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FROM THE MYTH OF A LOST PARADISE TO TARGETED RIVER RESTORATION: FORGET NATURAL REFERENCES AND FOCUS ON HUMAN BENEFITS

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ABSTRACT

In the last two decades river restoration has become increasingly a field of research asking a series of complex questions related not just to science but also to society. Why should we restore ecosystems? Is restoration always beneficial? When is it beneficial? What should be the target reference states? What is success and when can it be evaluated? Our objective is to chronicle and discuss the fundamental concepts of reference versus objective, state versus process-based actions, nature versus culture and ecosystem integrity versus ecosystem benefits driven restoration.

We discuss the dynamic and yet unresolved definition of a reference state. Although the desire to re-create the past is tempting, science has shown that river systems follow complex trajectories frequently making it impossible to return to a previous state. Therefore, restoration goals are moving away from explicitly defining a reference state because of the difficulty of attaining that reference state. We argue that the reference-based strategy should be progressively replaced by an objective-based strategy that reflects the practical limitations of developing sustainable landscapes and the emerging importance of accounting for human services of the target ecosystem. After a decade during which natural processes have been the focus of restoration, it appears that particular processes are not equally valuable everywhere and that regional complexity must be better understood to adjust restoration actions. Copyright © 2009 John Wiley & Sons, Ltd.

KEY WORDS: ecosystem function; human pressure; landscape trajectories; nature and culture; process-based restoration; reference functioning; reference state; Water Framework Directive

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INTRODUCTION

In the last two decades river management and restoration, as fields of applied research, have started to build on a holistic conceptual framework of the river system rather than considering a system of individual non-interacting components (see for example Schumm, 1977; Vannote *et al*., 1980; Amoros *et al*., 1987; Junk *et al*., 1989; Ward, 1989; Amoros and Petts, 1993; Brierley and Fryirs, 2005). However, some differences in objectives remain between managers and environmental scientists (Newson and Large, 2006), where managers are forced to weigh society's needs over Nature's reality, and scientists aim to understand natural processes with or without human influence. Recent scientific findings have demonstrated the importance and continuing emergence of restoration science and its application but fundamental questions still remain: Why should we restore ecosystems? When is it beneficial? What should be the target reference states? The objective of this paper is not to provide a general review or to give a general framework but to clarify the fundamental concepts of reference-based versus objective-based restoration, state versus process-based actions, nature versus culture and ecosystem integrity versus ecosystem benefit driven restoration. Although some general principles have been presented in the literature for over 20 years, some confusion remains regarding two particular aspects of restoration which require further discussion: (1) the increasingly complex definition of the reference state as new understanding of historical human pressures has been introduced and the system concept has been further developed and applied, and (2) the progressive replacement of a

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reference-based strategy by an objective-based strategy, reflecting increased understanding of the ecosystem services offered by target systems, including sustainability.

WHICH REFERENCE TO RESTORE ECOSYSTEMS?

The birth of restoration sciences and reference definitions

Restoration covers a broad range of actions that all aim to improve ecological features. Its definition has progressively changed through time, moving from ecological to wider human benefit goals (Table I).

Through the 1970s and 1980s our understanding of the negative impacts of development on ecosystems increased (Bravard *et al*., 1986; Gurnell and Petts, 1995; Gregory, 2006). Initially, the focus was on water quality, but then it moved to the broader restoration of ecosystems (Boon *et al*., 1992; Ormerod, 2004). Due to their high ecological value, fluvial corridors are a common focus of several gradual strategies to counteract the negative effects of development, including preservation, impact limitation, mitigation, restoration and dereliction, depending on the level of impact of the area from natural to degraded (Boon *et al*., 1992). Following this collective way of thinking, natural conditions have been associated with the highest level of ecological health (e.g. in the sense of the European Water Framework Directive or WFD).

Whereas in the 1980s and early 1990s, restoration was generally based on a static reference, a pre-disturbance state (Cairns, 1991), scientific discussions advanced from the mid-90s to distinguish restoration, where a pre-disturbance state can be defined, from rehabilitation, where there is a desire to move the degraded state closer to a natural state. In rehabilitation, it is accepted that the previous, pre-disturbance, state will not be achieved due to an inability to define and reconstruct the natural reference (Aronson *et al*., 1993). Moreover, investigators early recognized that since fluvial corridors are complex, continually evolving, dynamic systems, it is necessary to move from a reference state to a set of reference dynamics (Boon *et al*., 1992). The goal is not to reach a fixed pattern, but to achieve a combination of processes (such as flooding, sediment reworking, ecological succession or species migration and nutrient exchanges) that are by definition highly variable and partially unpredictable (Hughes *et al*., 2005; Thoms, 2006). During the 1990s, the need to understand ecological processes at a landscape scale led to the study of multiple systems where natural processes still operate in dynamic conditions, notably in Europe, and to use them as reference systems (Ward *et al*., 2001; Tockner *et al*., 2003). These studies highlighted the high spatial heterogeneity (Ward *et al*., 2001) and connectivity in dynamic systems (Ward and Stanford, 1995; Kondolf *et al*., 2006).

