercial fish species and invertebrates. Species of commercial interest are well studied in Lithuania, however, the non commercial species are much less documented. Therefore, there is a risk of undocumented loss of freshwater biodiversity (e.g. extinction of the glacial relict fauna due to global warming and/or invasive species). Studies should focus on the spatial and temporal species distribution and monitoring of rare and endangered non-commercial freshwater species, as well as their population dynamics.

2. Human impacts on freshwater species biodiversity. Studies should cover habitat destruction and their effects on rare or endangered species; water pollution; contaminants accumulation and their effect on freshwater species; genetic diversity loss due to artificial fish stocking; effects of artificial stocking on wild populations; spread of diseases from aquaculture and effect on rare or endangered species through e.g. stocking of commercial fish species to natural water bodies.

3. Invasive species and their effect on local freshwater biodiversity. These studies should aim to develop a national register of both native and invasive species records, clarify the routes (particularly the large rivers) and reasons of invasions (including human activities such as artificial stocking of fish or crayfish species), as well as invasive species interactions with the local populations, like the recent fast spread of ecologically aggressive alien crayfish species and the decline of native crayfish.

4. Native populations' booms (especially predatory species, e.g. cormorants) and their effects on freshwater biodiversity. Unusual booms of native populations can be caused by natural species dynamics fluctuations as well as by human activities (e.g. such as overfishing of top predators and destruction of the entire tier of food chain). In Lithuania as well as in the most European countries recent boom of cormorant population could have an important effect on freshwater fish populations including endangered species, however the effect on stocks and especially on non commercial species is largely unknown.

Research priorities for freshwater biodiversity in Romania

Compiled by **Simona Mihailescu** (Institute of Biology Bucharest, Romanian Academy) based on information from: **V. Zinevici, and Mihaela Pauca-Comanescu** (Institute of Biology Bucharest, Romanian Academy); **A. Vadineanu** (University of Bucharest); **D. Munteanu** (Romanian Academy, Commission for Nature Monuments); **D. Murariu** ("Grigore Antipa" National Museum of Natural History, Bucharest).

The conservation and management of biodiversity requires the combination of nature conservation and ecological sustainability while preserving the social-cultural values of local communities. Romania harbours 5 of the 11 European bio-geographic regions, the highest number found within a single EU Member State. A large number of applied and theoretical research projects are underway in Romania involving research institutes, universities, museums, botanic gardens, aquaria, vivaria, biosphere reserves, natural and national parks.

Landscape and cultural heritage: Romania is rich in freshwater landscapes from springs in the Carpathians Mountain areas, to rivers feeding into the Danube, all the way to the Delta Biosphere Reserve and the Black Sea. The cultural and historical landscape is a natural resource that contributes to the attractiveness of the country to tourists and business development. This heritage is documented in natural science collections. These collections are essential to taxonomic research and help to understand freshwater ecosystems better, by contributing to the identification of species and determining their conservation status.

Habitat fragmentation along springs, rivulets and rivers: Springs, rivulets and rivers in woodland areas are strongly affected by forest cutting, yet remain poorly studied. It is expected that intensification of investments as part of the country's economic development without mitigation measures for the impacts on biodiversity, will lead to further habitat fragmentation and biodiversity loss. The loss is likely to be accelerated by uncontrolled production linked with large scale forest cutting (including the Salix sp. and Populus sp. galleries of the rivers). Another important aspect is the fragmentation of rivers due to damming.

Research in this area includes:

- Restoration of riverbank plant cover after hydro amelioration works especially river regularization;
- Re-vegetation of mine spoils and mined surfaces especially cooper rock spoils;
- Restoration of rock quarries and spoil materials after erection of hydro-power plants.

Water quality: Water quality improvement in different water basins has been observed in recent years due to the reduction of animal farms and the closure of certain polluting industries over the last 17 years.

Ground water: An overall assessment of river basins shows a critical situation in the quality of aquifers in many areas of the country. These will affect both the water quality and biodiversity of these ecosystems. More attention should be focussed on developing risk assessments of water exploitation in the mountainous karst areas. These water sources are often used for supplying new buildings and resorts, which could result in potentially negative effects on subterraneous water regime and cave fauna.

