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# DEFINING CONSERVATION OBJECTIVES IN RIVER RESTORATION: THE RIVER DISORDER APPROACH

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## Abstract

The manifestation of the river system is the result of an array of discontinuous, non-equilibrium processes operating at different scales, influenced by the constellation of geographic, hydro- and bio-ecoregions in the river basin. We propose a multidimensional and multiscale approach to define conservation objectives for river ecosystems. The River Disorder Approach provides a framework for deriving objectives from observed patterns and structures in the river system, resulting from the discontinuous processes among the various temporal and spatial scales. We identified disorder elements for the River Meuse at the different scale levels for the floodplain meadows and immediately derived conservation objectives from it. These where then integrated in a guiding image, to prove the practicability of this approach.
Contrasting with the common view of rivers as continuous and self-repeating in components and patterns, we identified the non-equilibrium and stochastic processes as guiding for the definition of conservation objectives. This choice conflicts with presently used deterministic approaches. As this type of deterministic approaches is used for generalized goal setting for rivers in national or even pan-European legislative frameworks, but encounters strong problems, our plead for idiosyncratic, non-deterministic target setting might prove helpful for the implementation of river basin management.

## Introduction

Most large rivers and streams of the temperate regions have been drastically altered by human activity over the past centuries (Décamps et al. 1988; Petts 1989; Ward & Stanford 1995). Regulation for transportation, water supply, flood control, agriculture and power generation purposes, is recognised to come at great cost: large flood disasters at the end of last century, the loss of important natural resources and prospecting climatic changes in river catchments raised the awareness of the need for new approaches. Flood protection and harmonisation of functions need new perspectives and frameworks for the future (Giller 2005). Preservation of natural resources and restoration of ecosystem functions and health are essential elements in the development of strategies and the definition of objectives (Fairweather 1999; Karr 1999).

Whatever the initial drive to start a river restoration project: species conservation, habitat restoration, flood protection, gravel or sand extraction, water purification, there are always many parties involved to reach the point of decision and action. For the river system's hydrology, geomorphology and ecology are intimately linked, all functions and land use practices depend upon specific configurations and conditions of the river's functioning. Therefore, the development of one function can hamper many others or can be tailored towards a benefactor for other functions. Many examples exist of projects where functions are developed in such a way that they support others, or projects acquire new objectives through the planning process as win-win situations can come to light.

At the European scale, the Habitats Directive demands a clear definition of objectives for a favourable conservation status, for the species and habitats in the NATURA2000 pan-European network of protected areas, including many riverine habitats and species. Conservation objectives must represent a contribution to this achievement of favourable conservation status, and the wider goal of biodiversity conservation, for the present habitats and species based on the features for which it has been selected (EC 1992). Same counts for the Water Framework Directive that tries to initiate and organise the new perspective of integrated river basin management. It states a general objective for all water bodies, in the achievement of a good ecological status by 2015. This good ecological status achievement is subject of an integrated approach for assessing quality and goals for physicochemical, biotic and hydromorphic conditions with a common implementation strategy over the member states. It demands the definition of explicit objectives in the context of management plans and restoration strategies. Objective definition is further subject of legislations in different member states, as well as in other continents (Naiman & Bilby 1997; Boon 2000).

A clear definition of objectives in an early stage is essential and leads to the best realisation practices. The objectives for river restoration need to be realistic in relation to the natural physical processes, and their variation in time, and to the needs and demands society has brought about, and which in most instances are irreversible. Fundamental elements for the implementation of river basin management are quantitative analyses, dealing with risks, institutional organisation and the paradox of scale (Naiman et al.1998). Many handbooks and blueprint approaches for river restoration exist (European Centre for River Restoration ECRR, Nijland & Cals 2001; River Restoration Centre 2005; National Rivers Restoration Science Synthesis 2004; River Styles Framework, Brierly & Fryirs 2002), yet, most start from the idea of a universal river character. We present a stepwise approach for the definition of conservation objectives, starting from a disorder concept for rivers. It is an approach based on the discontinuities and heterogeneity in the river system, not starting from unifying principles.

The conservation objectives have to be made explicit within the context of biodiversity conservation, and then translated in decision frameworks. Quantitative measures have to be derived and integrated in restoration schemes. From our multidisciplinary research on the River Meuse, in light of the large-scale restoration project for the Common Meuse reach, emerged the here described conceptual framework to develop and prioritize restoration strategies.

For the introduced approach, two central questions are:

1 how do we define the objectives for biodiversity conservation and restoration

2 how can these be measured? Quantitative, tangible measures need to be defined for objectives

We first refer to existing approaches and methods in the definition of objectives, then introducing the River Disorder Approach and its application to the river Meuse. At the end we discuss the concept's merits and the gaps and constraints in existing frameworks and legislations for successful conservation and restoration of river systems.

## A. Existing approaches

### Reference conditions

As suggested in the legal frameworks, conservation objectives are in the first place derived from reference conditions. Reference conditions may be based either on historical or geographical comparisons or on modelling, or may be derived using a combination of these methods including historical data. When no references are at hand, conceptual frameworks are consulted to derive model or indicator approaches.

The few studies that have documented attributes of relatively intact or notionally pristine rivers (e.g. Ward et al. 1999a; Radwell & Kwak 2005), and countless studies that have provided detailed reconstructions of river evolution over timescales of decades, centuries, or longer (Petts 1989; Girel et al. 1997; Décamps et al. 1988), indicate just how profound human-induced changes to river forms and processes have been across most of the planet. The European Water Framework (WFD, EC, 2000) nevertheless does demand the definition of reference conditions, if not of a historic or actual reference, than derived from a retracing of impacts to communities (Wallin et al. 2003).

Biological conservation and restoration strategies often refer to 1900 as a reference situation for Western European cultural landscape before industrialisation and land use intensification (Haslam 1996). Proposed restoration measures, classified as mitigation by Boon (1992) concern piecemeal land use practices and internal management of hydrologic and soil conditions. The ecological integrity goal or natural baseline (Karr 1999, Jungwirth et al. 2000) for these strategies is determined for particular communities and/or species under specific management regimes of mowing or grazing. River restoration in the temperate region refers more often to a reference situation further back around 1800 as the larger river regulation works started around that time (Figure 6.1). And even this situation deviates from the unaltered pristine conditions (100% integrity) before the large landcover changes in the catchments took place.