At the same time as the justification for restoring the structure and functioning of ecosystems was evolving, the concept of ecosystem goods and services was also developing (De Groot, 1987; Costanza *et al*., 1997; Daily, 1997). Combining ecological integrity and human well-being underpins the definition given by WWF/IUCN in 2000 (WWF/IUCN, 2000) and leads to the definition of reference conditions as a ‘model for planning an ecological restoration project, and later serving in the evaluation of that project’ (SER, 2004). Palmer *et al.* (2005) discuss reference conditions as a guiding image using the Leitbilt concept (Kern, 1992), which integrated ‘natural properties’, ‘irreversible changes of factors’ and ‘aspects of cultural ecology’ (Jungwirth *et al*., 2002).

A pre-industrial or pre-European settlement state is no longer a realizable reference state

The desired conditions were usually defined as a pre-major impacted state, e.g. pre-industrial or pre-European settlement state (NRC, 1992). They are natural or quasi-natural contexts reflecting relatively limited large-scale influence of human actions on the features and processes of an ecosystem. When the disturbance (i.e. human impact) is recent, it is relatively easy to determine past conditions. However, in Western Europe for example, the current fluvial landscape is a result of multiple interactions between ecosystems and societies over millennia (Bravard, 1981; Petts *et al*., 1989; Muxart *et al*., 2003; Ashton *et al*., 2006). Most of floodplains have been heavily impacted by activities such as grazing, cultivation and wood cutting and most rivers have been used for water supply (irrigation, industry, mills). As a result, the human imprint is both long-term and ubiquitous (e.g. the evolution of the riparian land use pattern along the Ardèche River in France over the last two centuries, Figure 1).

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Table I. The progressive emergence of concepts and terminology to design actions within the restoration/rehabilitation framework

Restoration, rehabilitation...	
River restoration is the process of recovery enhancement. Recovery enhancement should establish a return to an ecosystem which closely resembles unstressed surrounding areas	Gore (1985) cited by Brookes and Shields (1996)
A return 'from a disturbed or totally altered condition to a previously existing natural, or altered condition by some action of man,' but 'for restoration to occur it is not necessary that a system be returned to pristine condition'	Lewis (1990), cited by Henry and Amoros (1995)
The complete structural and functional return to a pre-disturbance state	Cairns (1991) cited by Brookes and Shields (1996)
Restoration is re-establishment of the structure and function of ecosystems. Ecological restoration is the process of returning an ecosystem as closely as possible to pre-disturbance conditions and functions. It is therefore not possible to re-create a system exactly. The restoration process re-establishes the general structure, function and dynamic but self-sustaining behaviour of the ecosystem	NRC (1992) cited by FISRWG (1998)
Restoration program should aim to create a system with a stable channel or a channel in dynamic equilibrium that supports a self sustaining and functionally diverse community assemblage	Osborne *et al*. (1993) cited by Brookes and Shields (1996)
Distinction between restoration and rehabilitation: the latter are suggested when 'thresholds of irreversibility' have been crossed in the course of ecosystem degradation, and when 'passive' restoration to a presumed pre-disturbance condition is deemed impossible	Aronson *et al*. (1993); Gore and Shields (1995)
Rehabilitation involves the recovery of ecosystem functions and processes in a degraded habitat. Rehabilitation does not necessarily re-establish the pre-disturbance condition	Dunster and Dunster (1996) cited by FISRWG (1998)
Restoration is an action to assist biotic and abiotic components or processes of an ecosystem to allow it to return to its state prior to the degrading actions	Bradshaw (1997)
Restoration is a planned process that aims to regain ecological integrity and enhance human well-being in deforested or degraded forest landscapes	WWF/IUCN (2000)
Assisting the recovery of ecological integrity in a degraded watershed system by re-establishing natural hydrologic, geomorphic and ecological processes, and replacing lost, damaged or compromised biological elements	Wohl *et al*. (2005)
Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed to repair ecosystem processes, productivity and services, as well as re-establish the pre-existing biotic integrity in terms of species composition and community structure. Restoration thus consists in correcting multiple changes in various components of the ecosystem (also called rehabilitation by Aronson *et al*., 1993)	SER (2004)
Associated notions	
Ecological engineering is 'the design of ecosystems for the benefit of humans as well as the natural environment'	Mitsch and Jørgensen (1989) in van Bohemen (2004)
The leitbild concept is a set of desirable stream properties regarding only the natural potential, not considering the economical and political aspects that influence the realization of the scheme. It is based on three elements: natural stream properties, irreversible changes of abiotic and biotic factors, aspects of cultural ecology	Kern (1992)
The so-called 'Leitbild' (i.e. a target vision) assumes a key role in river restoration and the assessment of ecological integrity in general. An 'ideal situation' is defined that relates to the natural potential of a given water course in the absence of economic or political constraints (pristine, undisturbed condition)	Jungwirth *et al.* (2002)
Environmental functions are 'the capacity of natural processes and components to provide goods and services that satisfy human needs (directly or indirectly). Human needs may be divided in two main categories: physiological needs (O2, water, food, health) and the psychological needs (opportunities for cognitive and spiritual development, recreation, safe future for both present and future generations)'	De Groot (1992) cited by van Bohemen (2004)
Ecological integrity is perceived as the 'maintenance of all internal and external processes and attributes interacting with the environment in such a way that the biotic community corresponds to the natural state of the type-specific aquatic habitat, according to the principles of self-regulation, resilience and resistance'. The current deviations of ecological integrity is evaluated from undisturbed reference conditions	Angermeier and Karr (1994), cited in Jungwirth *et al.* (2002)