General objectives for freshwater biodiversity research in Romania include:

1. Understand how conservation of freshwater biodiversity and restoration schemes can contribute to the mitigation of climate change.
2. Understand the influence of extreme weather events, flood, drought, fire and other catastrophic events in southern and south-eastern European countries on biodiversity, conservation and sustainable use in the context of a changing climate and other long term drivers.
3. Understand the contribution of freshwater biodiversity to ecosystem services.
4. Understand and evaluate the contribution of natural capital and freshwater ecosystem services to sustainable economies.
5. Improve methodologies and tools for freshwater ecosystem assessment and adaptive management including: indicators for ecosystem functions and services; methods to deal with

uncertainties, irreversibility's, complex dynamics and non-linear changes; decision support systems and scenarios for future trends.

6. Identify new measures, and modifications to existing land and water use systems, including the potential contributions of rural businesses, to protect biodiversity in extensive systems and High Nature Value Farmland areas from negative impacts of land abandonment or land use intensification.

Taking into account all these aspects, high priority research regarding freshwater biodiversity in Romania includes:

• Research on long-term changes in land use and other human impacts as well as changes in biodiversity and ecosystems functioning in different types of inland waters.

• Effects of climate change on the distribution and abundance of species existing in freshwater habitats (e.g. freshwater habitat types for standing water and running water included in Natura 2000 such as: alpine rivers and their ligneous vegetation with *Salix elaeagnos* or with *Myricaria germanica*; *Salix alba* and *Populus alba* galleries, etc).

• Identify and quantify the factors responsible for the historical and current trend of aquatic bird species, namely species included in the Annex II of the Birds Directive, that are endangered and vulnerable in the European Union and Romania. A special interest should be allotted to declining species, in order to promote action plans aiming to reduce the intensity of these factors, or to eliminate them, and consequently to increase birds' abundance. Such plans could involve both species and habitats.

• Research on the genetic diversity of common and threatened species and the species included in Natura 2000.

• Determine the impact of non-native, invasive and alien species in freshwater habitats. Recent studies show an increase the number of invasive species of plants, gastropods, or univalves, fish, etc. in woodland and freshwater habitats.

• Species, ecosystems and genetic diversity in the process of ecological succession of lentic (as lakes or ponds) ecosystems from the deltaic system (e.g. Danube Delta). Inside a deltaic system, there are a series of lentic subsystems in different stages of development, which give a high biodiversity value of the whole area. Keeping these subsystems alive is key to the maintenance of the actual biodiversity to acceptable values and mitigates the upstream effects of human activities.

• Ecologic evaluation of restoration activities in areas with high anthropogenic impacts should be carried out.

• The impact of dams, diking and drainage on biodiversity. Constructing dams and dykes often results in the decrease of reophilous species and an increase in the number of species in stagnant water. Biotic diversity of running water highly depends on aquatic systems of flooded plains. More attention should given to the study of changes in the running water between dam reservoirs

• The impact of eutrophication on the structure and trophic links between various communities of organisms in flood plains.

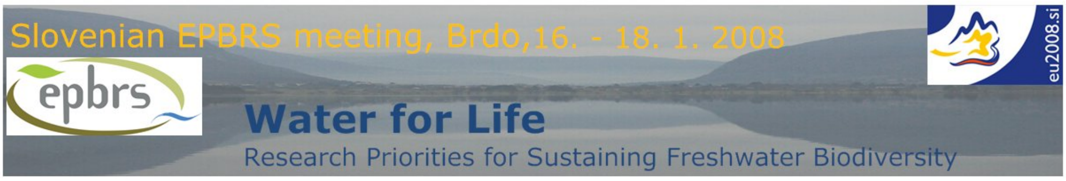
• Studies on the interactions between biodiversity in the Danube Delta and biodiversity in the coastal sea: in particular the study of bacterioplankton, phytoplankton, zooplankton, phytobenthos, macroinvertebrates and macrophytes and their interaction.

• Studies on the restoration of former lakes along the Danube flood plain, especially between dam Iron Gates I and dam Iron Gates II (Portile de Fier I - II).

• Studies on the effects of intensive gravel and sand exploitation from river valleys/riverbeds on the local terrestrial and aquatic habitats and biodiversity.

• Monitoring the chemical regimes of lakes and rivers.

In order to achieve the above, cross-border cooperation is necessary to mitigate and eliminate the effects of biodiversity loss.



References and further reading

Alcamo, J., Vörösmarty, C. Naiman, R. J., Lettenmaier, D., Pahl-Wostl, C. 2007. A grand challenge for freshwater research: Understanding the global water system. Environmental Research Letters (in press).