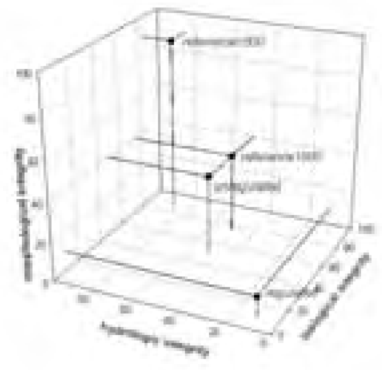

**Figure 6.1 Reference conditions and restoration pathways in terms of biological, morphological and hydrologic integrity.**

For the rivers of our temperate regions, most river alterations were already largely present in 1900. The deterioration of biological integrity since, is mainly due to further flow regulation and/or to intensification of land use. Further hydrological deterioration is caused by embankment and gravel or sand extraction, resulting in bed incision and distraction of large floodplain area. The unregulated reaches can readily be seen as reference for the regulated reaches, as they offer interesting prospective emphasizing on the definition of reference conditions and targets in the context of the WFD. Aquatic communities might even recover to a level comparable with the less disturbed unregulated reaches, even through immediate influx of species (Usseglio-Polatera et al. 2002). These river reaches are, however, only comparable to a certain degree, for some conditions and/or taxonomic groups (Pedroli et al. 2002).

### Conceptual approaches

In river ecology, the most important conceptual framework for biodiversity patterns in the river system is the River Continuum Concept (Vannote et al. 1980). It depicts a gradually changing biotic community in equilibrium with the physical environment of river systems from headwater to mouth, as physical, chemical and biological processes vary with river size. The concept states the important differences in ecological processes such as energy flow, organic matter breakdown and community structure in river channels along a longitudinal continuum.

In this way it follows the logic of Strahler's river order (Strahler 1957). Since the definition of the RCC, many contradictory observations and fundamental criticisms were the starting point for the definition of new concepts. From observations of strong discontinuities in geomorphologic and hydrologic regime, Statzner & Higler (1985) came to the formulation of the Stream Hydraulics Concept. Further concepts that make the variance and dynamics in hydrologic regime tangible for objectives are the Range of Variability Approach (Richter et al. 1996) and the Natural Flow Regime concept (Poff et al. 1997 ), concentrating on river specific flow variation and disturbance regimes. The discontinuities of both natural and anthropogenic origin in the system, can generate a regular pattern in processes and community structure, as is depicted in the Serial Discontinuity Concept (Ward & Stanford 1995) and the Telescoping Ecosystem

Model (Fisher et al. 1998). A further addition to the RCC based on local discontinuities due to strong lateral exchanges in large floodplain rivers, is the Flood Pulse Concept (Junk et al. 1989). This concept emphasizes more on the merits of the river dynamics and especially flooding processes. These dynamics and the forthcoming disturbance patterns are also the scope of the Patch Dynamics and Shifting Mosaics concepts (Petts & Bradley 1997; Forman 1995), interesting frameworks in the light of habitat network and population strategy approaches. Both concepts define equilibrium conditions with the physically changing environment over time and space in the river corridor, subject to disturbances  and dissipation of energy, but not in a continuous or orderly form.

### Functional versus structural approaches

Approaches to define objectives can be functional or structural. Productivity and nutrient cycling oriented approaches offer solutions to many management and quality related objectives. In these functional approaches the ecosystem health is in the first place defined in goals for nutrient cycling, buffer capacity and resilience, integrating discharge energy and water quality goals. Structural biodiversity approaches start from a well-defined appraisal of biological integrity and biological endpoints. In rivers, the physical structure of habitat is defined largely by the movement of water and sediment within the channel and between the channel and the floodplain. While reduction of environmental heterogeneity reduces options for species diversity (Naveh & Lieberman 1994), the ecological heterogeneity in river systems is closely related to flow regime and flood pulse characteristics, influenced by river management and floodplain land use. So, in both kind of approaches, objectives have to entail an array of factors.

Further we have to stress the scale-sensitivity of objectives. Different spatial scales require different target setting and actions as for example conditions of riparian corridors differ at reach or basin level.
Differences in the magnitudes and rates of many of these factors are governed by differences in discharge, channel width, channel depth and other management-related features. Scale-sensitive approaches to rivers are proposed moreover, determining functional units to the river system and the watershed management (Sear 1996). Different approaches apply to different river scales of basin, reach or site

(Stanley & Boulton 2000). In this way, we can present some materials for objective definition in this perspective of functional and structural approaches (Figure 6.2).

At the catchment scale the functional elements have much more weight in the definition of objectives than at the local scale where approaches are directed immediately at tangible structural conservation objectives.

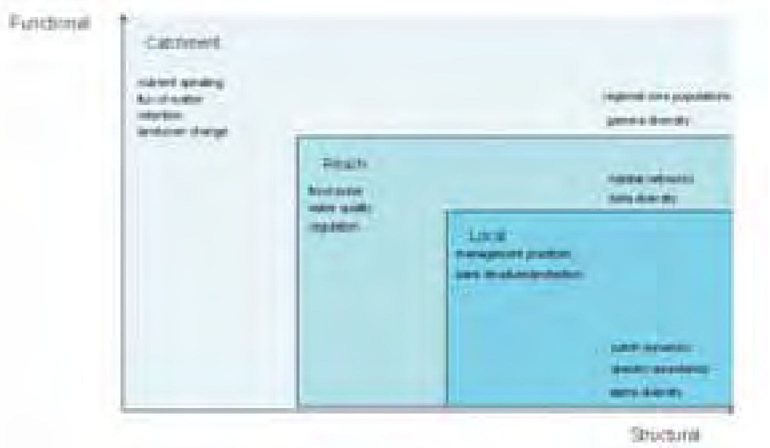

Figure 6.2 Presentation of functional and structural descriptive measures for objective definition in the watershed context.

So, conservation objectives can be defined in many ways; they can take the form of normative descriptions, qualifying conditions, units of target species or habitat. From the introduced definitions and frameworks we can derive 4 target fields for conservation and restoration, in which we can look for useful measures:

1. River corridor reservoir: the biodiversity of the fluvial system in terms of species populations and gene pools. Reviews on environmental interactions in riverine communities and river corridor species (Malanson 1993; Naiman & Décamps 1997; Naiman et al. 1999).
2. Connectivity: reviewed by Malanson 1993, Forman 1995, Gregory & Petts 1996.
3. Natural flow regime: reviews on this field and its interaction with conservation are given by Poff et al. 1997 and Growns & Growns 2001.
4. Morphodynamic equilibrium: reviews of this component by Leopold

(1994); Steiger et al. (2005) review the hydrogeomorphic processes of unconfined alluvial channel-floodplain rivers within the temperate zone, and Hughes ea (2001) its relation to riparian biodiversity.

Within these target fields of the river ecosystem conservation and restoration context, we can screen what kind of measures and approaches exist in objective definition (Table 6.1).