(*Continues*)

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Table I. (Continued)

Ecological integrity: maintaining the diversity and quality of ecosystems, and enhancing their capacity to adapt to change and provide for the needs of future generations. Human well-being: ensuring that all people have a role in shaping decisions that affect their ability to meet their needs, safeguard their livelihoods and realize their full potential	WWF/IUCN (2000)
An environment is healthy when the supply of goods and services required by both human and non-human residents is sustained	Karr (1999) see also Norris and Thoms (1999) Bunn *et al*. (1999) Vugteveen *et al.* (2006)

The uselessness of a goal that encompassed re-establishment of an original state was recognized in the 1990s (Stanford *et al*., 1996; Palmer *et al*., 2005), although old devils are sometimes difficult to completely eradicate. For example, at the SER conference (SER, 2004) it was posited that 'the restored ecosystem will not necessarily recover its former state' yet later in the same text it is stated that 'removing dams allows the return of an historical flooding regime', ignoring the fact that an unimpaired hydrograph would almost certainly be vastly different from pre-dam conditions due to, for example, climate changes. Again, in the same paper they state that the reference condition should use 'everything that gives some information of previous conditions' (SER, 2004). Whilst this may just be a semantic debate, if we are not very careful in using words the message can become unclear. Thus the use of words such as 'recovery' can give the impression of returning to a particular previous suite of processes.

In summary, our first conclusion is that past conditions should not be used as references because no former historical state can be justified in preference to another (i.e. a more natural one), since most systems were already human influenced at all prior known states. This point is highly relevant in areas with an extended history of intense human use (e.g. Europe, Mediterranean basin), but also in areas such as North American where Native Americans could have had a large impact on the landscape prior to European settlement for example in relation to wide spread fires (e.g. Denevan, 1992; Vale, 1998; Vale, 2000; Bonnicksen, 2000 cited by Keeley, 2002). Our second conclusion is that each of us is grounded in our own culture, which inevitably influences the way we perceive the role of Nature and Culture. Even if we understand that the natural reference state is a myth, we may still dream of a lost paradise (Le Lay, 2007).

From process-based understanding to the concept of trajectory

Restorationist thinking has progressively moved from applying static reference states to process-based 'functioning' references. Indeed fluvial corridors are dynamic and evolving systems, for example channel geometry adjusts to an array of controlling factors, both on the floodplain and within the watershed, and including natural and human impacts. Processes fluctuate and, even under natural conditions, river systems move along trajectories (Hughes *et al*., 2005; Brierley and Fryirs, 2005). As environmental conditions evolve, the ecological characteristics and social benefits fluctuate. The conjunction of key drivers is continuously variable in time and space (climate, society, species pools) and the local conditions are always new. Most ecological parameters are transitory, that is landscape diversity, growth conditions and nutrient fluxes change in response to evolution of channel morphology, hydrological connectivity, species colonization and human activities (e.g. evolution of landscape diversity along the Ain River, Figure 2). Is it valuable to artificially maintain the fluvial landscape just because it may represent a stage with the best set of environmental conditions?

Each fluvial corridor follows a complex and non-linear trajectory where cycles, long-term trends and short-term fluctuations are overlaid (Figure 3). If such landscapes no longer follow a cyclic evolution, it is idealistic to consider reverting to any previous stage, pristine or not. Indeed, such a recovery most likely cannot take place because long-term changes will have occurred since the time of degradation, changes that cannot always be reversed with the implementation of restoration techniques. How can natural systems, such as those observed in California (Mount, 1995; Florsheim and Mount, 2002) or mid Atlantic streams (Walter and Merritts, 2008), which have been subjected to a range of cumulative impacts over centuries, recover to their original form? Thus, our third conclusion is that