Arthington, A.H., Bunn, S.E., Poff, N.L., Naiman, R.J. 2006. The challenge of providing environmental flow rules to sustain river ecosystems. Ecological Applications 16: 1311-1318.

Balian, E.V, Lévêque, C., Segers, H., Martens M. (Eds.) 2008. Freshwater animal diversity assessment. Special Issue Hydrobiologia (In press).

Becker, C.G. et al. 2007. Habitat split and the global decline of amphibians. Science 318:1775-1777.

Boccone, P. 1674. Icones et descriptions rariorum plantarum Siciliae, Melitae, Gallieae et Italiae. Oxonii.

Bogutskaya, N.G., Naseka, A.M. 2002. An overview of non-indigenous fishes in inland waters of Russia. Proceedings of the Zoological Institute of the Russian Academy of Sciences 296: 21-30.

Brian, J.V. et al. 2005. Accurate prediction of the response of fish to mixtures of estrogenic chemicals. Environmental Health Perspectives 113: 721-728

Brian, J.V. et al. 2007. Evidence of estrogenic mixture effects on the reproductive performance of fish. Environmental Science and Technology 41: 337-334.

Bunn, S E., Arthington, A.H. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental Management 30:492-507.

Cachia, S. 1997. Aspects of the behavioural ecology of the freshwater crab *Potamon fluviatile lanfrancoi* in the Maltese Islands. B.Sc. (Hons.) dissertation. Malta: Faculty of Science, University of Malta.

Camilleri, M. 2006. Ecology of the perennial freshwater pool at il-Qattara (Qawra, Gozo). B. Sc. (Hons.) dissertation. Malta: Faculty of Science, University of Malta.

Casado, S., Montes, C. 1995. Guide of Spanish lakes and wetlands. J.M. Reyero Editor. Madrid, 255 pp.

Cirmo, C.P., McDonnell, J.J. 1997. Linking the hydrologic and biogeochemical controls of nitrogen transport in near-stream zones of temperate-forested catchments: a review. Journal of Hydrology 199:88-120.

Covich, A.P. et al. 2004. The role of biodiversity in the functioning of freshwater and marine benthic ecosystems. BioScience 54: 767-775.

Culver, D.C., Sket, B. 2000. Hotspots of subterranean biodiversity in caves and wells. Journal of Cave and Karst Studies 62(1): 11-17.

Dahm, C.N., Grimm, N.B., Marmonier, P.M., Valett, M.H., Vervier, P. 1998. Nutrient dynamics at the interface between surface waters and groundwaters. Freshwater Biology 40:427-451.

Davis, R., Hirji, R. 2003. Water resources and environment - Technical Note C.1 Environmental flows: concepts and methods. The World Bank, Washington, D.C.

Dent, C.L., Grimm, N.B., Fisher, S.G. 2001. Multiscale effects of surface-subsurface exchange on stream water nutrient concentrations. Journal of the North American Benthological Society 20:162-181.

