Criteria of sustainable management of large river systems – ecological aspects and challenges of the 21st century

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Abstract. River systems maintain unique biotic resources and provide essential renewable water supplies for humankind. Flood pulses are the key natural drivers of species richness and productivity of the large river-floodplain ecosystems, but traditional water management has sought to reduce the natural variability of river flows to achieve more stable water supplies for socio-economic water needs. The increasing human pressure on river systems directly threatens the biodiversity of fluvial ecosystems across the world. Ecologically sustainable river management is aimed at maintaining the ecological integrity of the affected ecosystems while meeting the intergenerational human needs and sustaining the full array of other goods and services provided by natural river ecosystems. Several criteria of ecologically sustainable water management are outlined, such as the assessment of the reference status, the documentation of the deficiencies of the baseline conditions, the identification of the causes of ecosystem degradation using the DPSIR framework, the analysis of the compatibility of water needs, the definition of the target vision, etc.

Keywords. Sustainability, DPSIR framework, floodplain ecosystem, restoration, ecological integrity

INTRODUCTION

Water and air are the two essential mediums that allow existence of life in the biosphere. It is well known that more than 70% of the surface of the Earth is covered with water. The total volume of the hydrosphere is 1.4 billion km^3, which is 0.02% of total mass of the Earth. Continental waters are 3.5% of the Earth's water resources, out of which about 69% is in ice caps and glaciers, and about 30% is groundwater. Liquid continental surface freshwaters (lakes, swamps and rivers), which are essential for terrestrial life and form a decisive precondition for social-economic development, constitute less than 0.3% of continental waters, and the total volume of the river systems amounts to only 2% of these (Shiklomanov 1993).

River systems maintain unique biotic resources and provide the most essential renewable water supplies for the livelihood of human communities. Water is indispensable in all the sectors of economy and parallel to social-technical-economic development, the utilisation of river systems has become more extensive. Since the Industrial Revolution, the growth rate of the human population has accelerated, and the world's population increased fourfold in the 20th century, whereas global water withdrawal has increased eightfold in the same period (Gleick 1998). A significant part of the human population is struggling with problems related to insufficient water supply, which may be exacerbated by climate change. In the future, annual global water withdrawal is expected to grow by about 10–12% every 10 years (UNEP 2008), therefore the water-crisis may become an escalating source of social-economic conflicts in the 21st century. The increasing human pressure on river systems has been directly threatening the water security for people and the biodiversity of river ecosystems across the world (Vörösmarty *et al.* 2010).

This study summarizes the main elements of environmental changes generated by the human interventions imposed on large rivers, and outlines some criteria of ecologically sustainable river management.

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ALTERATION OF RIVER ECOSYSTEMS

River systems, as part of the global hydrologic cycle, collect surface runoffs from their basins and flow to the seas and oceans with significant landscape forming impact. Their ecosystems, including floodplains, belong to the most diverse, dynamic and complex ecosystems of the Earth, and play a key role in the maintenance of the biodiversity of the landscape (Naiman *et al.* 1993). The river biota is adapted to living among various flow conditions, and the high degree of spatial and temporal heterogeneity which characterises the river systems. The considerable differences in the numbers of species inhabiting the various river systems are largely attributable to the size of the river and its basin area (Welcomme 1985).

The remarkable global biodiversity of the fluvial ecosystems is particularly obvious, when evaluated in relation to the area and volume of the river systems. For example, 13,000 strictly freshwater fish species live in lakes and rivers that cover only 1% of the Earth's surface, while the remaining 16,000 marine species live in oceans and seas covering a full 70% (Lévêque *et al.* 2008). Most of the freshwater fish species occur in rivers or their floodplains (Bayley & Li 1996), but the global volume of river systems is about eighty times less than the volume of the lakes of the Earth (Shiklomanov 1993).

Considerable modifications have been carried out in many river systems around the world (Dynesius & Nilson 1994) since the early human communities were established along the rivers about 5,000 years ago, and the systematic colonisation of floodplains lead to the development of the earliest civilizations. The ever increasing use of floodplains and the inherent risks of the seasonal flooding of such areas resulted in the widespread application of flood control measures (levee and canal constructions), and the associated development of in-stream structures (dams, impoundments, etc.). Rivers are disturbed not only by events occurring within their channel or the connected floodplains, but are also subject to a range of external influences. The changing conditions of the catchment basin can produce variations of the quality and quantity of water, as well as changes in its loading with a variety of materials including silt, which can affect river morphology.

The increasing human activity (related to industry, agriculture, urbanisation, transportation, etc.) throughout the catchment basins exert various types of additional pressures on the fluvial ecosystems, such as emissions of waste and contaminants, spreading of invasive species, etc. The water demand of humanity for agricultural, industrial, and communal uses continues to grow along with the economic development, rising populations and increased urbanization. These multiple pressures threaten river systems that serve 80% of the world's population, and endanger the biodiversity of 65% of the world's river habitats, putting thousands of aquatic wildlife species at the risk of extinction (Vörösmarty *et al.* 2010).

The ecological degradation of fluvial systems has been an unintended consequence of extensive river management. The unique species richness and productivity of large river-floodplain ecosystems is strongly dependent on the natural variability of the hydrologic and morphologic conditions (Sparks 1995), but traditional water management has sought to reduce the natural variability of river flows to achieve more stable water supply for industry, households, irrigation, navigation and hydropower exploitation, and to mitigate extreme situations, such as floods and droughts (Richter *et al.* 2003).

ECOLOGICALLY SUSTAINABLE MANAGEMENT OF LARGE RIVERS

Because of the degradation of the fluvial ecosystems, ecologically sustainable river management has become an increasingly widespread intension. Its goal should be to maintain the ecological integrity of the affected ecosystems, while also meeting the intergenerational human needs, and sustaining the full array of other goods and services provided by natural river ecosystems (Sparks 1995, Richter *et al.* 2003). The ecological integrity includes structural elements (landscape, habitats, assemblages, populations, species, genes, etc.) and functional processes that generate and maintain these elements (water and sediment regime, disturbance, succession, selection, nutriaent cycling, etc.) (Angermeier & Karr 1994).

The concept of sustainability often appears in various directives and laws related to river management, but its implementation has not been able to effectively influence the drivers exerting pressures on fluvial ecosystems and the loss of aquatic biodiversity. Most of the recent action plans and projects focus on the state of the environment and the negative impacts of degradation, and are not aimed at modifying the socio-economic driving forces of the unfavourable processes.

The series of causal factors of river ecosystem degradation can be determined by comprehensive assessment of the environmental changes generated by human activities. As the basis for any such assessment, the application of the *DPSIR* framework (Gabrielsen & Bosch 2003) is recommended to describe and interpret the interactions between the economy/society and the environment (Fig. 1).

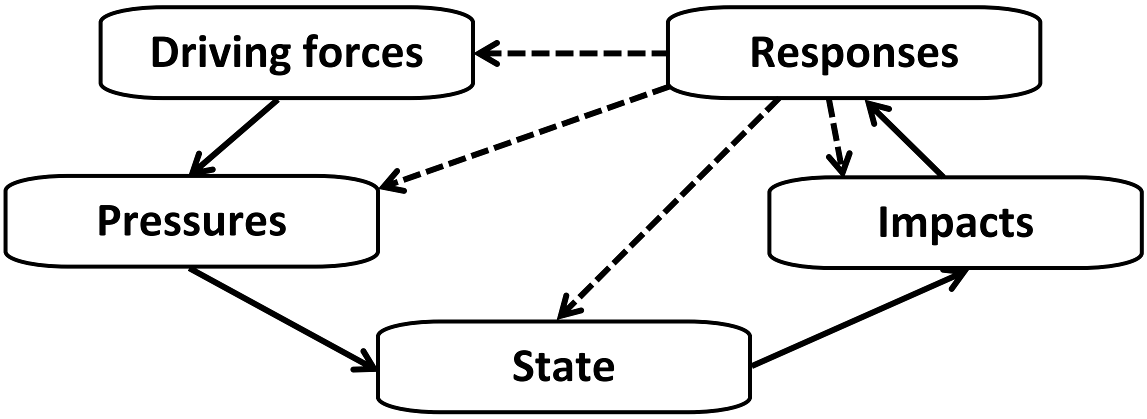

Figure 1. Overview of the continuous feedback process in the DPSIR framework

- *Driving forces (D)* of river utilisation are the social and individual needs, exerted by social, demographic, and economic development. Driving forces (river engineering, navigation, hydropower utilisation, fishery, irrigation, gravel mining, sewage disposal, etc.) provoke changes in the overall levels of economic production and consumption processes, and through these changes, the driving forces put pressure on the riverine environment.
- The *pressures (P)* are generated by a number of human activities (driving forces), which meet the needs of the economy and provide several benefits for the society. However, these human activities result in the excessive use and alteration of the river system, the transformation of the environmental conditions (connectivity, gradient, hydraulics, etc.), as well as changes of the natural resources (discharge, riparian forest, fish stock, etc.) and natural processes (water regime, bed load transport, ecological succession, etc.).
- The *state (S)* of the river depends on the pressures on the environment. State indicators describe the quantity and quality of the physical, chemical, hydrological, morphological, and biological elements and processes of the river system.

- The *impact (I)* indicators describe the impacts of the altered state of river on the functions of the river ecosystem and its resource availability. The alteration of a river ecosystem ensues from a series of causal factors. For example, the fragmentation of river continuity by a dam causes changes in bed load transport (primary effect, but it is a state indicator), which may in turn cause a river bed incision and the decline of low water levels in the downstream of the dam (secondary effect, but also a state indicator), which may provoke a progressive restriction of lateral connectivity between the river and the floodplain backwaters (tertiary effect, but still a state indicator), and this habitat change causes a loss of aquatic biodiversity and biological production. Only this last effect is the impact indicator. The change in the availability of riverine species (fish stock) influences the human usability of the natural resources. Strictly speaking, only those metrics or parameters that directly reflecting the environmental changes are called impacts which are important for human welfare (Gabrielsen & Bosch 2003).
- The *response (R)* by society or policy makers is the consequence of an undesired impact and is directed at any elements of the DPSIR causal chain from driving forces to impacts, in order to prevent, mitigate, restore, compensate or adapt to environmental changes.

The links between the DPSIR elements reveals a number of processes and the dynamics of the interactions in the framework. This information can be used in predictions of future changes in pressures, states, impacts, and responses.

The ecologically sustainable water management depends on a balance between the water requirements for ecosystem integrity and the social-economic water demands. In the last decades, a number of case studies (Buijse *et al.* 2002, Jungwirth *et al.* 2002, Richter & Thomas 2007) have shown that ecological integrity of fluvial ecosystems can be improved as well with the long-term fulfilment of human water needs. In order to achieve ecological sustainability in river management, the following criteria have to be taken into account:

1) Problem definition

- Assessment of the reference status of the river ecosystem functioning without or before human intervention. The reference status may refer to a historical period and is comparable to the "good ecological status" of the EU Water Framework Directive for natural water bodies.
- Documentation of the baseline (and the predictable future) situation with definition of the socio-economical water needs.
- Assessment of the deficiencies of the baseline conditions and identification of the causes of ecosystem degradation using the DPSIR framework, in order to better understand the effects of socio-economic drivers and pressures on the structural elements and functional processes of river ecosystems.
- Analysing the compatibility of the water needs for maintaining the ecological integrity and the socio-economical water demand, with respect to their spatial and temporal differences.

2) Search for solution

- Comparison of different approaches and searching for solutions for the uncovered problems of the incompatibilities of ecological and socio-economical water demands.
- Detailed analysis of the factors limiting the harmonization of ecological and socio-economical water needs, as well as assessment of other constraints through water- and land use obligations.

3) Development of an adaptive management plan, with the realization of ecological sustainability

- Developing an action plan on the basis of the definition of the target vision (environmental objectives), to be reached via the ecologically sustainable management of the river system.
- Formulate practicable indicators and assessment criteria for evaluating the ecological integrity and the sustainability of river management (within the DPSIR framework).

CLOSING REMARKS

Ecologically sustainable river management is an iterative process, in which both human water demands and ecosystem requirements can be refined and harmonized in the future (Richter *et al.* 2003). This includes a continual search for compatibility between the water needs of the ecosystem and the humans, and requires the active cooperation of an interdisciplinary group of scientists familiar with the hydrologic, geomorphic and landscape processes that influence habitat development and maintain natural biodiversity in river-floodplain ecosystems.

REFERENCES

ANGERMEIER, P. L. & KARR, J. R. (1994): Biological integrity versus biological diversity as policy directives. Protecting biotic resources. *BioSciences*, 44: 690–697.

BAYLEY, P. B. & LI, H. W. (1996): *Riverine Fishes.* In: G. PETTS, P. CALOW (eds.) River Biota. Blackwell Sciences Ltd., Oxford and Northampton.

BUIJSE, A. D., COOPS, H., STARAS, M., JANS, L. H., VAN GEEST, G. J., GRIFT, R. E., IBELINGS, B. W., OOSTERBERG, W. & ROOZEN, F. C. J. M. (2002): Restoration strategies for river floodplains along large lowland rivers in Europe. *Freshwater Biology*, 47: 889–907.

DYNESIUS, M. & NILSSON, C. (1994): Fragmentation and flow regulation of river systems in the northern third of the world. *Science*, 266: 753–762.

GABRIELSEN, P. & BOSCH, P. (2003): Environmental Indicators: Typology and Use in Reporting. *EEA internal working paper*

GLEICK, P. H. (1998): *The world's water 1998–1999: the biennial report on freshwater resources.* Island Press, Washington, D.C., USA.

JUNGWIRTH, M., MUHAR, S. & SCHMUTZ, S. (2002): Re-establishing and assessing ecological integrity in riverine landscape. *Freshwater Biology*, 47: 867–887.

LÉVÊQUE, C., T. OBERDORFF, D. PAUGY, M. L. J. STIASSNY, P. A. TEDESCO (2008): Global diversity of fish (Pisces) in freshwater. *Hydrobiologia*, 595: 545–567.

NAIMAN, R. J., DECAMPS, H. & POLLOCK, M. (1993): The role of riparian corridors in maintaining regional biodiversity. *Ecological applications*, 3(2): 209–212.

RICHTER, B. D., MATHEWS, R., HARRISON, D. L. & WIGINGTON, R. (2003): Ecologically sustainable water management: Managing river flows for ecological integrity. *Ecological Applications,* 13(1): 206–224.

RICHTER, B. D. & THOMAS, G. A. (2007): Restoring environmental flows by modifying dam operations. *Ecology and Society,* 12(1): 12. URL: http://www.ecologyandsociety.org/vol12/iss1/art12/

SHIKLOMANOV, I. A. (1993): *World freshwater resources.* In: GLEICK, P. H. (ed.) Water in Crisis: A Guide to the World's Fresh Water Resources, Oxford University Press, New York.

SPARKS, R. E. (1995): Need for ecosystem management of large rivers and their floodplains. *BioScience*, 45: 168-182.

UNEP (2008): Water withdrawal and consumption: the big gap. *www.unep.org/dewa/vitalwater/ article42*

VÖRÖSMARTY, C. J., MCINTYRE, P. B., GESSNER, M. O., DUDGEON, D., PRUSEVICH, A., GREEN, P., GLIDDEN, S., BUNN, S. E., SULLIVAN, C. A., REIDY LIERMANN, C. & DAVIES P. M. (2010): Global threats to human water security and river biodiversity. *Nature*, 467: 555–561.

WELCOMME, R. L. (1985): River fisheries. *FAO Fisheries Technical Paper*, 262.