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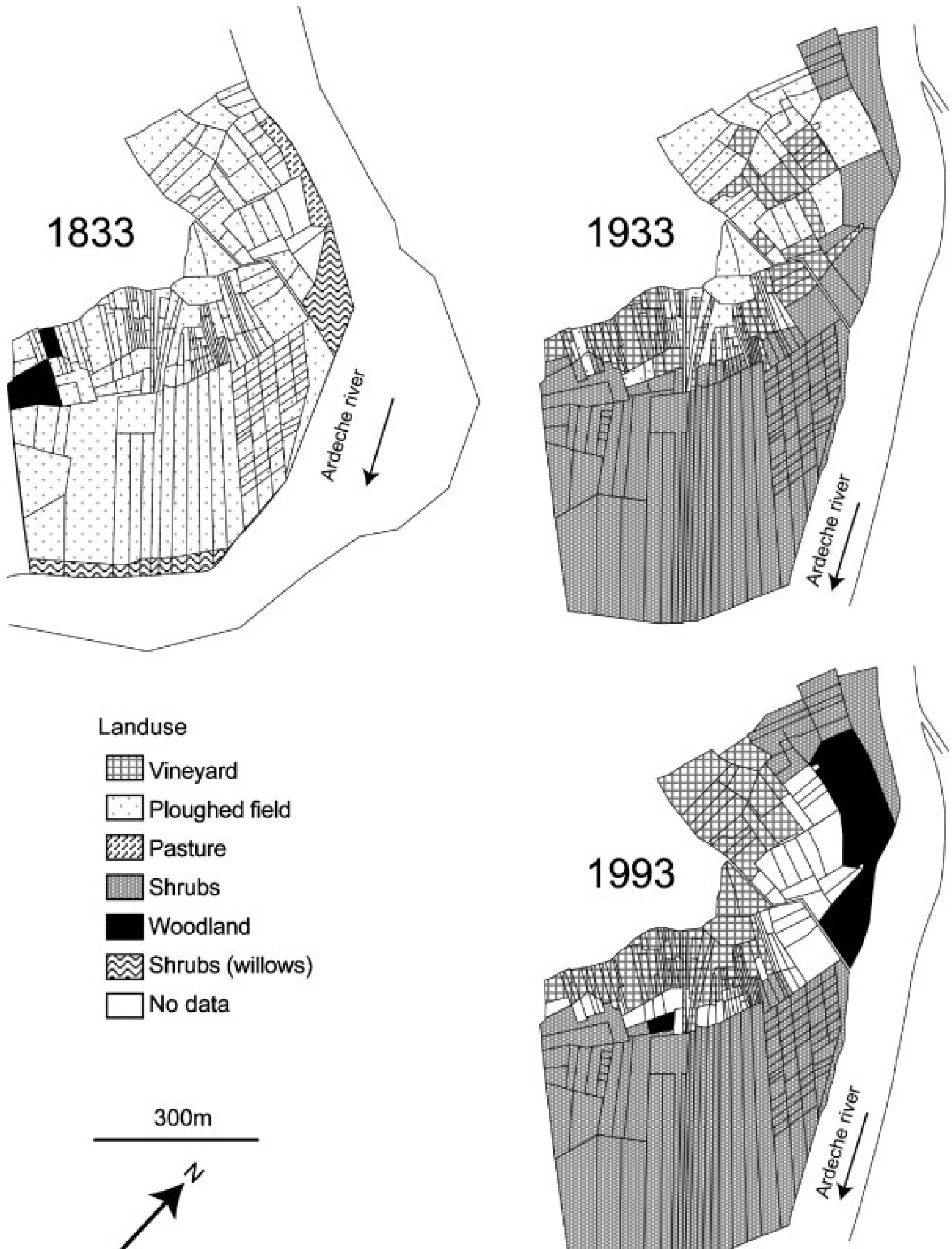

Figure 1. Evolution of land use types on the land-survey maps of 1833, 1933 and 1993 in Chauzon on the Ardèche River (SE, France; data from the cadastral map). The fluvial corridor was intensely used and cultivated from at least the 19th century. The land parcels in 1833 were of a small size and high density due to human pressure on the landscape at this period, reflecting a demographic maximum prior to the first industrial revolution

past structure and functioning are responses to a combination of driving factors that cannot be reached again (trajectory concept), even if they correspond to 'pristine' conditions that we can understand well. With the emergence of the trajectory concept, cyclicity, resilience, recovery and reversibility concepts can only be understandable at a short time scale when considering local perturbations. They cannot be of interest to targeting long-term actions, as they contribute to the myth of the lost paradise.

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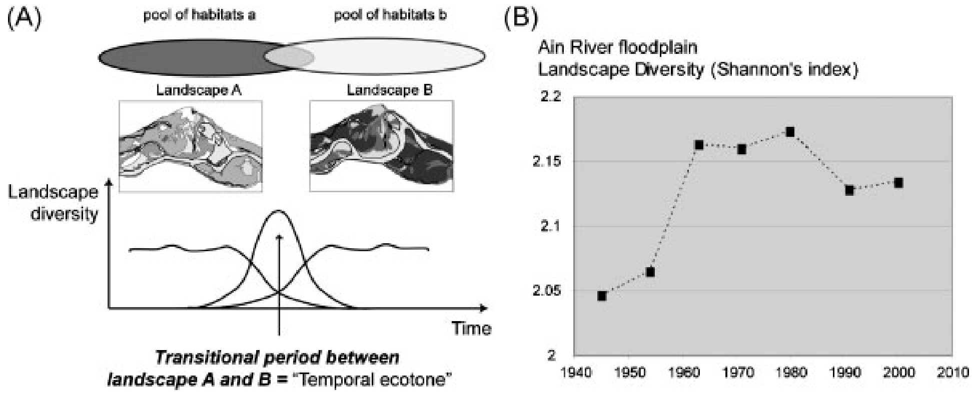

Figure 2. Evolution of landscape diversity and a transitional effect. (A) A theoretical framework which explains that landscape diversity can be high during the transition period between two different landscapes because of the presence of species specific to both habitats. (B) Evolution of landscape diversity of the Ain River floodplain since 1945 with a peak between the 1960s and the 1980s due to the transformation of a 'traditional rural' landscape dominated by open ecosystems (gravel bars, pastures...) to a 'forested' landscape dominated by woodlands that had colonized the river corridor (see also Marston *et al*., 1995 and Dufour, 2005)

