特集：土木工学と生態学の壁はとりのぞかれたか？ Feature: The wall between civil engineering and ecology has been removed?

REVIEW

River restoration: linking science with application

Klement TOCKNER

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Eawag: Swiss Federal Institute for Aquatic Science and Technology, Department of Aquatic Ecology, Box 611, 8600 Dübendorf, Switzerland: IGB: Institute of Freshwater Ecology and Inland Fisheries, Mueggelseedamm 310, 12587 Berlin, Germany

Abstract: Restoration of rivers and floodplains needs to be carried out based on the best scientific knowledge available. At the same time, restoration projects provide the great opportunity to link basic research with application for the benefit of both. In this short essay, I discuss four selected aspects that are scientifically challenging and highly relevant for restoration: (i) setting restoration priorities and need of reference systems, (ii) understanding the link between environmental heterogeneity, biodiversity, and ecosystem processes, (iii) focus on refugia for maintaining ecosystem resilience, and (iv) the potential role of ecosystem services in guiding restoration projects.

Key words: conservation, refugia, resilience, floodplain, ecosystem services

Introduction

The 21st century has been defined as the century of nature restoration. Indeed, the number of restoration projects has increased worldwide during the past years and it is expected to raise further (Bernhardt et al. 2005; Palmer et al. 2005; Nakamura et al. 2006; Woosley et al. 2007). Palmer et al. (2005) and Jansson et al. (2005) proposed six criteria to measure ecological success of river restoration: (1) the existence of a ‘guiding image’ as a dynamic endpoint that is identified *a priori* and guides the restoration, (2) that ecosystems are improved and the ecological conditions of the river are measurably enhanced, (3) adaptive capacity is increased so that the river ecosystem is more self-sustaining than before the restoration, (4) no lasting harm is done by the restoration, (5) some level of pre- and post-project assessment is implemented and the information is shared, and (6) that the guiding image has to be supplemented by some descriptions or predictions of the *ecological mechanisms* by which the intended restoration strategy will achieve its goal. However, a high proportion of restoration projects fails or does not meet their goals — if any have been defined. Key reasons for failure are (a) major gaps in our basic understanding of the functioning of complex ecosystems and (b) difficulty in transferring the existing scientific knowledge to the practitioners. Restoration projects need do be carried out based on the best scientific information available, at the same time they pose a great potential to advance our scientific knowledge. In this respect, restoration projects can be seen as the “acid test” of our present ecological knowledge. However, pure applied issues such as ecosystem restoration are still considered of limited interest for basic scientists. Hence, we urgently need to link basic research with application — for the benefit of both.

In this short essay, I would like to discuss selected aspects that are scientifically challenging and at the same time highly relevant for restoration: (i) setting priorities for restoration projects and the importance of reference sys-

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e-mail: *tockner@eawag.ch*

tems, (ii) the need to understand the link between environmental heterogeneity, ecosystem processes, and biodiversity, (iii) ecosystem resilience and the role of refugia, and (iv) the potential importance of "ecosystem services" in guiding restoration and management programs. The focus will be on river-floodplain ecosystems because they are particularly complex and diverse systems due to their open link to adjacent ecosystems, their interface position between land and water, and the constraints that hydrological and morphological dynamics place on their flora and fauna. At the same time they are among the most threatened systems world wide (Tockner & Stanford 2002). River-floodplain ecosystems are also topographically unique systems occupying the lowest position in the landscape, thereby integrating upstream catchment processes (Naiman et al. 2005; Tockner et al. in press).

Restoration projects: Ideal experiments to advance our basic understanding of complex ecosystems

Ecosystem ecology is seen as "a table borne by five legs" (Carpenter 1997), each essential for the intellectual support of the whole. The legs are the major approaches that scientists use to learn about ecosystems. These complementary approaches are: (i) **Theory**. A strong conceptual base is the pre-requisite for defining research questions and formulating hypotheses. Theory needs, however, a continuous linkage to observation. (ii) **Ecosystem experiments**. Well-designed field and laboratory experiments are necessary for testing hypotheses and identifying causal linkages between structure and function, (iii) **Long-term studies**. Greatest progress in ecology has been achieved by long-term research projects because short-term projects may result in misleading interpretations, (iv) **Comparisons**. Meta-analyses and inter-ecosystem empirical research following similar protocols may help to test hypotheses about spatial variation and detect spatial patterns across different ecosystems. (v) **Modeling**. There is an urgent need for predictive and mechanistic ecosystem models, both from a basic and an applied research perspective (see also Hein et al. 2006).

This 5-leg approach forms the basis for advancing basic research but it is also ideally to underpinning applied research programs. In particular restoration projects have the great potential to advance our scientific understanding because they are large-scale *in situ* experiments that allow us to test general ecological principles. Such large-scale experiments will never receive support by regular scientific funding sources because they are too expensive, they are at the interface of various disciplines, and they require the integration among scientists, practitioners, and the public.

Setting priorities and creating a network of reference systems

One of the most pressing issues in ecosystem management is how to distribute limited resources between regions identified as priorities for ecosystem restoration and biodiversity conservation. There are two fundamentally different approaches in setting priorities for conservation and restoration: (i) a reactive approach that prioritizes areas of high threat and high proportion of threatened/endemic species, and (ii) a proactive approach that prioritizes areas of low threat and high proportion of threatened/endemic species (see Brooks et al. 2006). The reactive approach primarily helps to identify areas for restoration while the proactive approach drives conservation planning. These two approaches can not be considered in isolation. For the sustainable management of our ecosystems we need to link these two approaches, e. g. by restoring river segments that are close to areas of high conservation value. However, in order to be able to link these two approaches, we need quantitative information about the key pressures (threats) in a spatially explicit way; and we need data on the distribution of threatened and endangered species. Although it is now common knowledge that the catchment must be the key spatial unit to understand and manage ecosystem processes and biodiversity patterns, the units most commonly used in systematic conservation planning are equal-area grids, biogeographic regions, and individual countries or counties (e. g. Dobson et al. 1997). In addition, available data are unevenly distributed within and among these units constraining comparability and the identification of areas of high priority.

We are just beginning to fully comprehend the great extent by which rivers in much of the world deviate from the natural state. Until quite recently, most concepts in river ecology were based on the implicit assumption that rivers are stable, single-thread channels hardly interactive with adjacent floodplains. Unfortunately, many European rivers, but also Japanese and North American rivers, are in such a state, but it should be recognized that this is not the natural condition. We believe that this incomplete understanding constrains scientific advances in river ecology and renders management and restoration initiatives less effective (Ward et al. 2001). Within the current project "Rivers of Europe", we quantified four major pressures on aquatic biodiversity: (i) the proportion of cropland within the catchment, (ii) the degree of river fragmentation, (iii) water stress (proportion of water withdraw to water availability), and (iv) the proportion of nonnative fish species (Tockner et al. 2008). At the continental scale, ~50% of the original wetlands and up to 95% of riverine floodplains have been lost. Around 60% of the European catchments have been transformed into cropland and urban area. European catchments are highly fragmented by > 6000 large dams and of the 20 largest European rivers only the Pechora in western Sibiria is considered free-flowing. The area that will suffer from severe water stress is expected to increase from 19% today to 34-36% in 2070 (Henrichs & Alcamo 2001).

The proportion of nonnative fish species per catchment can be as high as 50% (Fig. 1A). The areas that face the highest human pressures, namely catchments in the Iberian Peninsula, the Balkan, and Turkey, are at the same time the areas with the highest proportion of irreplaceable species (e. g. fish species; Fig. 1b). The western Balkan is an additional area with a high proportion of irreplaceable species, although the human pressures there are less severe. If we want to set priorities for restoration and conservation at the European scale, we need to focus on these areas of high conservation value and of high (reactive approach) and low (proactive approach) human pressures. However, the majority of restoration and conservation projects are carried out in Scandinavia, UK, and Central Europe, areas that are mostly outside of these key priority "hot spot" areas.

Beside high Arctic and northern Scandinavian catchments there are only few catchments in Europe that are still remaining in a semi-natural condition. These are primarily small catchments such as Frome & Piddle (UK), Tagliamento (Italy), Mondego (Portugal), or Evrotas (Greece). These catchments play a major role as reference systems for entire Europe. It is therefore of prime importance to preserve and actively manage those rivers that retain some of their natural functional attributes. We urgently need a network of reference ecosystems against which we can assess the deviation of catchments and their biodiversity; and we need long-term data sets to understand trends of both the environmental drivers and the response variables. Without being able to understand the functioning of near natural ecosystems, we will not be able to manage and restore rivers and their adjacent floodplains in a sustainable way.

The European Union has launched a highly ambiguous program, the Water Framework Directive (WFD; http://ec.europa.eu/environment/). The WFD creates a legislative framework to manage, use, protect, and restore surface water and groundwater resources in the European Union. The WFD approaches water management at the scale of the river catchment (river basin), which often includes several countries. The WFD requires the establishment of a 'river basin management plan' (RBMP) for each river catchment. The RBMP is a detailed account of how environmental objectives (i. e., good ecological status of natural water bodies and good ecological potential of heavily modified and artificial water bodies) are to be achieved by 2015. For defining good ecological status at the catchment scale, however, we need such a network of reference ecosystems.

The Tagliamento in NE Italy is one of these model ecosystems of European importance (Tockner et al. 2003). The results of our own research along the Tagliamento River are already used in planning restoration projects in Switzerland as well as in other mountainous regions world wide. This can be considered as an example of successful transfer of basic research results to restoration planning. For example, one focus of our research was on the ecological importance of riverine islands. Islands, proposed as an ecosystem-level indicator of the condition of a river corridor, are an endangered landform in Europe. They are among the first landscape elements that disappear as a consequence of river regulation and flow control. Our observations on the Tagliamento River demonstrate the important role played by islands and their associated aquatic habitats

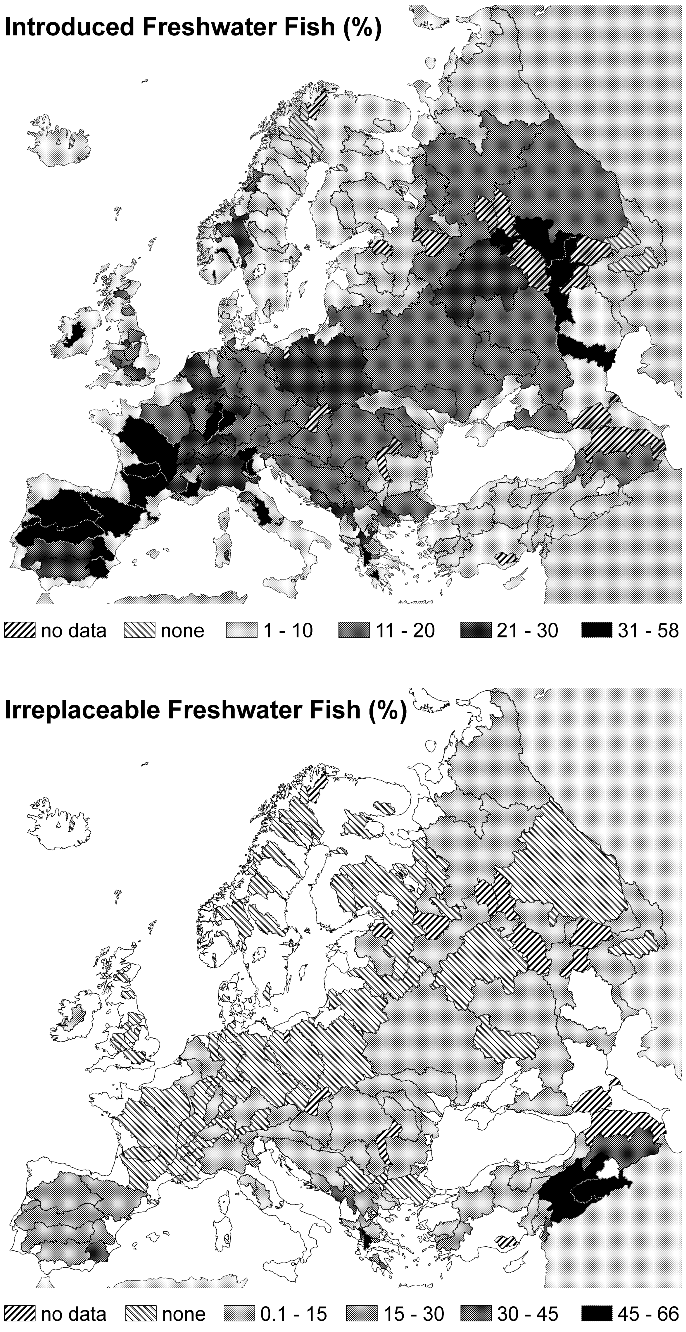

Fig. 1. The relative proportion of nonnative (A) and irreplaceable (B) fish species in 165 European catchments (F. Peter & K. Tockner, unpublished data; Tockner et al. 2008). Irreplaceable species are defined as species that are restricted in their natural occurrence to a maximum of three catchments (regionally endemic species).

and how they contribute to the high physical and biological complexity of a river corridor. Table 1 provides comparative data for two adjacent reaches (bar-braided and adjacent island-braided reach) and provides indices of their overall physical complexity and richness, and diversity of animal species (after Gurnell et al. 2005). The formation of vegetated islands requires (1) a natural flood regime, (2) an unconstrained river corridor, (3) a sediment sour-

Table 1. Biocomplexity of the active zone of an island-braided compared to a bar-braided reach, Tagliamento River, NE Italy (from Gurnell et al. 2005).

	Bar-braided	Island-braided
Approximate Reach Dimensions		
Channel slope (m m^{-1})	0.0035	0.0029
Reach length (km)	1.4	1.8
Width of active zone (km)	1	0.8
Physical Characteristics		
Large wood (t ha^{-1})	15–73	102–158
Channels (half-life expectancy; months)	4.1	7.7
Aquatic habitat diversity (H')	1.6	2.0
Average number of ponds	7	22
Average shoreline length (km km^{-1})	13.7	20.9
Animal Species Richness and Diversity		
Amphibian species: γ-diversity	5	7
Carabid beetle species: γ-diversity	34	47
Benthic invertebrates: α-diversity	30	27
Benthic invertebrates: β-diversity	10.5	21
Benthic invertebrates: γ-diversity	50	53

Diversity indices: α-diversity — the number of species in each habitat; β-diversity — the turnover of species between habitats; γ-diversity — the total species pool

ce, and (4) a source of large woody debris, a combination of conditions not present in highly managed river systems. It is now understood that restoring vegetated islands means to restore the underlying processes that are responsible for their formation and change.

Environmental heterogeneity, biodiversity, and ecosystem processes

Heterogeneity means the variability of patterns and processes in space and time. The loss of environmental heterogeneity is considered as the most serious thread to aquatic (and terrestrial) ecosystems. Hence, improving habitat heterogeneity has been a major restoration goal because it is expected that the creation of different habitat types will lead to an increase in species diversity, will stimulate ecosystem processes (e. g. increases organic matter retention), and finally enhances the natural resilience of a system. In some cases the simple creation of habitats may be sufficient, in most cases it is not. It largely depends on the landscape context a restoration project is carried out, as well as on additional components of heterogeneity such as the size of habitats, their spatial configuration, the degree of connectivity among habitat types, and the permeability of the habitat boundaries (see below and Fig. 2). Recent experiences in Switzerland have clearly shown that an improvement of habitat heterogeneity is only successful in rivers that are not impacted by hydropeaking (i. e. daily fluctuations of the water level due to hydropower production on demand) as well as in rivers that contain unmodified river sections in their upstream catchment (e. g. Paetzold et al. in press). It means that hydrology plays an overriding effect on community structure that can not be compensated simply by improving morphological heterogeneity. And newly created habitats can only be colonized by habitat-specific communities if there are sources for recolonisation in upstream segments. It is a popular myth in restoration ecology that "if you create habitats they (i. e. the specific animals and plants) will appear"! However, it remains mostly a myth.

To test the effect of habitat heterogeneity on biodiversity and ecosystem processes forms a major scientific challenge too. Indeed, embracing environmental heterogeneity is considered as the next frontier for ecosystem ecology (Lovett et al. 2005). Recently, we started a large interdisciplinary project entitled *"Assessment and Modeling of Coupled Ecological and Hydrological Dynamics in the Restored Corridor of a River"* (RECORD, http://www.cces.ethz.ch/projects/

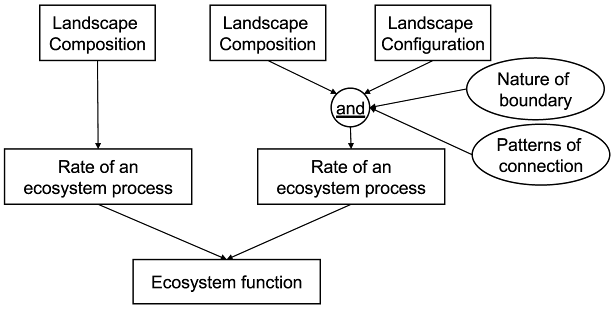

Fig. 2. Two different approaches to understand the effect of environmental heterogeneity on ecosystem processes and functions. The traditional way is to only consider habitat composition as the key driver of ecosystem processes (left part), while we must argue that the composition, the configuration, and the degree of connectivity control individual ecosystem processes (right part) (after Lovett et al. 2005).

Record). The goal of this project is to develop coupled hydrological, biogeochemical, and ecological models in order to understand the effect of environmental heterogeneity created through river restoration on surface-subsurface exchange processes. We postulate that heterogeneity in environmental drivers (e. g., hydrological, meteorological), in material properties (e. g., soil composition, hydraulic conductivity), in environmental conditions (e. g., variability in erosion/deposition processes, soil type) and ecosystem processes (e. g., succession of vegetation) underpin water quality, biodiversity, and physical and ecological resilience. This project will be carried out in (former) braided rivers. Indeed, braided gravel-bed rivers serve as excellent model systems to elaborate upon the complex relationships between habitat heterogeneity, ecosystem processes and biodiversity, because habitat turnover occurs much faster there than in most ecosystems. Literally, in braided rivers we can witness how an ecosystem evolves and transforms. Braided rivers were once widespread in temperate piedmont and mountain-valley areas, primarily in non-arid regions containing young, eroding mountains (e. g. New Zealand, the Himalayas, the Rocky Mountains, the Andes, European and Japanese Alps) which provide adequate sediment loads. Today, most braided rivers bear little resemblance to their highly dynamic natural state. However, in Europe, Japan and in most parts of the USA, remaining braided rivers are among the very limited areas — in otherwise highly managed landscapes — where natural large-scale disturbances still are allowed to occur (Tockner et al. 2006; Yoshimura et al. 2005).

Braided rivers contain a complex mosaic of hydrogeomorphic patches and associated functional process zones (Thorp et al. 2006). These patches have different system properties (flow history and regime, sediment, nutrient and organic matter composition, different shapes and boundaries), all critical factors shaping biological communities and delimiting ecosystem processes (Table 2). Little is known on how the variety, abundance and configuration of differential habitat patches affect biodiversity. Since many species require more than one habitat type during their entire life cycle, this can be of considerable importance for restoring and conserving biodiversity.

Because the various habitat patches of a floodplain are connected, there may be extensive fluxes of nutrients and energy across boundaries and many organisms may derive resources from more than one type of habitat. Understanding the nature of the linkages between the often very contrasting patches is therefore crucial to understanding how a floodplain ecosystem functions, and how it should be restored. In any case, we need to consider both the configuration and the composition of the floodplain landscape elements in order to understand its transformation capacity and its role in maintaining high biodiversity. This consideration of a floodplain as an interactive mosaic is a major step forward in our understanding of these complex and dynamic ecosystems (Fig. 2). As an initial step for under-

Table 2. Differences in soil/sediment organic matter, autotrophic biomass, Net Primary Productivity (NPP), sediment respiration, and leaf-litter decomposition in aquatic and terrestrial floodplain landscape elements (estimated values from different sources).

	Soil/sediment OM (g m^{-2})	Autotrophic Biomass (g OM m^{-2})	NPP (g OM m^{-2} yr^{-1})	Sediment respiration (g OM m^{-2} yr^{-1})[4−]	Decomposition (*P. nigra* leaves) k-value[5]
Terrestrial					
Bare gravel	500	200	200	50	0.0020
Pioneer island	2,000	600	800	300	0.0019
Established island	6,000	5000	2000	1500	0.0023
Riparian forest (softwood)	10,000	7000	2000	1500	0.0019
Riparian forest (hardwood)	12,000	7000	2000	1500	0.0019
Aquatic					
Lotic channel	500–5000	10–60[1]	0[2]	500–1500	0.0231
Parafluvial pond	6000	50	0[2]	1500	0.0052
Orthofluvial pond	10,000	1	−1500[3]	−1500	0.0055

[1] main channel presumably 10-20 g OM m^{-2}, surface-disconnected alluvial channel presumably up to 50 g OM m^{-2}

[2] lotic channels P/R = 1

[3] heterotrophic system (shading by dense riparian forest canopy) P/R ca. 0

[4] estimates based on preliminary data (M. Doering, unpubl.)

[5] preliminary data, coarse mesh-bags (S. Langhans, unpubl.)

standing the link between heterogeneity and ecosystem processes in river floodplains we will be answering the question, does habitat heterogeneity of subcomponents (wetlands, floodplains, hyporheic, islands etc.) influence ecosystem processes (using the water chemistry as a measure of the net result of the processes present in this system) in a restored (and a non-restored) river section. In a later phase, we may ask whether these relationships are consistent across a variety of river types and spatial scales (by using data from other well-studied systems).

Ecosystem resilience and role of refugia

The concept of resilience, as applied to an ecosystem, is loosely defined as the ability of the system to maintain its function when faced with novel disturbance that exceeds the historical range of variation (Webb 2007). A key goal of many restoration projects is to enhance the resilience of the system in order to increase its ecological stability (Lake et. al. 2007) . In particular rivers and floodplains are highly resilient systems in their natural state. Refugia, i. e. areas from which recolonisation following a disturbance event occurs, and their distribution and utilisation are of critical importance for maintaining the ecological stability of systems. Therefore, the potential availability of refugia can be used as an indirect indicator of ecosystem stability (resilience). Since the dominant disturbance regime is changing along the river corridor (“disturbance cascades” *sensu* Montgomery 1999; Table 3), the relative importance of individual refugia changes as well. Braided gravel-bed rivers offer various categories of refugia such as shore areas, and hypogeic and hyporheic habitats that are crucial for maintaining diversity in the face of frequent disturbances (Tockner et al. 2006). Therefore, the potential availability of refugia could be assessed at three different scales: (i) vertically, as the permeability of bed-sediments, (ii) laterally, as shoreline length, and longitudinally, as the relative proportion of unmodified tributaries (up to a distance of ~10 km, depending on stream size) or the number of hydrogeomorphic nodes (convergence and divergence areas) within the braided channel. This would allow an indirect assessment of the resilience of braided rivers as well as of the success of restoration measures. A description of how to apply various indicators to assess restoration projects can be found in Woosley et al. (2007) and at http://www.rivermanagement.ch/.

Until recently, the main river channel has been the key focus of river research. Lateral (semi-) aquatic habitats —

Table 3. Fluvial style, disturbance regime, refugia, and adaptation of aquatic macroinvertebrates along a fluvial corridor (after Tockner et al. 2006).

Location, Fluvial style	Disturbance regime	Refugia	Adaptation
Headwater Straight	Avalanches Debris flow Drying	Tributaries Hyporheic zone Substrate hetero-geneity	Drift Morphological adaptation Life cycle
Piedmont section Braided	Avulsion Cut and fill processes	Shore habitats Dead zones Large wood Hyporheic zone	Mobility Flexible life history Risk spreading
Lowland section Meandering	Inundation Lateral channel migration	Floodplain Large wood Backwater/pond	Physiologic/ethologic adaptation Diapause

ponds, backwaters, and tributary confluences — have been widely ignored or studied in isolation. A reason for the underestimation and undervaluation of lateral water bodies in river research is their almost complete absence in small headwater streams and along heavily modified downstream sections. Lateral aquatic habitats are among the first landscape elements that disappear as a consequence of river regulation and flow control (comparable to vegetated islands). However, the understanding of their functional and structural role along river corridors forms a prerequisite for a successful and sustainable river management (Coops et al. 2006). Karaus (2005) quantified species diversity of benthic invertebrates (Plecoptera, Ephemeroptera, Trichoptera) along three Alpine river corridors (Swiss Rhone, Thur, and Tagliamento) by including the lateral dimension along each corridor. Results clearly demonstrated that lateral habitats disproportionately contributed to longitudinal diversity (Fig. 3). Lateral habitats contributed > 50% to total corridor species richness, although they covered < 10% of the aquatic surface area (Karaus 2005, Fig. 3). Further, diversity was hierarchically partitioned into its components (alpha, beta and gamma diversity) to quantify the relative contribution of individual samples, habitats, and corridors to overall diversity of the three Alpine river corridors. Among-sample and among-corridor diversity components contributed

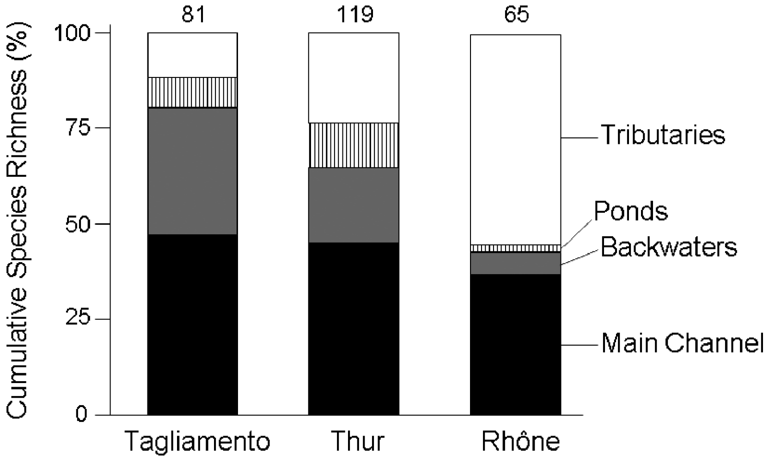

Fig. 3. Cumulative and total species richness of Epemeroptera, Plecoptera and Trichoptera along three river corridors. In backwaters, ponds and tributary confluences only those taxa that did not occur before were added (data: U. Karaus & K. Tockner, unpubllished, after Coops et al. 2006).

most to total taxa richness, while < 15% was due to within-sample and among-habitat components. This study clearly emphasised the importance of lateral aquatic habitats for maintaining high aquatic biodiversity along river corridors. Consequently, these habitats need to be fully integrated in future conservation and restoration projects.

Ecosystem Services and river restoration

The overarching goal of most ecosystem restoration projects is to link their sustainable use with human wellbeing. Ecosystem services are the benefits obtained by people from ecosystems (Millennium Ecosystem Assessment 2005). It is only in recent years that we have begun to recognize the range of ecosystem services provided by river-floodplain ecosystems and to develop strategies to protect and restore these services. Examples of the kinds of services we receive include:

- *Provisioning services* such as food, water, timber, fiber, and genetic resources;
- *Regulating services* such as the regulation of climate, floods, disease, and water quality;
- *Cultural services* such as recreational, aesthetic, and spiritual benefits;
- *Supporting services* such as soil formation, pollination, and nutrient cycling.

Recently, Kremen and Ostfeld (2005) emphasized the urgent need to develop a better understanding of the ecological underpinnings of ecosystem services, and to integrate this knowledge into a socioeconomic context to develop better policies and plans to manage and restore our ecosystems. This means that we need a mechanistic and not only a statistical understanding of the processes that control individual ecosystem processes and services. For example, it must be of great scientific challenge to develop an "**Ecosystem Service Calculator**" that can be applied for planning and assessing restoration projects. Such a calculator must contain an easy-to-apply software (with a set of modules for the different services) that allows us to predict the outcome of restoration projects under different scenarios and boundary conditions.

Most recently, we started a project in Switzerland where we use the "Sound" to assess the aesthetic value of river ecosystems. The key question is to what extent optical and acoustic criteria can be combined to evaluate the human appreciation of intact river ecosystems. At the same time, we are trying to develop an acoustic "fingerprinting" technique to assess the ecological integrity of river ecosystems. Figure 4 shows the sonogram, using a hydrophon, of a regulated and an unregulated river section. It shows that higher frequencies get lost with regulation and that that the sound becomes more uniform in time.

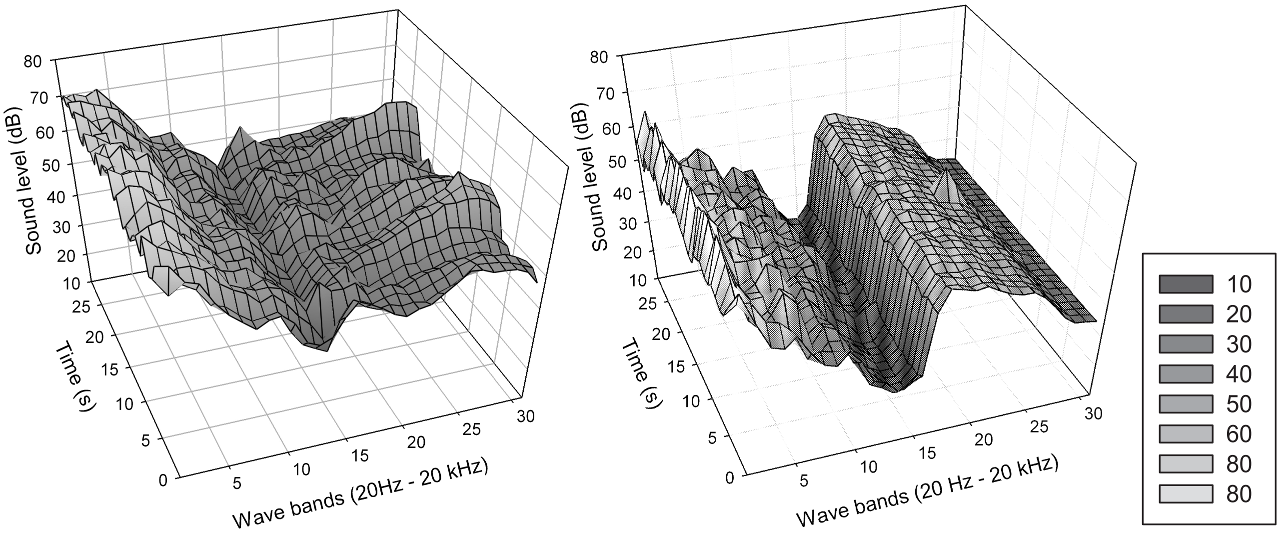

Fig. 4. Sonogram (30 wave bands, recording time: 30 seconds) of a restored (Birs, left panel) and a regulated (Wiese, right panel) river section (data: D. Tonolla, Eawag).
Please, note missing frequency bands and temporal homogeneity of the Wiese river section.

This project should help to develop a routine program to assessing the aesthetic value and ecological state of entire riverine landscapes. A major aim of the project is therefore to increase the sensitivity of the society for the aesthetic and ecological values of intact river ecosystems.

Conclusion

For managing river ecosystems, we urgently need to develop tools that allow us to predict the expected outcome of specific restoration goals (e. g. Reichert et al. 2007; Schweizer et al. 2007). However, the present capacity to predict, or forecast, the dynamics of ecosystems is limited by our understanding of the underlying principles that control ecosystem processes (Clark et al. 2001). Moreover, although we do have a conceptual understanding of the key forces driving ecosystem processes and riverine landscape configuration, we still lack quantitative information on how these dynamic driving factors (flow regime, thermal inputs and losses, resource pulses) control ecosystem processes (energy flow, ecological linkages) including complex feedback processes. The new tools which are needed must be a spatially and temporally explicit representation of ecosystem community dynamics of the floodplain and must both assess current conditions and impacts as well as to model and visualize the affects of any changes of the key factors affecting river-floodplain ecosystems. Further, while conservation planning is primarily driven by the number of native, endemic, and endangered species (so-called “hot spot” areas), there is an urgent need to incorporate other ecosystem aspects such as the evolutionary potential of the system and it’s capacity to perform key ecological processes in conservation and restoration planning. Finally, the cooperation among different disciplines and between basic and applied research will advance the management of our rivers and floodplain ecosystems in a sustainable way.

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