Downing, J.A., Cole, J.J., Middelburg J.J., Striegel, R.G., Duarte, C.M., Kortelainen, P., Prairie, Y.T., Laube, K.A. 2008. Sediment organic carbon burial in agriculturally eutrophic impoundments over the last century. Global Biogeochemical Cycles (in press).
Downing, J.A., Prairie, Y.T., Cole, J.J., Duarte, C.M., Tranvick, L.J., Striegel, R.G., McDowell, W.H., Kortelainen, P., Melack, J.M., Middleburg, J.J. 2006. The global abundance and size distribution of lakes, ponds and impoundments. Limnology and Oceanography, 51: 2388-2397.
Dudgeon, D., Arthington, A.H., Gessner, M.O., Kawabata, Z., Knowler, D., Lévêque, C., Naiman, R.J., Prieur-Richard, A.H., Soto, D., Stiassny, M.L.J., Sullivan, C.A. 2006. Freshwater biodiversity: importance, threats, status, and conservation challenges. Biological Reviews 81: 163-182.
Duthie, J.F. 1875. Notes on the flora of the Islands of Malta, Gozo, Comino and Cominotto and localities for some of the more interesting species collected during the months of March and April 1874. Il Barth 1: 542-544.
Dyson, M., Bergkamp, G., Scanlon, J. (Eds.). 2003. Flow: The essentials of environmental flows. Gland, Switzerland, IUCN.
EC. Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for Community action in the field of water policy. The European parliament and the Council of the European Union, Brussels.
EC-DGE. 2007. Interpretation manual of European Union Habitats. EUR 27. European Commission, Direction General of the Environment, Nature and Biodiversity, Brussels, 142 pp.
Giller, P.S. et al. 2004. Biodiversity effects on ecosystem functioning: emerging issues and their experimental test in aquatic environments. Oikos 104: 423-436.
Goriĉki, Š. 2006. Filogeografska in morfološka analiza populacij močerila (Proteus anguinus). (Phylogeographic and morphological analysis of European cave salamander (Proteus anguinus) populations). Doktorska disertacija, Univerza v Ljubljani, Biotehniška fakulteta, Oddelek za biologijo, Ljubljana. www.pif.si/dokumenti/29/2/2007/DoktorskadisertacijaSpelaGoricki_278.pdf
Grech Delicata, J.C. 1853. Flora Melitensis stirpes phanerogra mas in Malta insulisque adjacentibus hacusque detectas secundum systema Candolleanum digestas. Malta.
Gulia, G. 1871-1877. Maltese botany. Il Barth 1: 16-19. 43-44, 59-60, 116, 135, 175-176; 2: 239, 282-284; 3: 378-380, 403-404, 416-419.
Gunderson, L.H., Holling, C.S. (Eds.) 2002. Panarchy. Island Press, Washington DC.
Gunderson, L.H., Holling, C.S., Light, S.S. 1995. Barriers and bridges to the renewal of ecosystems and institutions. Columbia University Press, New York.
Haslam, S.M. 1999. Ponds and pools of Malta: Past and present. In Boothby, J. (Ed.) Ponds and pond landscapes of Europe. Liverpool, Pond Life Project, pp117- 124.
Hedin, L.O., von Fischer, J.C., Ostrom, N.E., Kennedy, B.P., Brown, M.G., Robertson, G.P. 1998. Thermodynamic constraints on nitrogen transformations and other biogeochemical processes at soil-stream interfaces. Ecology 79:684-703.
Henwood, J (in prep.) *Chara vulgaris* var. papillata , a new record for the Maltese Islands.
Henwood, J. 2004. Aspects of floristic ecology of Maltese freshwater rockpools. B.Sc. (Hons.) dissertation. Malta: Faculty of Science, University of Malta.
Henwood, J. 2006. Algal assemblages of three Maltese saline wetlands. M Sc. dissertation. Malta: Faculty of Science, University of Malta.
Henwood, J., Lanfranco, E., and Merritt, R (in prep). Vaucheria (Heterokontophyta, Vaucheriaceae) from the Maltese Islands (Central Mediterranean). (Available from Jonathan Henwood).
Heugens, E.H. et al. 2001. A review of the effects of multiple stressors on aquatic organisms and analysis of uncertainty factors for use in risk assessment. Critical Reviews in Toxicology 31: 247-284.
Heywood, V.H., Watson, R.T. (Eds.) 1995. Global Biodiversity Assessment. UNEP, Cambridge University Press, Cambridge, UK.