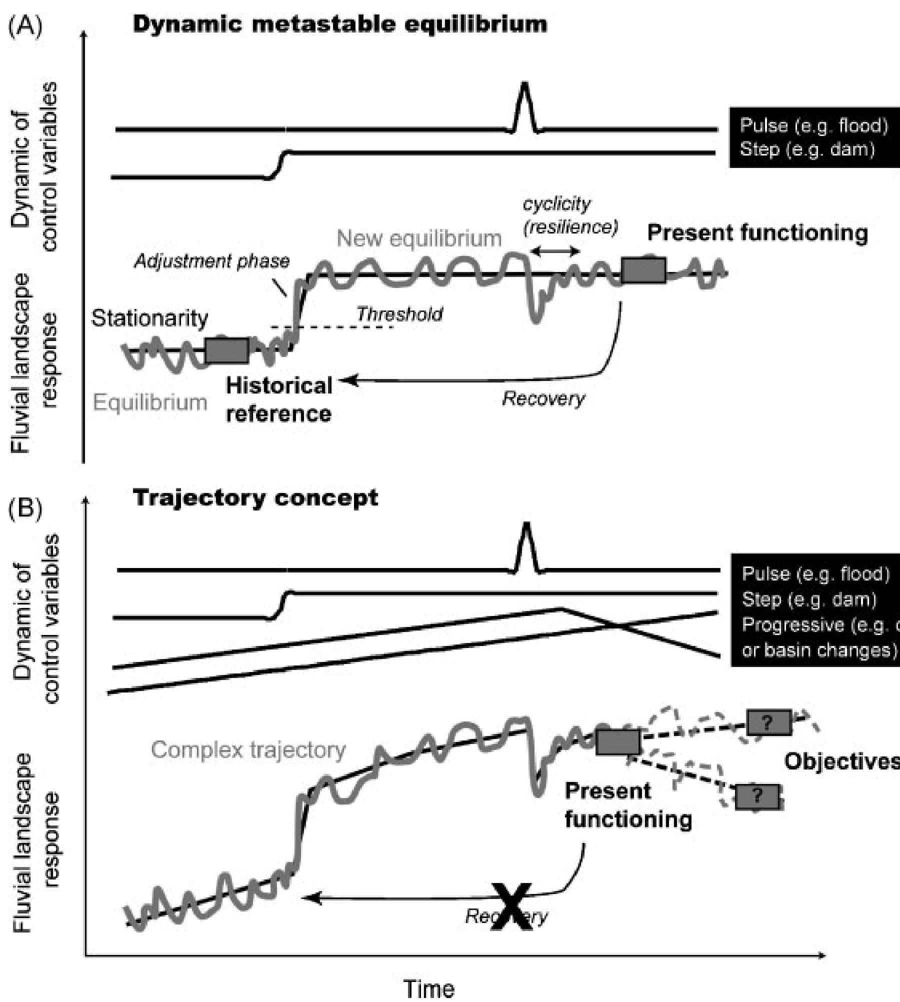

Figure 3. Fluvial landscape evolution results from the combination of numerous control variables; thus it follows a complex trajectory that justifies moving from a reference-based strategy to a objective-based strategy in restoration schemes

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FROM REFERENCE-BASED TO OBJECTIVE-BASED ACTIONS

If a past state or trajectory cannot form a reference, we must reconsider the paradigm within which restoration actions are developed. This is being achieved by integrating concepts such as ecosystem health, goods and services within recent definitions of restoration (Table I). One of the goals of restoration might be to 'repair ecosystem processes, productivity and services' (SER, 2004) in a sustainable manner for social benefit (Aronson *et al*., 2006a,b). Integration of these two perceived objectives, repairing ecosystem process and providing ecosystem services, is not yet complete. A next step is to consider natural preservation and restoration not as the only objective but also as a means to improve human well-being (see WWF/UICN, 2000). We move from a reference-based strategy built on the idea that ecosystems are damaged ('we are responsible to', 'we must repair') to an objective-based strategy, in which ecosystem degradation is damaging long-term development and repair or improve them is valuable because it provides services and goods. Implicitly, we consider natural features, independently of their origin, as a source of benefits for societies. Naturalness is then emerging as a key concept in river management. But why is naturalness considered as a mean to reach human well-being?

The emergence of the naturalness concept and the limitations of the process-based approach

Naturalness is a property of landscapes characterized by natural features and processes independent of the human or natural factors which create them (land-use changes, natural evolution) and is therefore different from 'wilderness' (for discussions about the ambiguity of the definitions see Landres *et al*., 2000 and Ridder, 2007). It has then been shown that maintaining river corridors characterized by a high level of naturalness, can be beneficial to humans. A natural landscape can improve water quality, protect populations from flooding and other natural hazards, but also can be a place for wildlife and its associated benefits (genetics, natural heritage, education, ethics, long-term natural ecosystem dynamics) (see Boon *et al*., 1992).