**Table 6.1 Published data on conservation approaches within the four target fields for rivers/catchments:**

| Target field | Approach | Quantified objective parameter/measure | Data dimension | Reference |
|---|---|---|---|---|
| Reservoir | Watershed analysis of habitat objectives | Fish habitat in Large woody debris, pool frequency, stream temperature, aquatic insects | Siuslaw River, USA | Kershner 1997 |
| | River health concept, with multimetric Index of Biotic Integrity | Bentic invertebrates and fish taxa, diversity | Kissimmee River, USA | Karr 1999 |
| | Biological modelling Salmon populations | Water temperature | Grande Ronde basin, USA | Watanabe et al 2005 |
| | Functional-geographical approach | Riverine pasture community patches | River Dinkel reach, NL | Wolfert et al. 2002 |
| Connectivity | Riparian corridor function | Seed input Northern and | River networks, Garonne rivers | Nilsson ea 1989,<br>Tabacchi ea 1996 |
| | Incidence function metapopulation model | Spatial population dynamics | Drainage basin, USA | Lowe 2002 |
| | Network Dynamics hypothesis | Channel networks structuring riverine habitats/communities | River basins, USA | Benda ea 2004 |
| | Patch dynamics concept and habitat templet theory | Habitat templets /patches | Small rivers, GB | Townsend ea 1997 |
| | Hydrologic connectivity | Material and organism transport | Reach Donau, Austria | Ward ea 1999b<br>Piégay 2000 |
| | River habitat networks approach Econet | Species habitat networks, dispersal capacities | River Rhine, NL | Reijnen ea 2001 |
| Flow regime | Natural flow regime | Magnitude and frequency, timing, duration and rate of change | River systems | Poff et al 1999 |

| Target field | Approach | Quantified objective parameter/measure | Data dimension | Reference |
|---|---|---|---|---|
| Geomorphology | Range of Variability Approach | Peak magnitude and timing | River reaches, USA | Richter ea 1997 |
| | Instream Flow Incremental Methodology | Depth, velocity and substrate varying with discharge | River reaches, USA | Bovee & Milhous 1978 |
| | Streamflow model | Flood duration | Colorado River reach, USA | Auble ea 1994, Shafroth ea 2002 |
| | Physical Habitat Simulation System (Phabsim) | Physical variables | Rivers | Bovée 1982 |
| | Habitat and species assemblages | Bank profile and structure | Reach | Armitage et al 2001 |
| | Hydrogeomorphic (HGM) method | Functional Capacity Index for physical/ biotic variables | watershed | Whigham et al 2003 |
| | River Styles | Geomorphic features, framework | Rivers/catchments channel form | Brierley & Fryirs 2000 |
| | Measures of physical diversity | Thalweg, cross-section, variability of sediment size | Reach, Creightons Creek, Australia | Bartley & Rutherfurd 2005 |
| | Reversibility and readjustment of channelized rivers | Specific streampower | Smaller rivers of Denmark and Great-Britain | Brookes 1988 |
| | Stream stabilization | Sediment supply | catchment | Sear 1996 |
| | Erodible Corridor Concept | Dynamic river corridor | Reach, Ain, Marne: France, Po: Italy | Piégay ea 2005 |
| | Riverine Ecosystem Synthesis | Functional Process Zones | River networks | Thorp ea 2006 |

## Where do problems arise and do most approaches fail in the definition of objectives?

Ideally the definition of biodiversity conservation objectives should include information on a variety of different taxa and be carried out at different scales and in different landscape ecological units, as biodiversity patterns are scale-sensitive (Wiens 1989). Nevertheless for many river projects objectives are formulated monospecific (e.g. for Salmonids), mostly leading to unsatisfactory results, as measures are ineffective or conflicting to other formulated objectives (Frissell and Nawa 1992). The pressure of timeframes, tangible results, and political interests has lead to a preponderance of short-term, transitory rehabili-

tation projects that ignore the underlying capacities and developmental histories of the systems under consideration, and seldom place the treatment reach in its catchment context (Ebersole et al. 1997, Lake 2001, Bernhardt et al. 2005). Restoration efforts typically have been directed at the site level, yet suffered from a lack of ecological understanding of watershed processes at the ecosystem level and have sometimes done more harm than good (Frissell et al. 1993; Doppelt et al. 1993).
Besides these failures caused by restricted investment in dimension and scale of the projects, some general points of concern for most approaches can be raised. Firstly, most approaches aim at deriving overall solutions and generally applicable principles. Especially in the context of regional typologies and legislative contexts, objectives are defined and solutions proposed as more generally applicable, for groups of rivers rather than river-specific.
The complexity of river functioning and the heterogeneous nature of stream and riparian conditions enlarges the risk of failure as specific conditions demand specific solutions and cumulative or threshold effects can occur. Cumulative effects of restoration practices arise when impacts accumulate and generate unwanted effects. Threshold effects refer to the responses of biological elements to restoration activities, which are often nonlinear relationships. For this reason, geographical or historical references do not offer target images and measures that can simply be transferred to actual conditions of a site to be restored. The scale-sensitivity, complexity and idiosyncrasy of the river system's functioning and processes, hampers these generalizing approaches.

Second critical aspect arises in the translation of the approaches towards objective definition for the biotic system. Mostly specific species groups or single target species are focussed in this exercise of deriving quantitative measures and objectives. The resulting measures often comprise species abundances and numbers, habitat suitability indices, species groups metric indices that are integrated in objectives for habitats. Best examples are conservation plans for fish species or species groups' spawning or breeding sites. Discussion between species-based and processes-based approaches is not new, but with respect to the complexity of the river system and its community patterns and processes, the process-based approaches offer the best perspective to our opinion.

## The River Disorder Approach

Referring to the conceptual approaches, Statzner & Higler (1985) already pointed at a first aspect of disorder in the river system with the hydrologic discontinuities in the river resulting in changes in aquatic communities. We observed discontinuities in floodplain meadow communities along the river in relation to adjacent ecoregions and the configuration of different ecoregions in the catchment (Van Looy et al. In press).

These observations lie at the basis of the definition of the River Disorder Approach, that we present here as a scale-sensitive approach to the definition of conservation objectives. The River Disorder Approach points at the ability of the river system to adopt the variability of geology, landform and climatic conditions in the catchment to its appearance and identity over its course, expressed in discontinuous patterns along longitudinal and lateral dimensions and in ecological patterns of diversity and structure in its biological and physical component. It is not just another aspect of disturbance in the river system we point at, but more the integration of influences of disturbance/perturbation/landscape origin operating in the river system, leading to the characteristic heterogeneity in the river system (Table 6.2).

**Table 6.2 Discontinuities and heterogeneity can be determined in the fields of hydrology, geomorphology, biogeography and biotic processes.**

| Disorder field | Natural disorder element | Anthropogenic disorder element |
|---|---|---|
| Hydrology | Confluence<br>Extreme peak event<br>Tidal impact<br>Peak velocity | Weirs<br>Water abstraction to canals<br>Hydropeaking |
| Geomorphology | Geologic discontinuity<br>Slope<br>Bank (in)stability | Gravel/sand extractions<br>Normalisation/regulation<br>Embankment |
| Biotic reservoir | Ephemeral habitats<br>Disturbance strategies<br>Stochastic assembly | Species eradication<br>Introductions |
| Biogeography / Connectivity | Ecoregion contact<br>River corridor discontinuity<br>Extinction-colonization dynamics | River corridor fragmentation<br>Isolation of floodplain area<br>Creation of new migration pathways (canals) |

The River Disorder Approach points at a crucial aspect of river ecology in the light of defining objectives for conservation and restoration; notably the natural dynamics and discontinuities in space and time as sources of heterogeneity at the different scale levels, present in geomorphic, hydrologic, geographic and biologic context. Several authors documented on the unpredictable character of the river heterogeneity, at different scales (Pollock et al. 1998) or under different regional settings (Sabo et al. 2005), and the relevance for conservation and restoration options.

The river system is an ever changing environment driven by different scale disturbances or disorder elements and a biotic system that shows a strong complexity in local ecological patterns across various temporal and spatial scales. Figure 6.3 presents these river disorder elements in their spatial and temporal scale of impact.

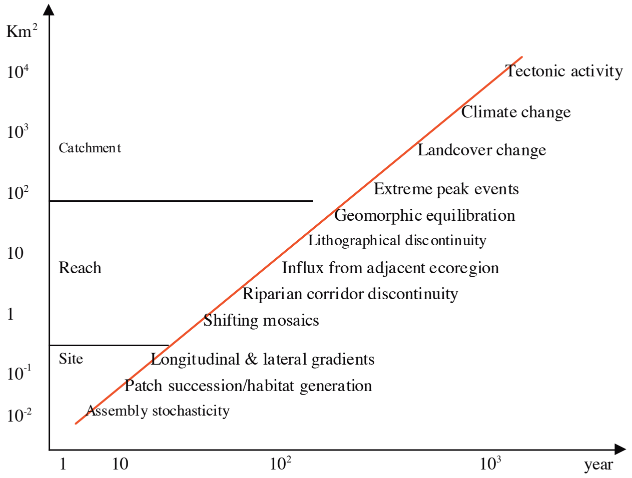

Figure 6.3 The river disorder elements in their spatial and temporal scales.

Salo (1990) presented a similar graph arranging in this spatiotemporal scale the fluvial geomorphic processes and their tentative biotic correlatives. He stressed the equilibrium responses of successions, life history strategies and biological differentiation, yet also gave some ideas of instability and discontinuous responses, like channel migration, extreme floods and fluvial dynamics creating patches varying from <1m? to tens of thousands of square kilometres. Shugart (1990) in the same book stressed non-equilibrium responses as crucial factor in river systems. He referred to discontinuities generated in nature in non-equilibrium systems.

The disorder elements at regional scale are often proposed as classification elements for river systems. The most widespread are (hydro)ecoregion delineations, integrating data of hydrogeology together with valley forms (Wasson 1992; Petit 2002). Reaches determining elements are defined in geomorphic and geographic characteristics of substrate, valley form and slope (Frissel et al.1986; Rosgen 1994; Sear 1996; Ebersole et al. 1997; Myers & Swanson 1997; Cohen et al. 1998). These typologies are useful in explaining changes in riverine communities. Schumm (2005) goes further in this reach scale analysis and reviews 36 elements destabilizing the geomorphic equilibrium of particular reaches as causes for incision for river beds. Within these causes, he included not only perturbations and disturbances to the river bed conditions but also natural fluctuations and even biotic processes impacting the physical system. So, in fact he determined an array of disorder elements of geologic, geomorphic, climatic, hydrologic, biotic and anthropogenic origin.

We identified some additional disorder elements at different scale levels (Figure 6.4); regional climatic differences over subcatchments, the connectivity and patch dynamics of the river corridor and the contact with the uplands and adjacent ecoregions causing discontinuities in the biotic system,.

In Figure 6.4, the cumulating of disorder elements in the river basin is illustrated, from the different geographical and regional climatic character of subcatchments, to the impact of the biogeographic regions and landscape configuration in contact/connection with the river system, and on the landscape and site level, illustrated for discontinuities in patch mosaics, habitat heterogeneity and community assembly.

The connectivity which is one of the main characteristics of the river corridor and the river-floodplain system, can show discontinuities and disorder in space and in time, due to anthropogenic as well as natural disturbances/alterations. The shifting mosaics of the river system (Naiman et al. 1988) can be seen as the result of two contrasting tendencies, towards homogeneity and heterogeneity, according to Pinay et al. (1990). He describes discontinuities of different origin in the ecotone conceptual approach; discontinuities at confluences as result of the complexity of the hydrographic network, or changes due to alterations of slope, reflected in changes or mixing of communities. He also depicted the non-equilibrium aspects of the river system in this ecotone approach.

Same counts for Thorp et al. (2006) who describe riverine ecosystems as nested, discontinuous hierarchies of patch mosaics, dominated by non-equilibrial and stochastic processes. These authors see these processes responsible for the formation of a quasi-equilibrial, metastable state of rivers, portrayed as downstream arrays of large hydrogeomorphic patches (e.g. constricted, braided and floodplain channel areas) formed by catchment geomorphology and climate. So, with this notion of quasi-equilibrium, they try to derive rules/generalizations for the patch mosaics.

The disorder concept depicts the riverine ecosystem as a complex, discontinuous system displaying structures that reflect the influence of the river basin constellation of georegions, hydroregions and bioregions and the processes determining fluxes of matter and species.

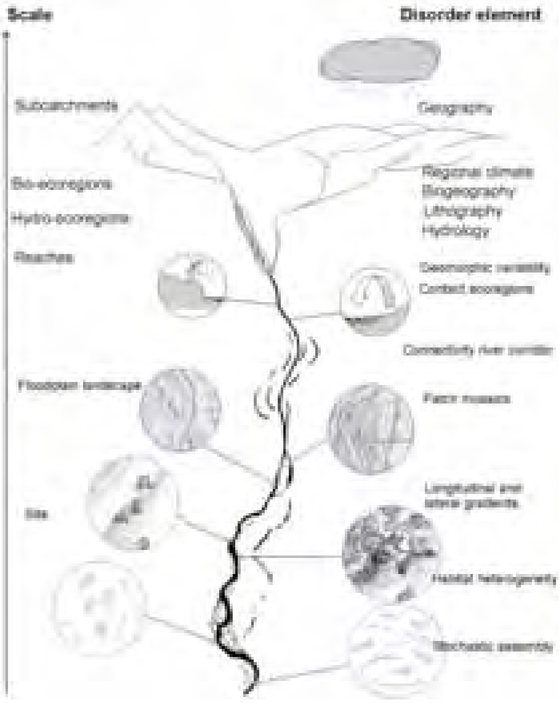

**Figure 6.4 Disorder elements in the river basin. The inset figures illustrate the discontinuity at the different scale levels caused by the specific disorder elements. The map insets are taken from single maps of reaches, with same legends for exactly adjacent sectors/stretches.**

These disorder elements can be tailored towards the definition of conservation objectives at the three scale-levels of the river system, here illustrated for the River Meuse.

## A multiscale approach

The River Disorder Approach looks for distinguishing features at different scale levels, explaining habitat heterogeneity and biotic diversity of the river system. Key factors contributing to the river's disorder character are flow regime related disturbances and gradients, geomorphic variety and morphodynamics, connectivity in longitudinal sense but also laterally with adjacent landscapes and ecoregions, and biotic reservoirs in their specific relation with the environment. In contrast to the commonly used species-based approaches to the definition of conservation objectives, it is a processes oriented approach.

In a first step (Table 6.3) the river basin is screened for sources of variety, rather than searching unifying elements as is done in most conceptual river frameworks - looking for the unifying principles in and between rivers. The disorder is detected between reaches, with the distinction of geomorphic, hydrological and biogeographic entities at catchment level. Differences in communities and gamma diversity can be attributed to disturbance regime, changes in environmental conditions and influx from adjacent ecoregions.

Table 6.3 Description of steps in the River Disorder Approach.

| Step 1. River basin level | Step 2. Reach level | Step 3. Local level |
|---|---|---|
| Discontinuities in geomorphology delineate | Beta-diversity analysis determines steering processes<br>reaches | Alpha diversity of patches and species environment relationships are determined |
| Gamma-diversity and dissimilarity analysis reveals key factors | Longitudinal and lateral gradients and heterogeneity results | System processes and management practices in habitat conditions |
| Driving variables are derived from geomorphic, biogeographic or anthropogenic origin. | Gradients can be of natural as well as anthropogenic origin. | Biologic integrity for species groups/communities with emphasis on stochastic and non-equilibrium conditions and compositions. |

The River Meuse, one of the larger rivers of the European Western Plains ecoregion, can be divided into 6 reaches based on geomorphic and hydrological characteristics (Figure 6.5). The two free-flowing reaches of the Lorraine Meuse and Common Meuse both have wide alluvial plains, whereas the other reaches are all regulated narrow floodplain-river systems.
The river's rain-fed character with torrent peak flows and a flow rate ranging from 30 to 3000 $m^3/s$, causes the riparian corridor to be highly impacted by the unpredictable hydrologic regime and catastrophic events.

Discontinuities and disorder in the catchment were revealed in the composition of floodplain meadow vegetation. In its middle course a high complexity of ecoregions and tributary confluences is present. In figure 6.4, the arrows for ecoregion contact indicate the influxes of species from distinct ecoregions in the catchment, as was observed in our data (Figure 6.6). The high disorder in the middle reaches of the river was determined in physical as well as biotic aspects of diversity (Figure 6.7, 6.8). The dissimilarities (Figure 6.9) in the floodplain meadow communities between the reaches shows high resemblance between the outer reaches I and VI, whereas for reaches I and III the highest overall dissimilarity with other reaches is present.
From the analysis of disorder in terms of geomorphic and hydrologic changes, ecoregion input and important biotic reservoirs, objectives and guidelines for conservation and restoration approaches can evolve. For reaches (like the Common Meuse) with high disorder, emphasis in conservation must be on promoting natural disturbance processes and influx of species from the surroundings. For the low disorder reaches of the Lorraine and Tidal Meuse, floodplain rehabilitation can be designed more isolated from the surroundings or the upstream/downstream influences.

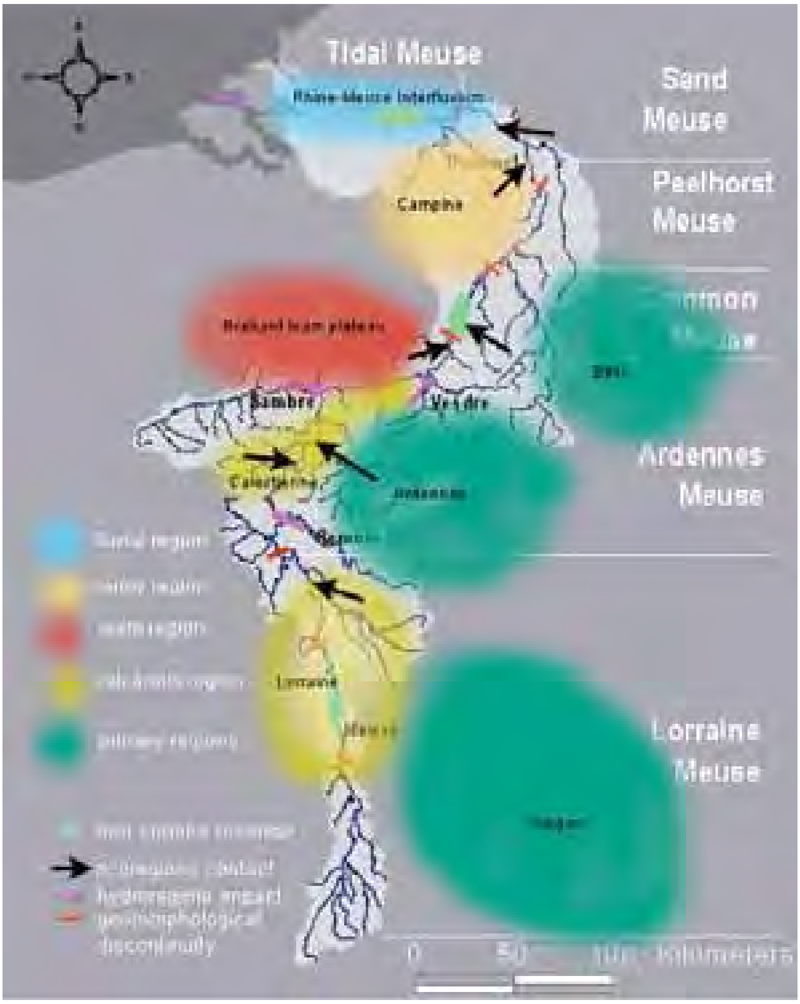

Figure 6.5 Map of the River Meuse basin with indication for the main disorder contributions at catchment's scale of the 4 components of disorder: flow regime, geomorphology, biotic reservoirs en connectivity.

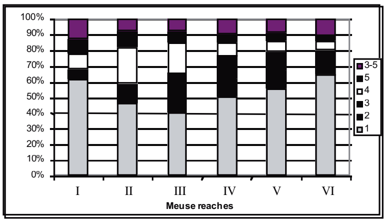

Figure 6.6 Species ecoregion partitions of the plots of the Meuse reaches (1: fluvial region, 2: sandy region,3: loam region, 4: calcareous region, 5: primary region

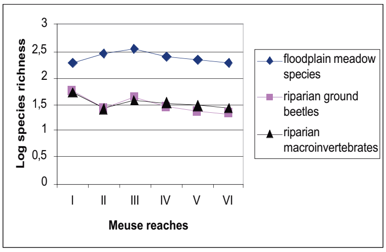

Figure 6.7 Species richness in Meuse surveys of different groups over the reaches. For floodplain vegetation, the species richness peaks in the middle reach, for the aquatic and semi-aquatic organisms, the unregulated upstream reach shows the highest species richness, still there is also in these groups a strong recovery in species richness in the middle reach.

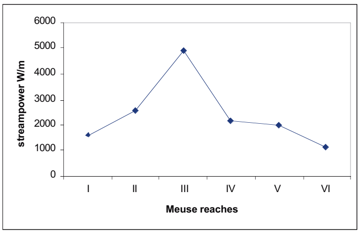

Figure 6.8 The stream power in the different Meuse reaches.

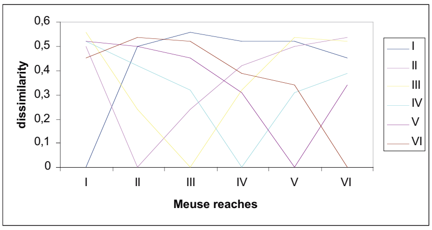

Figure 6.9 Coenocline dissimilarity projections of qualitative similarity along the river.

After the screening at basin level, and the delineation of reaches, in a second step the diversity within reaches is focussed. The reach scale disorder is governed by the stochasticity of flood events with strong shifts of energy, material and populations in time and place. The disorder in hydroregime and morphodynamic conditions is reflected in composition and diversity of communities in the river system in lateral and longitudinal gradients and patch mosaics.
These aspects were determined for the floodplain meadows in the population dynamics strategies (following Freckleton & Watkinson 2002) of the species at risk in these communities, the rare river corridor plant species (rare = less than 5 populations in the study area). Emphasis was on the dry river grassland communities, the main protected habitat in the NATURA2000 network for this area. Strong lateral gradients were documented for the floodplain meadows over the Common Meuse alluvial plain. Disorder was present in isolation caused by riverbed incision and dike construction that disconnect parts of the alluvial plain from river influence. The population dynamic strategies for the rare river corridor species are mostly remnant, patchy and metapopulation strategists (Table 6.4); typical strategies for species at risk. The colonisation index and extinction risks per population strategy group show the disorder elements at this scale level. The disorder is most tangible in the groups of remnant and metapopulation strategies, showing low colonization, linked to the disconnection and isolation from the river flooding. The colonization index differs strongly from more stable population strategies, indicating the determining role of seed dispersal in plant metapopulations undergoing recurrent local extinctions and colonization (Tilman 1985). Further it is important to distinguish populations with low extinction probabilities from populations with high extinction probabilities in the light of conservation and restoration options.
We revealed the necessity of dynamics for the conservation of these species, as we observed that dynamic habitats, with species in more dynamic strategies, show highest potential to recruitment and restoration in general. Furthermore, with respect to the catchment scale analysis, we observed influx from adjacent ecoregions to be highest for reaches with high disorder character (highest variability in hydrologic and morphologic conditions), mainly for the use of various population dynamic strategies.

**Table 6.4 Colonization rate and extinction risk of rare river corridor plants within the population dynamic strategies of Freckleton & Watkinson (2002).**

| Strategy | Remnant | Patchy | Meta-population | Source sink | Shifting cloud |
|---|---|---|---|---|---|
| share of species (%) | 24 | 55 | 16 | 2 | 4 |
| colonization index | 1.31 | 4.1 | 1.38 | 4 | 6 |
| extinction risk | 10 | 28 | 42 | 50 | 70 |

Colonization index is an observed recruitment rate (group average of colonised patches/species/peak) for the rare river corridor plant species within the Common Meuse floodplain survey. Extinction risk is the probability of disappearance, measured in the percentage of highly dynamic sites for a species (averaged for each population strategy group).

Floods and hydrodynamics are not only responsible for a lateral gradient in community composition, they were also significant parameters in determining habitat generation and succession. In this way, they are a discontinuity and disorder element, as the flood peak events prove to be a crucial element in generating habitat and in seed dispersal. So, the community composition and diversity is for its spatial and temporal pattern more explained by the infrequent large floods and only to a lesser extent by the regular flooding.

**Table 6.5 The River Disorder Approach results derived from the floodplain meadow analysis of the River Meuse.**

| Scale | Disorder element | Driver | Measure |
|---|---|---|---|
| Catchment | Discontinuity in community composition | Ecoregion influx and river dynamics | Stream power and adjacent ecoregions contact |
| Reach | Discontinuity in patch mosaics, in riparian corridor connectivity and in species strategies | Infrequent large floods | Flood power and floodplain gradient/ alterations |
| Site | Stochastic assembly and site idiosyncrasy | Extreme local heterogeneity and unique conditions in space and time | Habitat heterogeneity and species diversity |

In step 3, this analysis is taken up to the level of patches' alpha diversity and local habitat conditions. At this level, the disorder can be determined for specific communities or species groups. The most important factor sustaining high biodiversity at the local level, is habitat heterogeneity (Rosenzweig 1995). This was revealed in the diversity analysis of the floodplain meadows emphasizing on the presence of rare river corridor species. The exceptional high slope of the species-area relationship (highest species richness corresponds to small patch size) shows the effects of habitat heterogeneity and fragmentation of habitat in the Common Meuse floodplain. This is illustrated for the individual patch richness in Figure 6.10 with the indication of the relicts rich in rare species. The smallest patches are the richest in rare species, and even generally most species-rich. This illustrates the stochastic character of community assembly in the riverine landscape. No stable structure or dependence on local environmental conditions for communities were observed, no pattern of saturation or equal distribution for patches in different states was present. We can conclude that the specific context of disturbances and landscape features is responsible for the erratic/stochastic distribution patterns of habitat patches and species, and thus for the non-equilibrium conditions for communities in the riparian corridor.
As we observed riverine communities to be loosely structured and not saturation-oriented, and as larger patches in river systems tend to be poorer in species diversity, maximizing heterogeneity is a good option for biodiversity conservation in the river system.

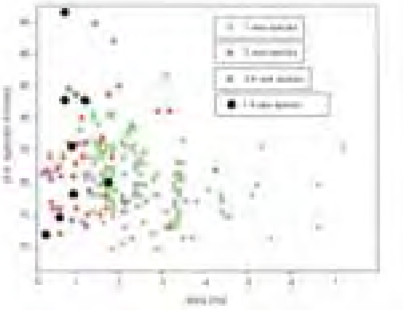

**Figure 6.10 The species richness-area relationship for the individual plots of the Common Meuse floodplain meadows. The graph shows that the smallest patches are the richest in rare species, and even generally most species-rich. This is a proof of the extreme habitat heterogeneity in the river system.**

Bringing about this concept; a multidimensional approach in generating conservation objectives

These observed disorder elements, determined for the most relevant physical and biotic elements, can generate tangible measures and guide conservation and restoration options.

**Figure 6.11 Observed disorder elements for the River Meuse at the different scale levels, along the functional and structural axis**

Figure 6.11 presents the measures we quantified for the River Meuse at the different scale levels, based on study of floodplain meadow vegetation (see above), riparian forest (Van Looy et al. 2003, Van Looy et al. 2005a) and riparian ground beetles (Van Looy et al. 2005b).

With this analysis, the River Disorder Approach can be seen as a multiscale and multidimensional approach for defining conservation objectives and prioritizing river restoration strategies. The early establishment of a ‘guiding image’ with a dynamical ecological end state is seen as the most critical aspect of river restoration projects (Giller 2005). This guiding image must specify how (i) the system works, (ii) it has been impaired (i.e. the key stressors and how they impact on ecosystem health), and (iii) the intended restoration alleviates or reverses the key stressors (Jansson ea 2005). The defined conservation objectives have to be translated in comprehensive forms for decision frameworks and managerial plans. A set of key ecological factors at reach and local level identified in the River Disorder Approach, with tangible measures and model application, can be used to make a guiding image of the restoration project. For the Common Meuse, the following factors were selected, based on identified responses in specific communities: flood frequency, peak velocity, flooding power, habitat fragmentation and the need for

sediment supply (eroding banks). The relationships between composition and diversity of these groups and the physical variables were quantified with general linear regressions and thresholds were determined for the disorder elements. In this way quantitative measures were generated.
The guiding image (Figure 6.12) shows for a Common Meuse stretch all the criteria for restoration in a way that is comprehensible for river managers and other possible stakeholders.

Figure 6.12 Guiding image for the Common Meuse restoration project. It shows the different disorder components starting from the geomorphic near-equilibrium conditions in the historic situation, over the biotic reservoir in habitat and species relicts, the connectivity in flood channels and riparian forest corridor on to the flooding regime in sedimentation zones. All these key factors were integrated in the restoration objectives, defined in preservation of relicts, connection of natural areas in the riparian corridor, provision of eroding banks and lowering of banks to allow flooding and the development of riparian forest.

# 5. Discussion

## 5.1 Approach

Stochastic processes and non-equilibrium conditions in both the physical and biotic compartment of the river system are at the basis of the disorder concept. Shugart (2005) describes the scale-aspects of disturbance and landscape with respect to equilibrium conditions as follows; quasi-equilibrium landscapes are much larger than the disturbances that drive them, and show a relatively constant proportion of patches in a given successional state. Landscapes influenced by a disturbance regime whose spatial scale extent is so large that it could be termed a catastrophe, or  landscapes whose dynamics and proportion of patches in differing states are subject to chance variation, are non-equilibrium landscapes. In this respect, he documented the large rivers as effective non-equilibrium landscapes, based on the relation between spatial extent of floodplain forests and the spatial extent of floods (Shugart 2005). Wiens (1984) proposed for biotic communities a gradient from equilibrium to non-equilibrium in the following characteristics: saturation, competition, stable or loose structure and stochasticity of disturbances. Looking at the community level, we observed several causes for disorder and non-equilibrium in composition and diversity of communities. Where saturation and the striving for equilibrium are the classical foundations for community ecology, we observed mostly unstable and non-saturated assemblies. Most determining for community composition proved recruitment and dispersal limitation, extinction by fluvial or anthropogenic disturbance and responses to the changing physical conditions by resilience or disturbance strategies.

Fitter et al. (1999) point at temporal variations leading to disequilibria at a point in space and to the possibility of coexistence of species which could not coexist if competition was allowed to proceed. We think most species assemblies in river systems can be categorized as non-equilibrium communities. Strong indications were documented for: 1) aquatic macroinvertebrate assemblies, for which strong disorder is observed in the Meuse in frequent consecutive invasions of exotic species last decades (bij de Vaate et al. 2002); 2) riparian ground beetle assemblies responding to extreme local heterogeneity in flow dynamics (Van Looy et al. 2005b); 3) floodplain meadow vegetation for which the species-area relationship and the need for stochastic processes/extreme flood dynamics observed for the

rare river corridor species, proves the opposing trend to saturation. So, these non-equilibrium communities are loosely structured assemblies with species more responding to environmental variations largely independent of one another (Wiens 1984). Especially the major contribution of stochastic events (extreme peak flows) to species dispersal and colonization/extinction, proves determining for observed diversity and composition patterns. As the persistence of small populations is strongly affected by stochastic problems (Foose et al. 1995), our analysis of the population dynamic strategies of the rare river corridor species highlighted the threats for the characteristic river species of the Meuse. Many riverine species only persist as metapopulations in the fragmented habitats and it may therefore be insufficient to protect small areas along a river to save its riparian communities (Andersen & Hanssen 2005).
Conservation efforts should neither be oriented in preserving and maintaining local conditions and communities, as these are part of the ever-changing riverine landscape. Objectives should be tailored towards the non-equilibrium conditions and the driving forces behind them. In this way, we think that this disorder approach highlights crucial aspects of riverine communities and provide useful frameworks for the definition of conservation objectives for river restoration and conservation programmes.

### 5.2 Application

Two key concepts drive the River Disorder Approach: the non-equilibrium and the idiosyncrasy of the river and its (biotic) components at the different scale levels. This implies that no deterministic approach can be followed to derive objectives, and that for each river/reach/site specific objectives are needed. To prove the merits of the River Disorder Approach, we discuss the outcome of classical approaches to the River Meuse's natural resources (Table 6.6).

Generalized (nationally derived) objectives for protected habitats or river-types
Conservation objectives derived for the protected habitats and species for the Common Meuse reach, the 50km border reach between Flanders and the Netherlands, result in mitigation measures trying to stop further alterations in physical conditions and deterioration by habitat loss. With the dry river grasslands as main protected habitat, no restoration efforts to the riverbanks and

the contact between river and floodplain would be envisaged, as these might alter present assumed-critical habitat conditions. So, here a conflict might arise.

On the Dutch side of the same Common Meuse stretch, a large river restoration programme was initiated (Van Leussen et al. 2000). This project starts from a specific reference situation as target (more conform to the WFD objective definition). A uniform set of measures will be reproduced all over the reach; the riverbed will be widened and banks lowered over the whole river reach.. The following aspects of our River Disorder Approach, presented in the guiding image, are not envisaged with this project approach: 1) Local relicts of dry river grasslands are not regarded, 2) eroding banks to supply the river with sediment for the restoration of morphological processes are not integrated, 3) parts of the floodplain will be disconnected from regular flooding and 4) riparian forest restoration will not be allowed as this is seen as a threat for the flood protection objectives of the project.
Some crucial elements and measures of our approach, as presented in the guiding image, are overlooked or underrated in both the 'classical' conservation and restoration approaches.

### Species-based approaches to objective definition

For the protected habitat of the dry river grasslands and the threatened river corridor species, several authors argument the necessity of protecting existing populations outside the river's influence (Jongman 1992; Hegland et al. 2001; Vervuren et al. 2003; Eck et al., 2005) and reintroducing species and habitat in an artificial way (Stroh et al. 2005). Yet, we found evidence for their need for river contact and river dynamics. We did not determine the dispersal limitation but the recruitment limitation to be the major threat, as we observed a strong ability to colonize newly generated patches (Van Looy & Meire in Prep).
The same conclusion counts for the protected fish species, present in disconnected river arms. Here is discussion to the reconnection of this habitat to the river, as contact with the river might favour predator species. Yet, their extinction probability is extremely high in this isolated habitat. So, with regard to the natural disorder character of the habitat, we argue that a natural flood contact with the river might favour the population survival in the long run.

Table 6.6 Comparison of approaches and measures in the classical approaches and the River Disorder Approach to conservation and restoration of river systems.

| **Classical approaches** | **River Disorder Approach** |
|---|---|
| APPROACHES | |
| • equilibrium oriented | • non-equilibrium oriented |
| • uniform, general rules | • idiosyncrasy oriented |
| • deterministic approach | • freedom for stochastic character |
| *Strict conservation approach* | *Disorder conservation approach* |
| • disturbance mitigation | • dynamics rehabilitation |
| • species and habitat preservation | • dynamic community/habitat approach |
| • habitat restoration | • process restoration |
| *Classic restoration approach* | *Disorder restoration approach* |
| • reference/'Leitbild' oriented | • disorder features oriented |
| • continuity oriented | • discontinuity oriented |
| • single species- or habitat-based approach | • complexity based approach |
| • one-dimensional approach | • multidimensional approach |
| MEASURES | |
| • relict preservation, e.g. isolated patches | • restoring contacts |
| • preserving species, e.g. restocking fish | • preserving populations in their spatial and temporal context |
| • managing up to community level, e.g. hayfield restoration | • free community assembly, result of dynamic conditions in space and time |
| • preserving actual habitat conditions, e.g. fish in stagnant cut-off branches | • rehabilitating dynamics, maximizing connectivity |
| • uniform bank lowering | • locally preserving erodible banks |
| • putting back forest development for reasons of flow resistance | • leaving it up to the river to maintain its flow section |
| • restricting hydropeaking by limiting hydropower production | • remediating hydropeaks by bed widening that dampens peak velocity |

Possible win-win situations with the River Disorder Approach immediately come to light in Table 6.6. The merits of the River Disorder Approach lie in the combined effects of the multidimensionality and multiscale analysis of problems and key factors. From the level of discontinuities at river basin level onto local rules of assemblies, the identified disorder elements provided strong insights in key factors and communities to the detection of measures and the definition of objectives, as they play a major role to biodiversity in its functional and structural organisation of communities.

### 5.3 Gaps and constraints for effective river restoration programmes; problems in definition of objectives for non-equilibrium and river-specific conditions

It is difficult to effectively manage non-equilibrium landscapes toward a goal of constancy because they are regularly disequilibriated by disturbance events (Shugart 2005). Nevertheless this type of goals is present in the pan-European legislative contexts of the Habitats and the Water Framework Directives. Although these legislations tried to integrate a sense of dynamics; this still conforms to quasi-equilibrium conditions of constant proportions of patches and more or less stable structures of communities. Furthermore, every river, every reach has its identity, posing critical questions for designers and managers (Pedroli et al. 2002; Décamps 2005). This idiosyncrasy is hard to handle in legislative frameworks that cover different countries or entire continents.

So, the European legislative frameworks show the same risks of failure as the presented concepts and approaches in the perspective of river restoration. The comparison of applications for both a Water (WFD) or Habitats directive (NATURA2000) proof approach for the Common Meuse (par. 5.1), showed the shortcomings of both deterministic approaches  and the merits for the proposed River Disorder Approach.

For the Meuse basin, the NATURA2000 network of protected areas under the Habitats directive comprises large parts of floodplains in the upstream reach and less in the middle course, in the lower course large parts of the estuary and the aquatic system are protected. The Habitats Directive implementation is mainly strictly preservation oriented. The protection can even come to hamper river restoration projects, as these should be oriented to a dynamic habitat approach. For the Water Framework Directive, as a result of a centralised organisation, no river-specific approach is possible and for all types of rivers the same (kind of) options and objectives will result from the pressures and impact analyses. For both legislations, generalized approaches to define conservation objectives and favourable status are applied to/over larger geographical regions (countries), leaving less freedom to analyse the habitat or species in its regional setting. Especially for river systems, this context of spatial and temporal coherence, as was described in terms of appearance and character of the river (Pedroli ea 2002), is essential and works over larger regional scales than those addressed in the habitat and species conservation approaches.

For our Meuse example, as the NATURA2000 and WFD guidance documents do not mention terrestrial riparian fauna, riparian forests, river corridor plants or sediment deposition habitat, these elements are overlooked in the present exercises for the WFD implementation and in the development of management plans. We believe the here presented River Disorder Approach for river restoration adds important elements for successful restoration and conservation attempts.

## General conclusion

Goal setting for conservation and restoration efforts in river systems mostly starts from the assumed presence of equilibrium or quasi-equilibrium conditions that can guide the planning and measures. We believe that the dominance of non-equilibrial and stochastic processes in riverine landscapes demands a non-deterministic, idiosyncratic approach, that we proposed in a conceptual model for river restoration, named the River Disorder Approach.

The non-equilibrium state together with the uniqueness and idiosyncracy of riverine landscape processes, patch mosaics and community assembly within the river discontinuum, were illustrated for the River Meuse with emphasis on the floodplain meadow communities. We highlighted what knowledge of disorder elements and non-equilibrium conditions can add to develop good conservation strategies and define clear objectives at the same time.

New aspects to the existing concepts on variability and discontinuity in the river system in the River Disorder Approach are 1) the cumulating of disorder elements in spatial and temporal context, indicating that no equilibrium can be sustained and 2) some newly observed sources of variability in river ecosystems, especially in lateral relations to the river.

As we observed riverine communities to be typically in a non-equilibrium state, objectives and strategies for conservation need to be dynamic. Benchmark projects disregarding stochastic processes and site-, region- and catchment-specific potentials and constraints risk failure. The highlighting of discontinuous patch mosaics and non-equilibrium community structures also contrasts to traditional conservationist approaches. We can conclude that this identified non-deterministic, idiosyncratic character of riverine processes and communities poses problems for many generalizing approaches and legislations and demands adopted approaches to the defining and prioritizing of conservation objectives and restoration strategies.

Conclusion for strategies and policies is that a non-deterministic approach for objective formulation is needed, treating each patch, each part of a river system as a unique feature. The River Disorder Approach integrates these aspects in a multiscale, multidimensional approach.