Holling, C.S. (Ed.) 1978. Adaptive environmental assessment and management. J Wiley, New York.
Hooper, D.U. et al. 2005. Effects of biodiversity on ecosystem functioning: A consensus of current knowledge. Ecological Monographs 75: 3-35.
IPCC. 2007. Outline of the IPCC Working Group II contribution to the fourth assessment report, available at: www.ipcc.ch
Katz, D. 2006. Going with the flow: Preserving and restoring instream water allocations. In Gleick, P. (Ed.) The World's Water: 2006-2007: The Biennial Report on Freshwater Resources. Island Press, pp. 29-49.
King, J., Brown, C., Sabet, H. 2003. A scenario-based holistic approach to environmental flow assessments for rivers. River Research and Applications 19: 619-639.
Kottelat, M., Freyhof, J. 2007. Handbook of European Freshwater Fishes. Kottelat, Cornol, Switzerland and Freyhof, Berlin Germany.
Lanfranco, E. 1969. A revised checklist of Maltese algae. Pieta: National Press. 20pp.
Lanfranco, E. 1990. The vegetation of the Ghadira Nature Reserve. Centro 1(5): 1-4.
Lanfranco, E. 2002a. A contribution to the freshwater macroalgal flora of the Maltese islands. The Central Mediterranean Naturalist 3(4): 203-206.
Lanfranco, E., Schembri, P.J. 1986. Maltese wetlands and wetland biota. Valletta: SSCN.
Lanfranco, S. 1990. The ecology of freshwater rockpools in Malta. (Unpublished B.Ed.(Hons) dissertation). Malta: Faculty of Education, University of Malta. ix + 195pp.
Lanfranco, S. 1995a. An ecological appraisal of a site at Tal-Wej, limits of Naxxar and Mosta. Report of ecological consultancy prepared for Naxxar Local Council. 4pp.
Lanfranco, S. 1995b. Ecological succession in Maltese freshwater rockpools. (Unpublished M.Sc dissertation). Malta: Faculty of Science, University of Malta. xi + 205pp.
Lanfranco, S. 2001. Saline marshlands and transitional coastal wetlands. Malta: SSCN
Lanfranco, S., Lanfranco, E. 1999. Riella helicophylla (Mpnt.) Hook. (Bryopsida; Hepaticae; riellaceae), a new addition to the macrophytic wetland flora of the Maltese Islands. The Central Mediterranean Naturalist 3(1): 13- 14.
Laurenti, J.N. 1768. Specimen medicum, exhibens synopsin reptilium emendatam cum experimentis circa venena et antidota reptilium Austriacorum. Vienna.
Lovett et al. 2005. Ecosystem function in heterogeneous landscapes. Springer, New York
Lytle, D.H., Poff, N.L. 2004. Adaptation to natural flow regimes. Trends in Ecology and Evolution 19: 94-100.
Marczak, L.B. et al. 2007. Trophic interception: how a boundary-foraging organism influences cross-ecosystem fluxes. Oikos 116: 1651-1662.
Max-Neef, M.A. 2005. Foundations of transdisciplinarity. Ecological Economics 53:5-16.
Millennium Ecosystem Assessment. 2005. Millennium Ecosystem Assessment. Island Press, Washington, D.C.
Moore, M. 2004. Perceptions and interpretations of environmental flows and implications for future water resource management-A survey study. Linkoping University, Sweden: Masters Thesis, Department of Water and Environmental Studies.
Munns, W.R. 2006. Assessing risks to wildlife populations from multiple stressors: overview of the problem and research needs. Ecology and Society 11: Article 23.
Naiman, R.J. (Ed.) 1992. Watershed Management: Balancing Sustainability and Environmental Change. Springer-Verlag, New York.
Naiman, R.J., Bunn, S.E., Nilsson, C., Petts, G.E., Pinay, G., Thompson, L.C. 2002. Legitimizing fluvial ecosystems as users of water: an overview. Environmental Management 30: 455-467.
Naiman, R.J., Prieur-Richard, A-H., Arthington, A., Dudgeon, D., Gessner, M.O., Kawabata, Z., Knowler, D., O'Keeffe, J., Lévêque, C., Soto, D., Stiassny, M., Sullivan C. 2006. Challenges for freshwater biodiversity research. DIVERSITAS Report No. 5. 48pp.
Nilsson, C., Reidy, C.A., Dynesius, M., Revenga, C. 2005. Regulation of the world's large river systems. Science 308: 405-408.
Nilsson, C., Svedmark, M. 2002. Basic principles and ecological consequences of changing water regimes: riparian plant communities. Environmental Management 30: 468-480.

Paetzold, A. et al. 2008. Aquatic–terrestrial subsidies along river corridors. In: Wood, P.J., Hannah, D.M. and Sadler, J.P. (Eds.) Hydroecology and Ecohydrology: Past, Present and Future. John Wiley & Sons.

Petřík, P. (ed.), Květ, J., Pithart, D., Pokorný, J., Matěna, J., Elster, J., Maršálek, B., Ráb, P., Poštulka, Z., Ansorge, L. 2007. Research Priorities in the Freshwater Ecosystems of the Czech Republic. Institute of Botany, Academy of Sciences of the Czech Republic.

Poff, N.L. and 17 other authors. 2008. The ecological limits of hydrologic alteration: A framework for developing regional environmental flow standards. Freshwater Biology (Submitted)

Poff, N.L., Allan, J.D., Bain, M.B., Karr, J.R., Prestegaard, K.L., Richter, B.D., Sparks, R.E., Stromberg J.C. 1997. The natural flow regime - a paradigm for river conservation and restoration. BioScience 47: 769-784.

Poff, N.L., Allan, J.D., Palmer, M.A., Hart, D.D., Richter, B.D., Arthington, A.H., Rogers, K.H., Meyer, J.L., Stanford, J.A. 2003. River flows and water wars: emerging science for environmental decision-making. Frontiers in Ecology and the Environment 1: 298-306.

Postel, S., Richter, B.D. 2003. Rivers for life: Managing water for people and nature. Washington, DC: Island Press.

Richter, B., Baumgartner, J.V., Powell J., Braun, D.P. 1996. A method for assessing hydrologic alteration within ecosystems. Conservation Biology 10: 1163-1174.

Scanlon, J., A. Iza. 2004. International Legal Foundations for Environmental Flows. Yearbook of International Law: 81-100.

Schmidt, F. 1832. Leptodirus hochenwartii n. g. n. sp. Illyrisches Blatt, 21, 3: 9

Schmidt-Kloiber, A., Nijboer, R.C. 2004. The effect of taxonomic resolution on the assessment of ecological water quality classes. Hydrobiologia 516: 269-283.

Sket, B. 1972. Zaščita podzemeljske favne se ujema z življenskimi interesi prebivalstva (Protection of subterranean life consonant with human interests). In: Zelena knjiga (Green Book), PDS, Ljubljana 137-140, 164-165

Sket, B. 1977. Gegenseitige Beeinflussung der Wasserpollution und des Hohlenmilieus. Proceedings of the 6th International Congress of Speleology, Olomouc 1973, 5: 253-262

Sket, B. 1999. High biodiversity in hypogean waters and its endangerment – the situation in Slovenia, Dinaric karst, and Europe. Crustaceana 72(8): 767-779.

Sket, B., Paragamian, K., Trontelj, P. 2004. A census of the obligate subterranean fauna in the Balkan Peninsula. In: Griffiths, H.I., Krystufek, B. (Eds.) Balkan Biodiversity. Pattern and Process in Europe's Biodiversity Hotspot. Kluwer Academic Publishers B.V., pp 309-322.

Sovremennye problemy lososevykh rybovodnykh zavodov Dal'nego Vostoka (Modern problems of fish-breeding farms in the Far East). 2006. Sharov, P.O. (Ed.) Petropavlovsk-Kamchatsky. 248 p (in Russian).

Straškrabová, V., Brandl, Z., Hrbáèek, J., Komárková, J., Šeda, J., Straškraba, M. Šimek, K. 1998. Long-term changes of bacteria, phytoplankton and zooplankton: Temporal coherence between deep stratified reservoirs. International Review of Hydrobiology 83: 21–30.

Strayer, D.L. et al. 2003. A classification of ecological boundaries. BioScience 53: 723-729.

Tharme, R E. 2003. A global perspective on environmental flow assessment: emerging trends in the development and application of environmental flow methodologies for rivers. River Research and Applications 19: 397-442.

Trontelj, P., Douady, C.J., Fišer, C., Gibert, J., Gorièki, Š., Lefebure, T., Sket, B., Zakšek, V. (in print) A molecular test for cryptic diversity in groundwater: how large are the ranges of macro-stygobionts? Freshwater Biology.

Vaisman, A. 2002. Promysel v tumane. Rybolovstvo i torgovlja ryboprodukciej v rossijskoj chasti Beringova morja. Analiticheskij otchet (Fishing industry in the fog. Fishing and trading of fish products in the Russian part of Bering sea. Analytical report). Moscow. 80 pp (in Russian).

Vörösmarty, C., Lettenmaier, D., Leveque, C., Meybeck, M., Pahl-Wostl, C., Alcamo, J., Cosgrove, H., Grassl, H., Hoff, H., Kabat, P., Lansigan, P., Lawford, R., Naiman, R. 2004. Humans transforming the global water system. EOS, American Geophysical Union Transactions 85: 509-514.

Williams, P., Whitfield, M., Biggs, J., Bray, S., Fox, G., Nicolet, P., Sear, D. 2004. Comparative biodiversity of rivers, streams, ditches and ponds in an agricultural landscape in Southern England. Biological Conservation 115: 329-341.

Zakšek, V., Sket, B., Trontelj, P. 2006. Phylogeny of the cave shrimp Troglocaris: evidence of a young connection between Balkans and Caucasus. Molecular Phylogenetics and Evolution, doi:10.1016/j.ympev.2006.07.009.