While this new paradigm is now driving actions, we must nevertheless remember that our way of thinking is strongly influenced by our cultural environment. In western countries, Nature is opposed to Culture, and natural landscapes are often idealized. For example they are more positively evaluated in aesthetic terms than are humanized landscapes (Lowenthal, 1964; Calvin *et al*., 1972; Hodgson and Thayer, 1980; Le Lay, 2007). Natural rivers have always been more positively viewed by the scientific community. As a consequence, urban streams are under studied (respectively 3 and 10% of papers referenced in the ISI Web of knowledge for 'river + restoration' and 'stream + restoration') yet people mainly interact with urban not natural streams. The trend of studying natural areas to understand the world leads to consider a man-made state composed of natural features to be degraded.

However, an increase in human influence within a given landscape is not systematically synonymous with low diversity or low functionality, it depends on the indicators we select. In some cases, some human-made sites are more ecologically interesting now than they were a century ago, for example the lower Eygues River (France) (Kondolf *et al*., 2007). Along the Arve River (SE, France), gravel mining in the channel and on the floodplain has heavily impacted river corridor dynamics (channel degradation, evolution from a multi- to single thread channel, propagation of geometric aquatic ponds in the floodplain) (Peiry, 1987). Former mining sites, still present in the landscape, have reduced floodplain forest area and increased fragmentation (Figure 4A). Yet, currently following naturalization, these areas have a high ecosystem value at the regional scale because they provide specific habitats that are otherwise absent across the rest of the floodplain (attractive for birds or odonates) and they contribute to an important ecotone between aquatic and terrestrial ecosystems (Figure 4B; Dufour, 2005).

Conversely, natural processes can lead to a decrease in rare habitats, and reaches that undergo natural processes can sometimes present a lower biodiversity than man-made reaches. For example, a bar braided system can be poorer in terrestrial vegetation units than an active meandering river system even though the transition from braided to meandering has been caused by artificial sediment starvation or by hydrological control. This is not just a rhetorical point. Obviously, diversity of one element (i.e. vegetation communities) cannot be used as a unique indicator and the actual channel form (e.g. braided channels) can be important to specific species (endangered species). At a larger scale deeply impacted systems are usually less functional than less impacted ones (Ward *et al*., 2001), however, what should we do when, for example, under natural conditions a gravel-bed reach tends to bar-braided rather than island-braided? Should we prioritize bar habitats over island vegetation communities? Which

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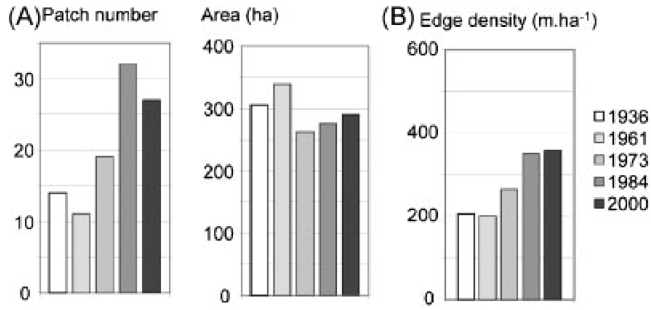

Figure 4. Evolution of the Arve River corridor over recent decades with simultaneously (A) an increase in woodlands fragmentation (increase in patch number with constant area), and (B) an increase in edge density (Contamine site) mainly due to the development of gravel mining in the 1960s

community or process should we focus our attention on? One solution is to integrate the reach within a network framework to consider diversity across a broader spatial scale and then, over time, build a network of complementary reaches (Graf, 1996; Brierley and Fryirs, 2000).

The link between natural process and associated benefits seems to be assumed by most investigators. With the interruption of process comes the damaging of the river ecosystem integrity (*sensu* the ability to maintain 'the diversity and quality of ecosystems, and enhancing their capacity to adapt to change...' see Table I). Indeed, the reduction in fluvial dynamics leads typically to a decrease in spatial heterogeneity and therefore in biodiversity, however, it is still unclear how, for example, the ecological value of mobile gravel-bed rivers compares to more stable beds in terms of benthic habitats (Piégay *et al*., 2006). Bank erosion is valuable along some reaches (Florsheim *et al*., 2008), but is simultaneously not valuable along others because of habitat destruction. The value of each process depends on system characteristics. We know also that connectivity can be desired in some networks but be undesirable in others (Kondolf *et al*., 2006). The strategy of maximizing processes does not always lead to ecological improvements as we define them.

After a decade during which natural processes have been the focus of restoration, it appears that a given process is not valuable everywhere and regional complexity must be better understood to adjust restoration actions. The relationship between process and associated services is not always evident. To demonstrate and evaluate how naturalness is profitable to human society is probably one of the main challenges to future progress in river restoration and management. This is a critical question as we scale up restoration from the site to the landscape (Moreira *et al*., 2006). For this purpose, conditions expected by society must be defined and fully integrated at an early stage of the restoration or management process.

Towards a strategy that integrates man-made features and processes

A major challenge for the scientific community is to understand natural processes in human dominated environments as well as to reconsider the place of man-made rivers. We must overpass our conservatism, the feeling that the past, when humans were not altering the earth at such a large-scale, is better than the present.

One possible way to reconcile the natural and cultural aspects is to move from a reference-based strategy to an objective-based strategy that drives actions within a given framework (i.e. what it is feasible and sustainable in a given system). Such changes in environmental policy have been observed in France where former or inherited practices were recently reconsidered (Piégay and Landon, 1997; Boyer, 1998). For several decades channel maintenance was based on the reference state of the channel in the 19th century when rural society maintained its traditional practices (fire wood cutting, grazing). The law allowed riparian vegetation clearing and wood removal as a way for a river to reach this reference state. With the increasing value given to riparian wood for ecosystems actions are now more based on objectives than on idealized reference to reach (Gregory *et al*., 2003). From a practical point of view, a simple scheme should be promoted to make sure that all aspects are developed

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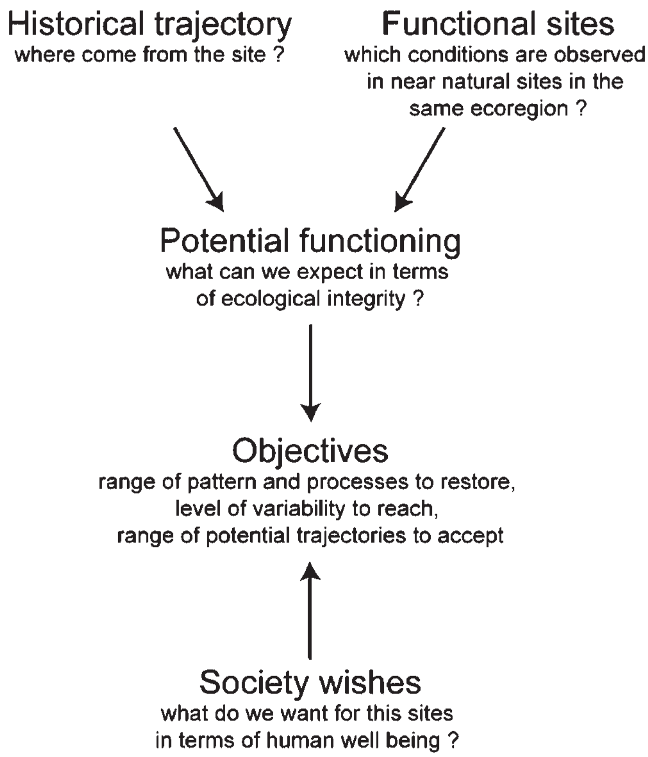

Figure 5. A framework to define objectives for river restoration projects

before implementing a restoration project (Figure 5, see also Jungwirth *et al*., 2002; Brierley and Fryirs, 2005; Aronson *et al*., 2006b).

Step one: diagnosis, problem statement and potential functioning appraisal. First, we need to know the historical trajectory of the system to be restored, to understand its properties, to identify both natural and human influences on the past landscape (Antrop, 2005; Brierley and Fryirs, 2005; Wohl, 2005; Hoyle *et al*., 2008). What are the critical past and present processes? Where might the system move, given its connectivity and adjustment to previous pressures? Second, we have to study other reaches in the same ecoregion to define the potential response of the target reach if some features or processes are modified (potential functioning, close from the 'visionary Leitbild' in Jungwirth *et al*., 2002). This would provide information on the range of conditions that what we can and should expect (notably in more dynamic contexts) with a range of uncertainty (Sear *et al*., 2007). We will have a better idea of the potential functioning of a given reach by integrating the historical trajectory into a process-based understanding (given by some functional and dynamic site) (see below Figure 5). Thus it is important to design what nature will accept (i.e. probabilistic rivers Graf, 2001) by understanding natural processes in a specific regional condition, even when they are human-induced.

Step two: identify human requirements. Identifying and defining society's needs require society's participation at different levels (local, catchment, regional, national to international). To achieve this step it is important to clearly identify priorities in relation to restoration motives (Wheaton, 2005; Nilsson *et al*., 2007) and what is possible in the system knowing that it must provide various services and that the system and society's values are ever changing. The process must place values on natural conservation, landscape aesthetics, fish resources, water quality, cultural heritage conservation and flood management. In the context of working with objectives it will be necessary to limit the effects of social preferences and changing fashions in terms of landscape aesthetics and restoration design (Piégay *et al*., 2005; Kondolf and Yang, 2008). To achieve all of this we need more accurate tools to evaluate the social, economic and cultural values of a given pattern or site, which depend upon addressing a number of questions. How do we identify the needs and expectations of stakeholders? What are the

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associated functions and economic benefits? How can we pay sociological, cultural and ecological benefits to landowner or other structures that assume management or constraints? Can restored sites underpin an economic development strategy (see for example Blignaut and Moolman, 2006)? This is a new research frontier in environmental sciences.

Step three: definition of objectives and selection of actions. The confrontation between society's wishes and the potential functioning should lead to the defining of objectives. Clewell and Aronson (2006) describe five main motivations for acting on degraded systems: idealistic, technocratic, heuristic, biotic and pragmatic. Objectives are generally a compromise between several functions that we have to place in a hierarchy (Wheaton, 2005; Wohl, 2005). They are dynamic because both constraints and services provided to society and also potential functioning evolve, changing what it is possible to achieve. Actions can preserve (act locally or widely to preserve process—see Rollet *et al.* submitted), mitigate, or enhance (repair, restore in the wider sense or rehabilitate if natural features and ecosystems are the main objective). As is often the case, a given action can provide benefits but also constraints; some measures can be good for given ecosystem goals but not to others (See Schmidt *et al*., 1998; Kondolf *et al*., 2006). Over the last five decades we have come to understand how humans can simplify ecosystems and how a complex natural system can be changed, but we still need to learn how to (re)create complex self-maintaining ecosystems by promoting a given processes in one specific context in comparison with another. We need to be pragmatic, humble and support decisions on clear objectives (Kondolf *et al*., 2006).

Implications for application of the water framework directive (WFD)

Can we hope to plan actions as suggested by the WFD? It is evident from the above discussion that reference conditions may not represent a situation with 'no, or only very minor, anthropogenic alterations of the physicochemical and hydromorphologic characteristics' as required by the WFD [Annex V, Table I.II]. The WFD is one of the most ambitious collective planned actions to promote naturalness as a means of achieving human well-being (Newson and Large, 2006). However, we believe that the ideas presented here help clarify the running actions and validate conceptually the pragmatic options that may be chosen to determine a framework from which the efficiency of future restoration measures can be evaluated.

First, within the WFD, ecologic status refers to 'the quality of the structure and functioning aquatic ecosystems' (WFD [article 2]). As far as there is no linkage with past-imagined conditions, it is fully acceptable. Good ecological status is a 'slight deviation' from type-specific reference conditions. We can establish what can be the ecological conditions by substituting a time reference by a space reference, which it is already pragmatically suggested for large, heavily impacted rivers (Van Looy *et al*., 2008) and considering the most natural rivers as references. But this change assumes that more natural conditions are the goal to reach whatever the (cultural) context and that we can transpose processes from one reach to another, which is the foundation of the WFD and a question not yet completely solved. This is why the concept of Naturalness, which drives the WFD, must be better understood. In turn, this addresses the issues of ecosystem services in the WFD vision: is Naturalness a source of benefit for society and human well-being? A more detailed demonstration (attribute by attribute, region by region) is still lacking.

Following from the above, we need to return to the initial simple, but sometimes forgotten, question, why do we try to restore systems and according to which objective? Since the links between ecological status and ecosystem services is not clear, some questions need to be reconsidered. What kind of services would we expect or would we not lose by promoting Naturalness? What kind of landscape features and biotic assemblages would improve the condition of the environment? Finally, one option to explicitly motivate actions could be to move from an objective of 'minor alteration' to one of 'maximize conditions for a given ecoregion'. In other words, which ecological systems provide the best ecological function for a given area? Also, can we manipulate natural objects in order to produce some services to society? This is also an ethical issue—where is the limit and should we be afraid of manipulating nature too much? In the future when altering our environment we must establish a clear definition of 'Naturalness' and move away from a protective definition and closer to a more pro-active solution from an ethical point of view that promotes Naturalness.

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CONCLUSIONS AND PERSPCTIVES

Usually human actions are perceived as 'unnatural to the extent that they rely on technology to transform natural ecosystems' (Angermeier, 2000). In 1964, David Lowenthal expressed the idea that man is a part of nature and there is no reason to prefer the original world to the present one (Lowenthal, 1964). Indeed man is a part of river system evolution and in many contexts going back is impossible or at least difficult within a single lifetime. However, the capacity to maintain and restore the expression of hydrological, morphological and ecological processes must be considered. We clearly need to find some technical and political solutions in order to maximize ecosystem integrity and human well-being without affecting our future, which supports conservation of ecological values of fluvial corridor as well as their sociological and economical functions in a sustainable way. Restoration actions are a way to achieve this, but they are just a way and not the goal *per se*. To be successful, we need a coherent framework to assess the impact of our actions, but also a solid basis from which to define the objectives (Palmer *et al*., 2005). We believe that these objectives should result from a combination of the wished state (what we want) and the potential functioning (what we can have). Studying functional sites is essential to scale-up the vision by studying a broader range of contexts (Brierley *et al*., 2002). This scaling ultimately needs to integrate humanity, which thus far has been relatively underdeveloped. By minimizing society's wishes (i.e. constraints and provided services), we have probably overestimated the value of some natural properties such as meander patterns or spatial heterogeneity and underestimated cultural values and the complexity of the river corridor trajectory.

Further research is needed to link system structure to process (Cortina *et al*., 2006) and then process to ecological and social benefits to understand regional complexity. This is fundamental to evaluating the efficiency of restoration by including all costs and benefits (Loomis, 2006). Monitoring target species does not really consider ecosystem integrity, but rather a resource. Moreover biodiversity is not always a valuable property of an ecosystem, specificity (e.g. presence of phreatophyte species) can be more interesting in some cases. We probably should use healthy and unhealthy gradients (defined by a range of criteria such as process, species/composition, services provided) rather than a simple spectrum from natural to degraded in order to evaluate the position of each site in comparison with the maximum expected for each context.

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