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River restoration in France.

Changes in definitions and techniques over space and time. Outlook for the future

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N°27

Contents

What does river restoration consist of? How is the concept defined? What is the difference between restoration, rehabilitation and renaturation? How are these different concepts applied? What are the corresponding techniques?

Restoration is an important issue in managing water and aquatic environments, however the concept itself is still debated. There is still no consensus concerning the answers to the above questions, whether among participants in management work or among researchers. **The discussions address the multiple dimensions (scientific, technical, ethical, political and social) of the concept.**

To improve our understanding of this paradigm, investigate its contributions and limits, and look at the potential changes in its application in the field of water and aquatic environments, we reviewed current definitions of restoration as it is now practised in France and abroad.

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As of 1 January 2017, the Agency for marine protected areas, the Technical workshop for natural areas, the National agency for water and aquatic environments (Onema) and the French national parks joined forces to form the French biodiversity agency.
The work and studies carried out prior to 2017 by Onema are mentioned as such in this document.

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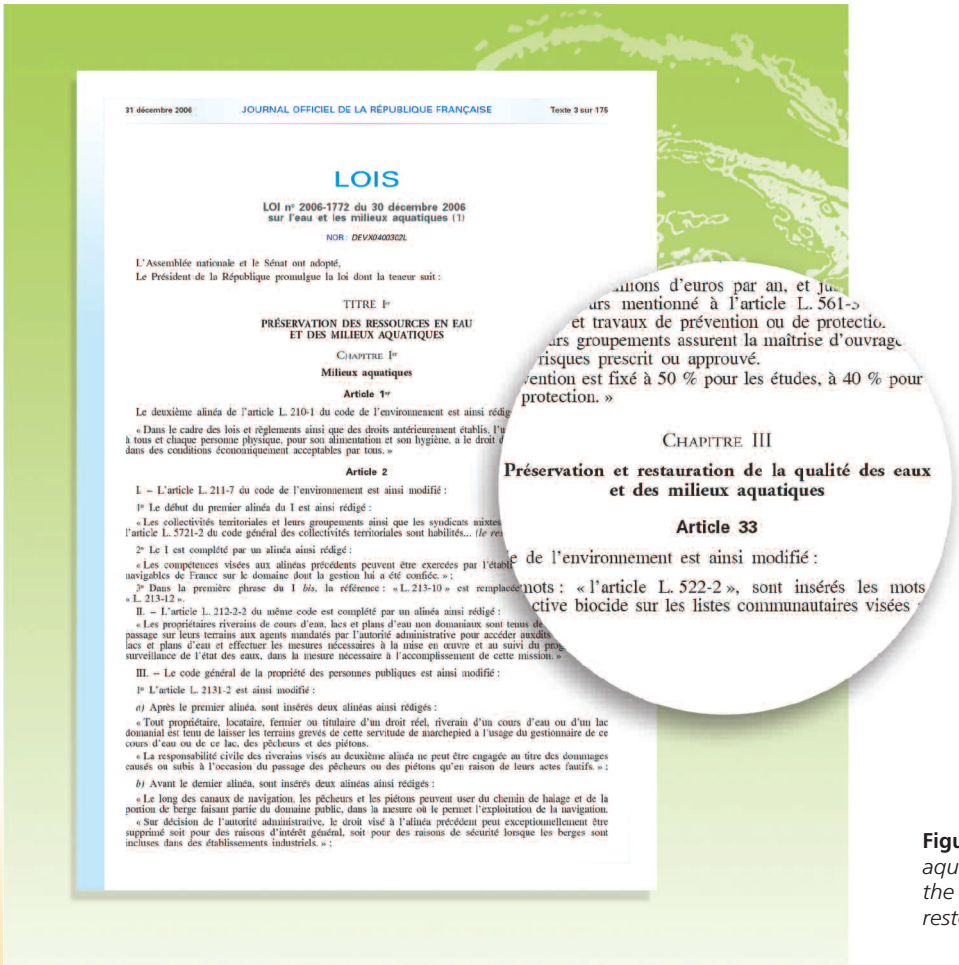
1. A concept in use, but whose meaning is still debated

1.1. From the 1992 Water law to GEMAPI[1], the evolution of the river-restoration concept in legal documents

The concept of restoration is used in most of the legislative and regulatory documents that form the basis of French policy for the management of water and aquatic environments. The concept received its first legislative confirmation in the 1992 Water law. "Restoration of the quality of surface waters" was set as the second objective for balanced management of water resources, whose overall purpose was to satisfy the various needs through quantitative and qualitative preservation of water and environments. The concept of restoration was subsequently acknowledged institutionally in executing public policy for the management of water and aquatic environments. More recently, the European water framework directive (WFD), adopted in 2000 and transposed into French law in 2004, confirmed the importance of the restoration concept.The directive sets guidelines to achieve the "good ecological status" of rivers. The 2006 law on water and aquatic environments (LEMA) met the obligations contained in the WFD and made even more intensive use of the restoration concept (see Figure 1). The concept is also mentioned in the 2009 law implementing the results of the Grenelle environmental conference, which defined, among other objectives, the "preservation of biodiversity, notably by conserving, restoring and creating ecological continuities", and it is contained in the new national strategy for biodiversity (2011-2020), that aims notably to "Preserve and restore ecosystems and their functioning". The recent reports commissioned by the French government in the field of water and aquatic environments (Lesage 2013 and Levrault 2014) also place considerable importance on restoration and include it in their recommendations.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LOIS

LOI n° 2006-1772 du 30 décembre 2006 sur l'eau et les milieux aquatiques (1)

NOR : DEVX0400302L

L'Assemblée nationale et le Sénat ont adopté,
Le Président de la République promulgue la loi dont la teneur suit :

TITRE Ier

PRÉSERVATION DES RESSOURCES EN EAU ET DES MILIEUX AQUATIQUES

CHAPITRE Ier

Milieux aquatiques

Article 1er

Article 2

Article 33

CHAPITRE III

Préservation et restauration de la qualité des eaux et des milieux aquatiques

Figure 1. *The 2006 law on water and aquatic environments (LEMA) reinforced the role played by the concept of restoration, but did not precisely define it.*

1. The GEMAPI system assigns the management of aquatic environments and flood prevention to local governments. For more information, see Loupsans, 2014).

1.2. From the legal aspects to actual policy, the concept of river restoration in operational terms

Using the established legal basis, **French stakeholders in the management of water and aquatic environments implemented the restoration concept on the various levels of public policy**. On the national level, the National agency for water and aquatic environments (Onema, now AFB) made the restoration and rehabilitation of aquatic environments one of its priority objectives from the moment it was created in 2006. On the regional level, the Water agencies (WA) were created by the 1964 Water law and included the concept in their active policy during the 1980s, notably in the framework of their financial-aid policy for improving aquatic environments (see the Results[2] box 1) (Morandi *et al.*, 2016). **The first river-basin management plans (RBMP), set up in 1996 in compliance with the 1992 Water law, reinforced the already significant role played by the concept of restoration.** Finally, on the local level, the concept is clearly linked to the tools for territorial water management, such as river contracts and sub-basin management plans (SBMP). In addition, the Water agencies have created specific restoration instruments such as the restoration-maintenance contract in the Loire-Bretagne basin, the multi-annual restoration and maintenance programmes and the aquatic-environment restoration and enhancement programmes in the Rhône-Méditerranée-Corse basin, and the ecological development, management and maintenance plans for rivers in the Rhin-Meuse basin. Above and beyond the instruments of public policy, **the river-restoration concept is an important feature for many stakeholders in the water sector, including river managers and users.** The concept is defined in technical terms, outlining how work can be done on the river, but this definition is nonetheless multi-faceted in that it calls on different types of knowledge, perceptions and individual and collective representations of the river, of how to live with it, to develop it and to manage it (Rivière-Honegger *et al.*, 2014). Each person defines the river to be restored according to their own criteria on how it should be, e.g. lush and verdant, free running, accessible, open for bathing, rich with fish, dotted with mill dams, wild, managed, etc.

1

Results box 1

The restoration concept in the funding programmes of the Loire-Bretagne, Rhin-Meuse and Rhône-Méditerranée-Corse Water agencies

© Agence de l'eau Loire-Bretagne, 1987

The river-restoration concept was first formally defined in the fourth funding programmes (1982-1986) of the Loire-Bretagne, Rhin-Meuse and Rhône-Méditerranée-Corse Water agencies and linked to the new "River development" budget line (Morandi *et al.*, 2016). From that point on, it started to permeate work policies. What began as a simple technical solution launched on an experimental basis became a permanent and growing element in budgets in the early 1990s. **From there it progressively became a basic component in funding programmes. Following the 1992 Water law, restoration and management in general became integrated to meet the multiple aspects (hydraulic, ecological, socio-economic) of the problems confronting river basins as a whole.** River restoration, taken as a physical intervention, is part of a larger approach, that of the restoration of water and aquatic environments, which includes an array of activities ranging from sanitation to quantitative management of water resources.

Restoration took on increasing importance over the sixth, seventh and eighth programmes of the Water agencies, in terms of the funds in-

Figure 2. *Starting at the end of the 1980s, the ecological quality of aquatic environments was a central component in the funding programmes of the Water agencies, as illustrated by the cover of the fifth programme of the Loire-Bretagne Water agency (1987-1991).*

2. This document includes two types of boxes, Results boxes printed on a green background and Methods boxes printed on an orange background.

vested, the percentage of aid granted and the applications processed. **The ninth and tenth programmes, structured around the new legislative and regulatory frameworks created by the WFD (2000) on the European level and the LEMA law (2006) on the national level, constituted a second surge in the interest of the Water agencies for river restoration.** The environmental aspects of programmes were constantly reinforced and the notion of the intrinsic quality of environments became a dominant factor (see Figure 2). Hydrosystems, erodable corridor, morphological disturbances, hydromorphological damage, among other aspects, became basic concepts in river-restoration issues. The WDF, followed by the LEMA law, reinforced this approach to work on the part of the Water agencies by including it in the legislative texts and by requiring mandatory results toward achieving "good ecological status". To meet this objective, an ambitious policy of incentives was launched and the funds invested (see Figure 3a), the percentage of aid granted and the number of applications processed increased sharply up to 2011. However, the overall position of restoration in the field of water and aquatic environments must be put into perspective. The percentage represented by restoration work in the total aid budgets of the Water agencies did not reach 10% until the tenth funding programmes (see Figure 3b).

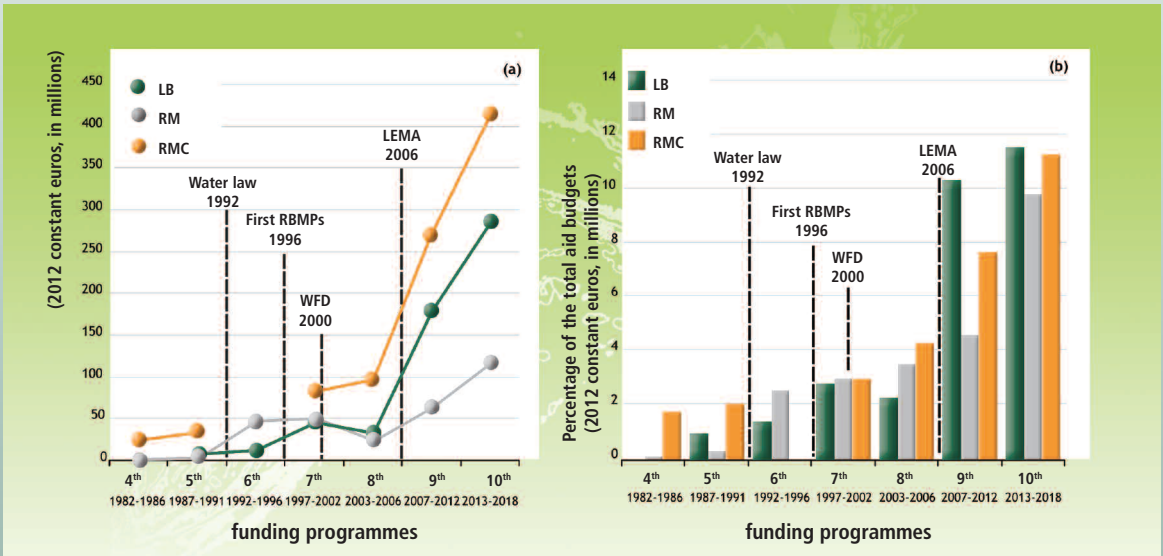


Figure 3. *The aid budgets programmed by the Loire-Bretagne (LB), Rhin-Meuse (RM) and Rhône-Méditerranée-Corse (RMC) Water agencies for the management of aquatic environments (budget line 240) increased significantly between the early 1980s and the present time, in both absolute amounts (a) and in the percentage of the total aid budgets (b). See B. Morandi et al, 2016.*

1.3. A debated concept in the scientific community

The concept of river restoration was also well received by the scientific community (Roux-Michollet *et al.*, 2013). Researchers latched on to and developed the concept, defining it in conjunction with rivers (Roni and Beechie, 2012) and more generally in the environmental domain (Clewell and Aronson, 2010). Bibliometric analysis using international bibliographic databases[3] revealed the increasing interest of the scientific community for the concept, while highlighting geographic differences that evolved over the past four decades. North America dominates the scene with 48% of publications. It is followed somewhat closely by Europe with 29% and Asia and Oceania (8% and 6% respectively). Even though Australian researchers published in this field as early as 1986, truly significant scientific activity in the region began only toward the end of the 1990s. The first paper was published in Asia in 2003 and the number of Asian publications approached the level observed in Europe only toward the end of the period studied in this document. Finally, the most recent data, from 2008 onwards, indicate that the gap between Europe and North America is closing (see Figure 4). **The analysis specifically addressing research work on the topic listed in French bibliographic databases[4], between the years 1984 and 2013, revealed a total of 62 publications on river restoration.** Compared to the research work done in the field of water and aquatic environments in general (Mettoux-Petchimoutou, 2015), this number of publications would appear fairly limited.

3. Scopus / Web of Science.
4. Cairns / Erudit / Persée / Thèse.fr / Sudoc.

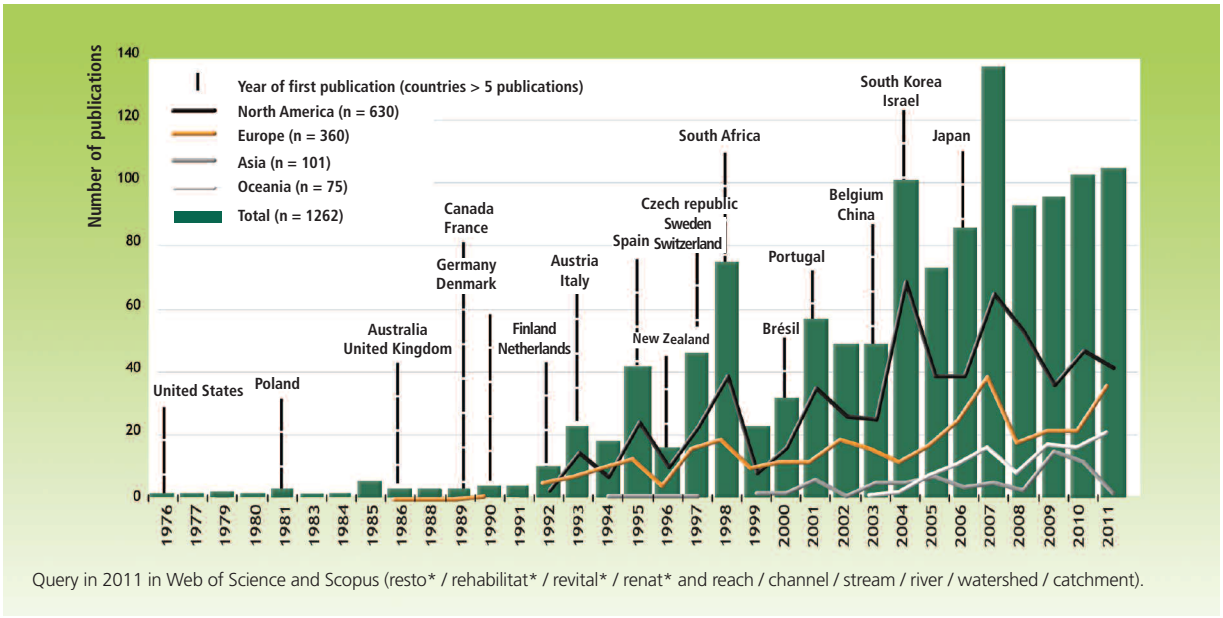


Figure 4. *The number of scientific publications in the field of river restoration increased from 1976 to 2011. A period of more numerous publications in North America and in Europe started in the 1990s. Publications in Asia and Oceania increased from the beginning of the new century. The first international paper from France was published in 1989. See B. Morandi et al, 2014.*

1

Methods box 1

How are documents used to study the definitions and techniques of river restoration ?

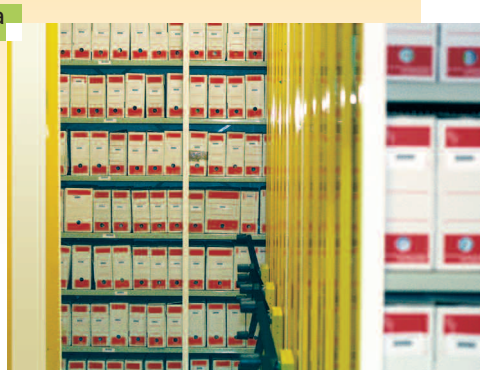
The definitions and techniques of restoration are studied using different types of written documents, French and international, selected on the basis of key words (restoration, rehabilitation, renaturation, revitalisation). Four sets of documents were constituted:

- French and international scientific publications listed in the bibliographic databases, e.g. Web of science, Scopus, