



Roads to Transdisciplinarity: Developing a Sustainable Management Approach

¹Fritz Schiemer

¹Department of Limnology and Bio-Oceanography, Faculty of Life Sciences, University Vienna,
Vienna

ABSTRACT

Exploring strategies for sustainable management requires an integrated, scientific and problem-oriented approach involving a combination of environmental and socio-economic aspects in view of the manifold issues and often conflicting stakeholder interests which have to be addressed. It calls for more interdisciplinarity in science, translational research (see below) and transdisciplinarity in form of a science-practitioners dialogue and interaction. There are constraints to crossing interdisciplinary boundaries in science. By tradition, scientists are usually confined to specialized niches of knowledge and are not easily prepared to embark on interdisciplinary endeavors. Interdisciplinarity, even among natural sciences, requires new research approaches and new ways of thinking. The challenges become even more formidable when bridging natural and social sciences, e.g. when connecting abiotic framework conditions with environmental processes and social and socio-economic aspects. Translational research – oriented towards defining ways to communicate with practitioners and introducing research findings into political decisions – requires new and diverse formats of education, training and networking.

I use examples of personal engagement in water issues over the last 30 years to outline the challenges of getting involved in applied research and science-policy interactions. The first two examples refer to a long-term engagement in resource-management in SE-Asian reservoirs and lakes. Following an early ecosystem-oriented study on the Parakrama Samudra reservoir in Sri Lanka (1979-1982), a multidisciplinary EU-program was launched. The international project, carried out by a consortium of Asian and European scientists, provided a large amount of factual information (Schiemer et al. 2008) and a wealth of experience regarding the challenges of formulating a system-oriented approach comprising environmental and socio-economic aspects and transferring the scientific knowledge into real-world politics.

The second set of experience refers to the management of the riverine landscape of the Danube in Austria. Large rivers with their extensive wetlands and floodplains offer a wide variety of ecological services, e.g. flood retention, drinking water supply, fisheries and conservation. Other human uses are

Corresponding author: Fritz Schiemer, Email: friedrich.schiemer@univie.ac.at

hydropower production and navigation. They represent partially conflicting stakeholder interests of different political power. Human impacts over the past 150 years through river regulation, damming and pollution have reduced some of the service capacities and call for rehabilitation measures. In 1983/84, I became engaged in a major public discussion over a projected hydropower dam. As a result of the critical position taken by scientists, we were invited by the government to take part in a commission of practitioners, planners and scientists to develop long-term management and restoration concepts. The panel was requested to find science-based compromises for conflicting stakeholder interests. This engagement forced scientists of various disciplines – ecologists, hydrologists and geo-morphologists – to develop a common understanding of the vulnerability of river-floodplain systems to human interventions. Over the past thirty years, scientists played a significant role in this discussion process, defining environmental targets and developing benchmarking and assessment criteria for management options. This involvement was also a school of learning regarding interaction with stakeholders and decision makers.

KEYWORDS: *Aquatic resource management, eco-hydrology, eco-sociology, translational science, stakeholder controversies, co-management, fisheries, trophic state, river restoration*

1. THE CHALLENGES FOR SCIENCE

The paper is based on a key-note address at a conference on multidisciplinary approaches from 11th – 12th September 2015 in Colombo, Sri Lanka. The title reflects the long and tedious paths necessary to achieve and implement integrated management strategies. There are many steps to be taken and many hurdles to overcome. It is now generally recognized that science has to play an important and manifold role. Within academia there is growing awareness that pure research is insufficient and that a transdisciplinary approach by connecting science to real world decisions is required.

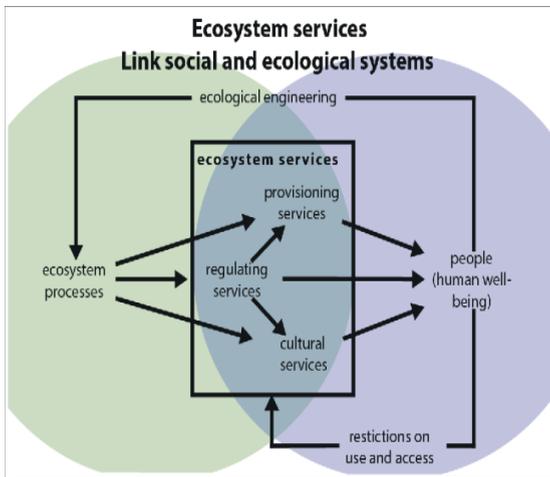


Figure 1. Ecosystem Services

Sustainable resource management has to approach a harmonization between environmental, social and economical requirements without detrimental effects to the resource itself. A primary aspect is the understanding of ecosystem functions which guarantee the ecological services (Daily et al. 1997) in form of provisional services like clean water or fisheries, regulating services like flood control and self purification processes, and cultural services like landscape aesthetics (tourism) and recreation. They are dependent on the

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structure and functioning of the ecological system. The manifold interactions and human interferences e.g. through engineering, pollution, carbon dioxide output, nutrient accumulation etc. can lead to degradations and deficiencies. An understanding of the environmental system providing the ecological services requires a systemic approach (Figure 1).

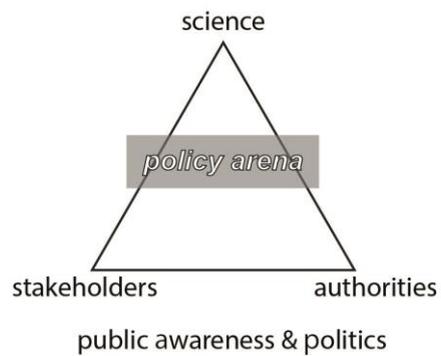


Figure 2. Science & policy arena

In pursuing sustainable management issues, three parties play a significant role (Figure 2): firstly responsible authorities, secondly stakeholders of various interests, political influence and power, and thirdly scientists of different disciplines interacting to understand the environmental and socio-economic system. The acceptance of management plans depends strongly on public opinion and the political will. The policy arena, the interaction between scientists and practitioners, requires a transdisciplinary approach.

A global and burning issue, which requires a sound scientific basis, concerns an integrated water resource management (Bogardi et al. 2012, Korsgaard & Schou, 2010). I will exemplify the challenges on the basis of personal experiences from engagements over the past 35 years on such issues, both in the tropics and the temperate

zone. The chronology of these experiences presents a long process of recognizing the importance of interdisciplinarity and transdisciplinarity.

The following comments address

- the multiple challenges for science,
- the necessity to develop a functional understanding of resource systems including human use and impacts,
- the necessity for hypothesis-based research programs for analyzing the effects of management measures,
- the required interdisciplinary and translational research,
- the required interaction of scientists, authorities and stakeholders in planning and decision making, and
- the required improvement of legislative tools in order to achieve these goals.

2. EXAMPLES

2.1. The Parakrama Samudra Limnology Project

My long-term involvement in aquatic resource management in SE-Asian reservoirs and lakes started with the "Parakramas Samudra Project" in Sri Lanka, with field research from 1979 to 1982. The scientific program was aimed at gaining a better background on aquatic ecology in tropical countries, in order to strengthen our teaching in a postgraduate training program in limnology for students from developing countries. This course has been running since 1975 with an initial syllabus based on temperate zone limnology.

We recognized the need for capacity building through continued cooperation. Therefore we planned a limnological project at the Parakrama Samudra reservoir. A. Gunatilaka, a participant of one of the first courses in Austria, established contacts

with colleagues from the Kelaniya University (H.H. Costa and S. De Silva), the National Science Foundation, the Ceylon Institute of Scientific and Industrial Research (C.I.S.I.R.) and the Ministry of Fisheries in Sri Lanka. The project was conceived as a cooperative effort between European and Sri Lankan scientists (Figure 3).

The reservoirs in SE Asia are generally more intensively utilized than water-bodies in the temperate zone, with a broad range of uses, e.g. for irrigation, drinking water abstraction, fisheries amongst others. The need for sustainable management is more pressing and complex. The research scope followed the ecosystem concept as applied in the "International Biological Program" (1968-1973) (Le Cren & Lowe-McConnell, 1975). We focused on ecosystem properties that are especially relevant for fisheries. Our working plan (Figure 4) was based on a scheme of major ecosystem-interrelationships (Schiemer, 1981).

Factors of overruling importance are the meteorological events of the monsoonal cycle and the use of water for irrigation, which cause a series of "macroevents". A study of the reactions of the ecosystem towards the imposed boundary conditions necessitates a multidisciplinary approach including hydro-meteorology, nutrient chemistry and biology. By drawing information from the various disciplines we were able to define the important ecosystem interlinks. A main focus of the Parakrama Samudra program was the control of the trophic state and the water quality of the reservoir and the internal nutrient recycling processes (Gunatilaka, 1983). A further focus was a detailed analysis of the structure of the fish community as well as the limnological role and fisheries-potential of the high densities of small sized species (see below).

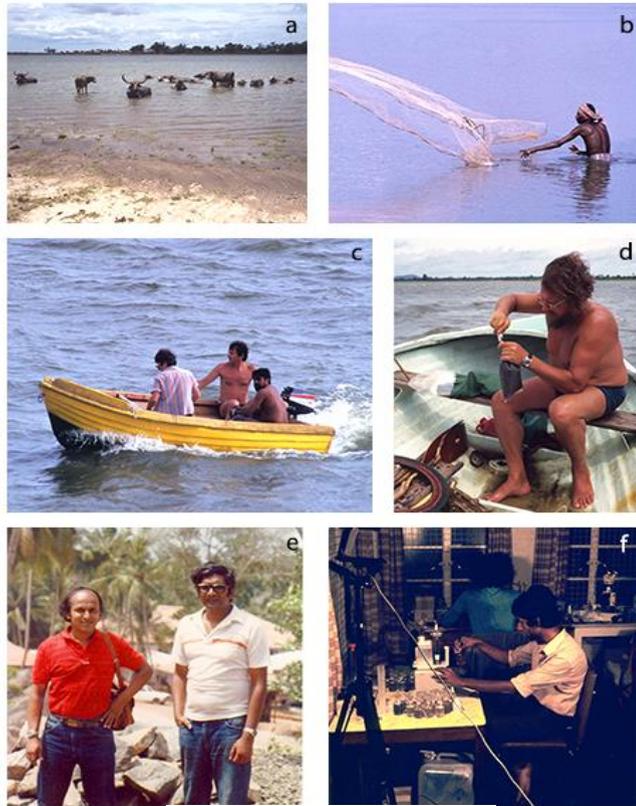


Figure 3. Photo Collage

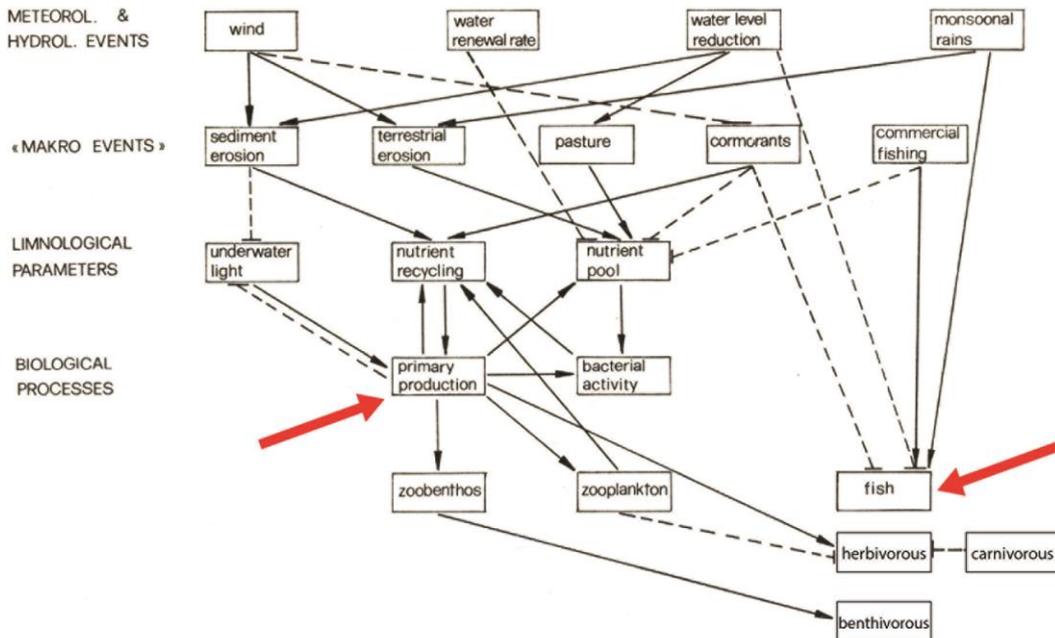


Figure 4. Working plan

These findings opened up avenues for a stronger science-oriented approach regarding the utilization of the reservoirs, and stimulated more intensive inland fisheries (De Silva & Sirisena 1987). Some of the graduates involved in the program gained key positions in aquatic and fisheries science and the relevant administration in the country.

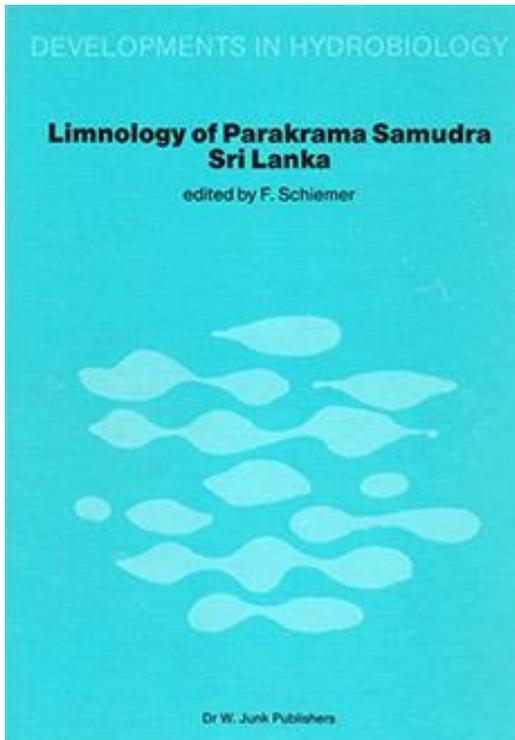


Figure 5. Limnology Book cover

The Parakrama Samudra project was successful as an ecosystem-oriented study, which demonstrated the value and the challenges of multidisciplinary research. Results were published in a book (Schiemer 1983) (Figure 5). In summarizing papers we proposed recommendations for fisheries (Schiemer & Duncan 1983) and landscape management (Duncan et al. 1993). However, the program was not sufficient (and apparently the time not right) for an overall concept for sustainable management.

2.2. The EU-funded “Fishstrat” program

Based on these experiences, in the mid 1990’s we conceived a more comprehensive study on sustainable aquatic resource management of SE-Asian water bodies. The EU-funded Fishstrat program, which ran officially from 1998-2003, had a long-winded title: “Strategies for partitioning the productivity of Asian reservoirs and lakes between capture fisheries and aquaculture for social benefit and local market without negative environmental impacts” (Amarasinghe et al. 2001). We followed a praxis-oriented approach with the main goal of analyzing the potential of fisheries and aquaculture in order to increase the protein supply for the local population. The program included a detailed socio-economic analysis of the riparian population, their economic activities and resource uses (Figure 6).

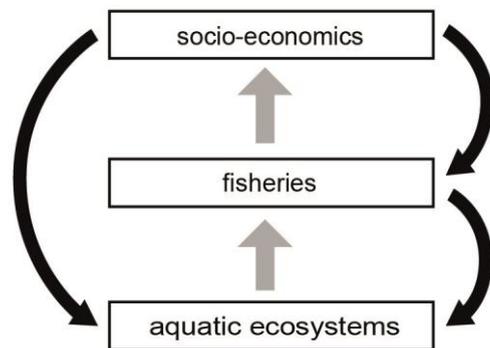


Figure 6. Socio economics

The Fishstrat project involved research teams from Sri Lanka, Thailand, the Phillipines, UK, Austria, France, the Netherlands and the Czech Republic. It was organized in three phases. In phase 1 – the preparatory phase – a very significant meeting was held at the “Institute of Fundamental Studies” at Kandy, Sri Lanka, where all the research teams from the different countries met and formulated the research plan and methodologies to be applied. Phase 2, the practical fieldwork,

was organized in four work packages – limnology, fisheries, aquaculture and socio-economics – during which the teams worked largely independently from each other. In phase 3, the data sets of the individual disciplines were analyzed and attempts were made in several meetings to integrate the results and formulate recommendations for management. Finally a “user meeting” was held in Bangkok, in which results and recommendations were discussed with practitioners.

The principal challenge was to understand the systems interactions and interlinks between limnology, fisheries and socio-economics both in a bottom-up and a top-down form.

“Bottom-up” means an assessment of the loading with nutrients and hazardous substances from the catchment, its effects on the primary productivity and water quality of the reservoir and, in turn, on the fisheries and the livelihood conditions for the rural population (Fig. 7a). “Top-down” addresses the multiple effects via the hydrological management for irrigation as well as the controlling effects of biological interactions within the aquatic system (Fig. 7b).

The intersection between the catchment and the reservoir or lake ecosystem is mainly controlled by hydrology. Phytoplankton biomass and primary productivity of the reservoir are to a large extent dependent on the external loading, especially of phosphorus, from the catchment. On the other hand, clear evidence from our research indicates that hydrological engineering of the reservoirs exerts a profound influence on the trophic state (Silva & Schiemer 2008).

Algal biomass is reduced by high throughflow and short retention times, i.e. during periods of increased water demand, i.e. during periods of increased water demand for irrigation. Draw-down, on the other hand, enhances the trophic state by increased recycling of nutrients from the sediments due to wind induced currents. Moreover the activity of dense fish populations, including tilapias, contribute to the internal nutrient loading and the danger of hyper-eutrophication. These processes have to be addressed by management. (Duncan & Schiemer 1988, Schiemer & Duncan 1988, Schiemer 1996, Schiemer 2008).

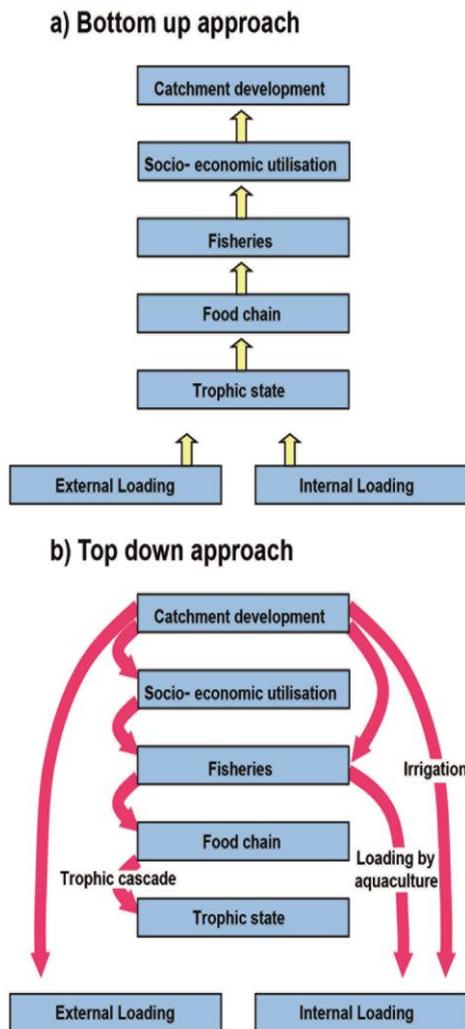


Figure 7. Bottom up & top down approaches

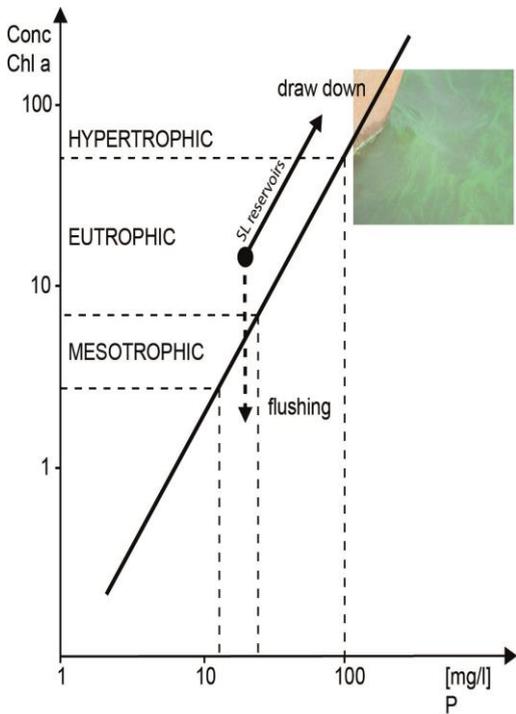


Figure 8. Chlorophyll a concentration

Figure 8 illustrates the relationship between the phosphorus content and phytoplankton biomass, expressed as concentrations of chlorophyll a. For lakes and reservoirs of the temperate zone there exists a well-established relationship (thick line). The comparison shows that the values found for Sri Lankan reservoirs are high and generally lie above the temperate zone regression line.

Phytoplankton concentrations are strongly influenced by the hydrological management of water bodies. They are enhanced at high water retention due to internal loading processes but strongly decrease during times of reservoir flushing. The findings clearly demonstrate that the trophic situation is critical and very sensitive to management and that care has to be taken to control both the external and internal nutrient loading.

Research carried out on fish addressed the population dynamics of major exploited and unexploited species. We discovered high densities and a high productivity of small sized fish species in the shallow lowland reservoirs, representing unexploited resources and a high potential for fisheries development (Figure 9).

The possibilities for additional cage culturing of fish, e.g. tilapias, in the irrigation reservoirs were carefully evaluated. We came to the conclusion that the potential is low, primarily due to the danger of hypertrophication through fish feeding. Periodic phases of deoxygenation and fish kills in the inshore zones in lakes with intensive cage culturing, e.g. in the Philippines, gave clear warning signals. A further obstacle for cage culturing in irrigation reservoirs are operational difficulties due to the large seasonal water level fluctuations.

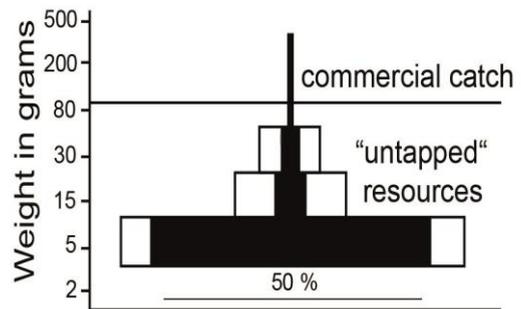


Figure 9. Biomass pyramid

A strong focus of the Fishstrat program was the detailed assessment of the socio-economics of the riparian population, especially the role of fisheries and fish marketing for the rural development. An intensive interview program gave insight into the significance of the rural population's fisheries-related income but also into their critical livelihood situation close to the national poverty line.

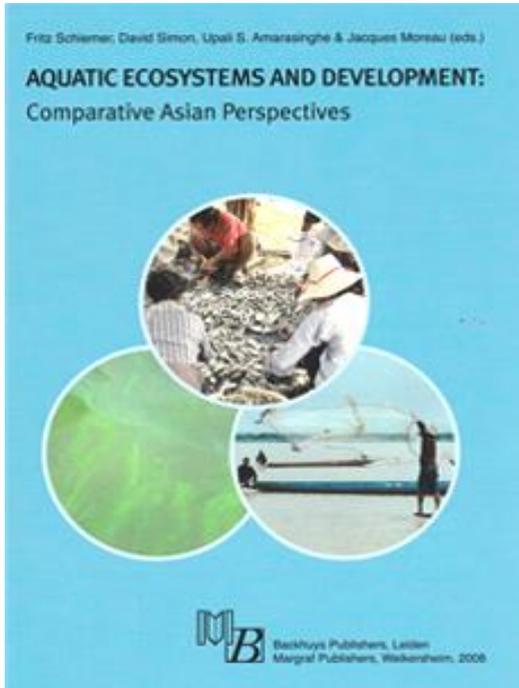


Figure 10. Aquatic ecosystems & development Book cover

The program was officially finished in 2003, however it required several more years to analyze and integrate the results from more than forty scientists involved in the project. The major findings were published in a book on “Aquatic ecosystems and development: Comparative Asian perspectives” (Schiemer, Simon, Amarasinghe & Moreau, ed. 2008) (Figure 10). The volume contains a number of summarizing papers on resource management.

The “Fishstrat” program, with its broad focus on limnology, fish ecology and socio-economics of the riparian population, was a major step in learning with regard to the requirements for sustainable management. The project led to a combination of several scientific disciplines, although the teams carried out their work independently from each other. We moved in the right direction, however we did not accomplish the transdisciplinary step of a long-term

interaction with practitioners and an immediate “real world” application.

2.3. Danube restoration: a transdisciplinary approach for developing remediation concepts for large rivers

An example of a more transdisciplinary nature refers to the conception of restoration programs at the Danube in Austria. It illustrates the advantage and potential of scientists becoming directly involved in a continued dialogue with stakeholders, authorities and decision makers. My engagement started more than 30 years ago with the discussion surrounding the possible effects of a projected hydropower dam in the alluvial floodplains at Hainburg, downstream of Vienna. Scientists expressed warnings of the ecological consequences. After strong public intervention, the project was stopped and an “Ecology Commission” was tasked by the Austrian government to discuss options for future management of the river-floodplain system. This discussion process, which continued over several years, involved authorities, stakeholders, engineers, hydrologists and ecologists. It led to a growing mutual understanding between the various parties and demonstrated the necessity for a more integrated, interdisciplinary approach of science and a transdisciplinary approach of all parties for the identification of problems and potential solutions.

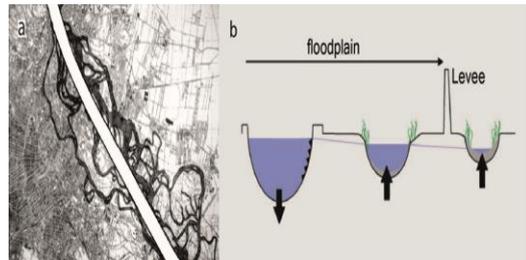


Figure 11.

Despite long-term consequences of river regulation and the effects of river damming in the upstream section, the “Ecology Commission” recognized the conservation value and the potential for restoring fluvial processes in the Danubian floodplains between Vienna and the Slovakian border. A decision was therefore reached to conserve this river-floodplain section by creating an “Alluvial Zone National Park”. All of the major rivers in the industrialized world have been changed by regulation and damming. The Danube, for example, has been strongly affected by regulation schemes starting in the second half of the 19th century. The channelization and limitation of flood events through lateral levees led to a continued trend of incision of the riverbed, causing an accelerating loss of connectivity between the river and its extensive floodplains (Figure 11). This led to ecological deficiencies and a growing request from various stakeholders for remediation measures (Buijse et al. 2005).

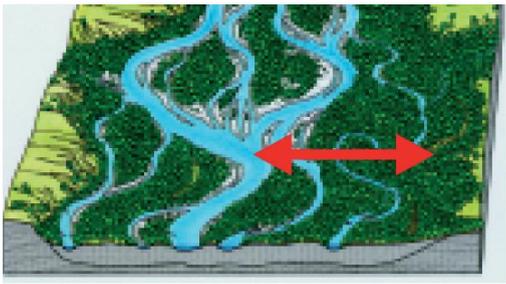


Figure 12. Land water exchange

Practical measures have to be based on a detailed understanding of the major drivers governing the interactive river-floodplain ecosystem (Figure 12). For river-floodplain systems, the key feature is the flood-controlled geomorphological dynamics, which result in a characteristic habitat turnover rate of the riverine landscapes, their habitat composition and specific ecological functions and biota. To understand these interactions between

fluvial processes and ecology, an interdisciplinary analytical approach is required. The apparent challenge is to follow the cause-effect chain between the governing factors hydrology and sediment load and the resulting landscape dynamics and ecology (Arthington et al. 2010, Naiman et al. 1988, Naiman et al. 2005, Zalewski 2000) (Figure 13). This approach allows diagnostic and prognostic tools regarding the effects of management measures on ecological processes (McClain et al. 2003, Decamps et al. 2004) and biodiversity (Ward et al. 1999) to be derived. Such an ecohydrological framework constitutes the basis for management (Poff et al. 2003, Surridge & Harris 2007, Nilsson et al. 2007, Schiemer 2015).

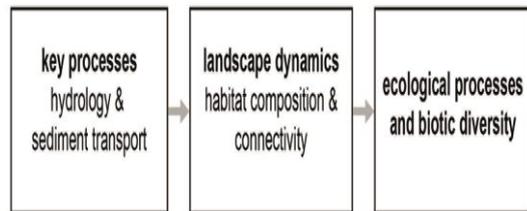


Figure 13. Key processes

Management faces the challenge to incorporate the interests of various stakeholders of different power and influence in the conception and implementation of a given program. For the floodplains downstream of Vienna, the interests in question are flood control, provision of drinking-water, navigation and conservation.

There is a high political priority for improving a Trans-European navigation network (Pan-European Transport Corridor), for which the river section of the national park is considered a bottleneck. On the other hand, administration of the “Alluvial Zone National Park” is responsible for improving the ecological conditions, especially the integration of the

floodplains with the river, and the natural dynamics of the inshore with its high ecological relevance for aquatic processes and habitat for characteristic biota.

It is apparent that navigation and conservation have contrary interests (Schiemer et al. 1999). In order to find a solution and bridge these diverging interests, an executive board consisting of administrators, planners, hydrologists, ecologists and major stakeholders was commissioned. The envisaged goal was to develop an “Integrated River Engineering Project”, for the 50 km stretch from Vienna to the Austrian-Slovakian border, combining measures to improve both the navigation channel and the ecological conditions.

In the process to reach a compromise, it proved necessary to generate new planning concepts and technical means to achieve these goals. This planning of the possible alternatives had to be detailed enough to allow a benchmarking of their ecological consequences, especially with regard to the nature of the inshore structure and the lateral integration of the river and floodplain (Reckendorfer et al. 2005).

The effort to achieve a compromise and find a technical solution was a long and winding road. The discussion continued over nearly three years, during which the guiding role of science for the conception and evaluation of restoration plans became apparent. It proved imperative to involve scientific teams and provide them with a strong mandate in the search for sustainable management and restoration concepts for waterways. The assignment was a major school of learning of transdisciplinary approaches and of the obstacles in the cooperation between scientists, engineers, stakeholders and authorities. Meanwhile several experimental steps of the program have been realized, but the political will for

implementation of the whole engineering program is still pending.

3. LEARNINGS AND RECOMMENDATIONS

Combining these long-term experiences with different environmental scenarios, stakeholder interests and political frameworks, some overall conclusions can be formulated regarding integrated research scope and the necessity for science to get involved in a continued dialogue with practitioners. Science faces multiple challenges. In a recent paper based on research on water resource management in South-East Asia, we discussed these issues and illustrated the difficulties in a simple schematic graph (Figure 14) (Simon & Schiemer 2015).

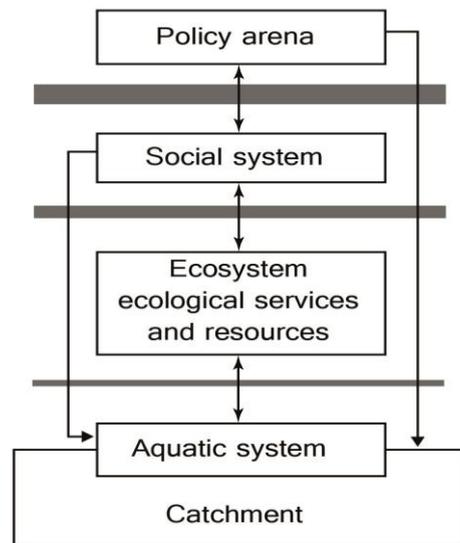


Figure 14. Policy arena

The graph identifies the different aspects and compartments which have to be considered: the ecology of the water bodies within their catchment context, their ecosystem services, the associated socio-ecological system of the rural people and the policy arena where the rules for the utilization of the resource are defined. The vertical arrows show bottom-up and top-

down influences. The horizontal bars indicate the barriers and degrees of resistance for an integrative scope and especially the challenge of achieving a transdisciplinary planning and decision process based on praxis-oriented research.

3.1. The challenge for science: combining an analytical with a synoptic approach

Sustainable management has to be based on a system understanding. The principal task is to define and identify key environmental factors governing the resource base, including human interactions and impacts.

It is necessary to assess the social forces and traditions of resource use in an analytical form and to derive predictive models to evaluate the possible impacts of management measures. For practical reasons, it is imperative to analyze the chain of cause-effect relationships of key influences. In a very simplified scheme, this is illustrated for the utilization of tropical reservoirs for fisheries.

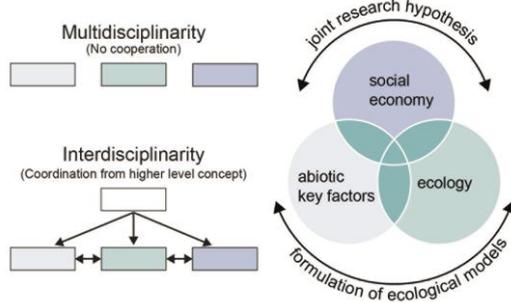


Figure 15. Interdisciplinarity

The cause-effect chain is illustrated in a bottom-up form (Figure 15), starting with the regulation of the trophic state by the loading of nutrients from the catchment. This trophic state of a waterbody in turn determines the productivity of fisheries and consequently the protein supply for the

riparian population. In a similar way, the top-down effects have to be analyzed. This analytical scope is imperative. However, since we are dealing with complex interactions and networks of interrelationships, it is impossible in praxis to model all the interactions. Therefore it is necessary to maintain a synoptic view of the socio-ecological system as a whole.

3.2. From multidisciplinary to interdisciplinarity

It slowly becomes apparent that a multidisciplinary research orientation, where the problem identification is carried out within the individual disciplines and the integration of research findings occur posthoc, is insufficient in order to gain a detailed understanding of the functioning of complex systems.

It has to be substituted by an interdisciplinary approach with a stronger conceptual integration of individual research fields leading to new science profiles e.g. ecology-hydrology or eco-sociology (Figure 16). This has to be achieved by joint problem identification and hypothesis building (Simon & Schieler 2015).

The practice shows that scientists commonly find it difficult to step beyond the “comfort zone” of their individual subject. Even among natural sciences, e.g. hydrology and ecology, such barriers for the formulation of integrative research exist. The challenges are even more formidable in bridging disciplines with a different epistemological structure, e.g. ecology and sociology. In order to overcome these intellectual barriers, academic curricula with an integrative scope have to be strengthened (Bruce et al. 2004).

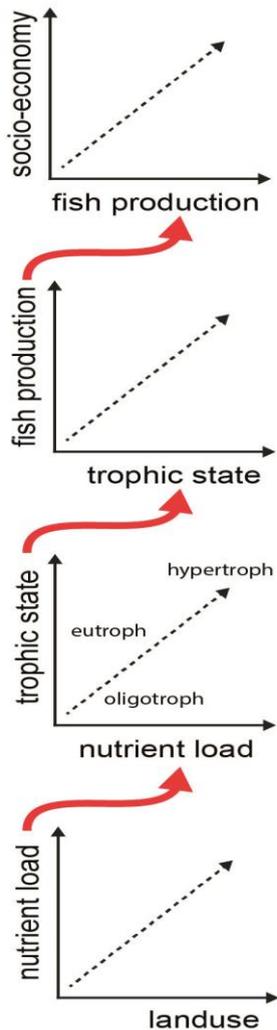


Figure 16. Cause effect chain

A further challenge is the knowledge transfer to practitioners. The rapidly expanding field of translational research identifies ways that provide new knowledge and recommendations for practical application. Despite the enormous growth of literature in this new research orientation, at present there is a lack of a common glossary, a focused communication platform and a shared research framework (Brandt et al. 2013). Further development in this direction requires incentives both from the social and environmental disciplines.

3.3. Policy arena: scientists should get involved in “real world” issues

Although there is growing awareness that sustainable management requires a scientific foundation, in practice the acceptance and utilization of research findings for management is a slow process. Decisions are rarely based on evidence-based information but are traditionally controlled by stakeholder interests of different socio-economic standing and political influence. Controversies between the various interests often delay urgent practical measures. We experience this continuously in issues of global scale.

From the point of view of science, this means that pure academic work is not sufficient. In order to be effective, a more direct involvement with stakeholders and decision makers is necessary. Acceptance of scientific knowledge is increased through direct engagement and a continued science-practitioners dialogue (Max-Neef 2005, Lawton 2007, Likens 2010).

However, there is often resistance by authorities and decision makers to involve independent expert panels for fear of loss of control and influence. On the other side, there is also hesitation in part of the scientific community to become involved in real-world problems, because applied science is often considered academically less rewarding. This definitely is a misguided attitude: a direct involvement in management-oriented research stimulates new and significant avenues of science. It offers science the advantage of readily applying “real world” framework conditions in its research programs and model building.

Scientists should take a manifold and guiding role in the formulation of sustainable management concepts. Their role lies in identifying problems and

hazards, and defining procedures and pathways for finding acceptable compromises and comprehensive solutions. The implementation of management programs has to be carried out in a step-wise, adaptive form, accompanied by a research-oriented monitoring to assess the impacts of measures and – if necessary – make corrections and improvements. In this form, the development of sustainable management can be seen as a large-scale experiment at the eco-social system level.

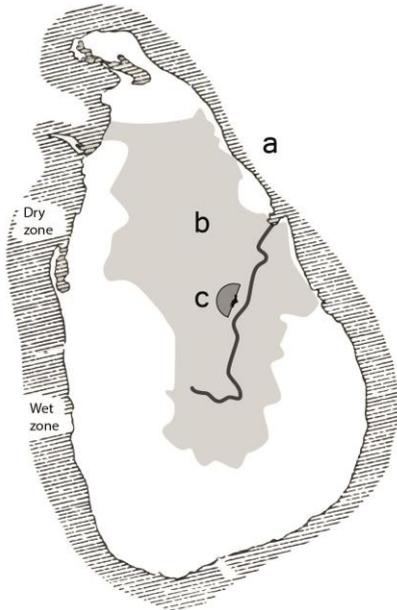


Figure 17. Mahaweli river, Sri Lanka

The involvement of scientists can range from consultation to participation in advisory expert panels, or to being part of co-management boards with executive power. The adequate structures and forms of involvement of science depend on the geographic scale – national, regional or local – the nature of the environmental systems and the order and dimensions of problems which have to be addressed (Figure 17). Larger, more complex systems raise higher difficulties, due to larger numbers of stakeholders, greater socio-

ecological diversity and more complex linkages.

The selection of expert panels – if they are of an advisory nature or involved in co-management arrangements – has to be based on a set of well-defined criteria. Members selected should have a high scientific profile, a proven ability for interdisciplinary research and willingness to be involved in transdisciplinary approaches. Expert panels should be independent and not interfered with by short-term political interests. They should have clearly identified goals, a rigid time structure, well-defined responsibilities and long-term mandates. Their recommendations should be made public. Especially in countries with small research communities like in Austria or Sri Lanka, it is advisable to seek international support and advice in structuring such expert panels and identifying the candidates.

Taking the water issues of Sri Lanka as an example, there are many demands for a bridging approach in problem identification and assessment, which go far beyond the responsibility of individual ministries or governmental institutions. The hydrological control for hydropower generation and irrigation, for example, has major effects on the fisheries- potential of the reservoirs and the water quality of the aquatic network including the groundwater table.

The issue of water quality and the identification of hazardous and toxic substances leading to health problems, e.g. the chronic kidney disease (Noble et al. 2014), require an integrated view on the land-use of the catchment, the socio-economic conditions, the agricultural practices, the hydrological regulations etc.

In order to achieve such an integrated view, a wide range of research fields – from meteorology, limnology, soil geochemistry

to health sciences and socio-ecology – has to be involved in an interdisciplinary form. Independent expert panels on integrated aquatic resource management should be installed in order to define the bridging aspects of water issues beyond the scope of individual ministries.

They have to make use of the information provided by governmental research institutions and help to direct their research scope, orientation and priorities. Their task should be supported by a nation-wide water quality assessment scheme covering biological, chemical and toxicological parameters with a strongly improved capacity and quality control.

In summing up, we can formulate recommendations for science involvement and operational procedures in the development of sustainable management plans. The focus has to be on the promotion of comprehensive concepts, taking into account all concerned parties and assuring their active involvement. The main challenge is to achieve a continued dialogue between stakeholders, authorities, decision makers and scientists.

The primary task for science is to develop an integrative system-oriented understanding with predictive power and to provide this knowledge to the practitioners in appropriate form. The cooperation with practitioners ranges from being part of advisory panels to being engaged in executive co-management boards. A stronger and longer-term involvement improves the chances both for an advancement of science as well as of management skills to achieve sustainable solutions.

Management programs should be implemented in an adaptive form, i.e. guided by science-based monitoring programs to assess successes and failures

and increase our knowledge base by learning on the way. The participation of science requires well-defined institutional frameworks with long-term mandates and clearly defined responsibilities. Our experiences point to the necessity to strengthen institutional and legal frameworks, which guarantee a scientific approach for holistic planning and transdisciplinary decision processes.

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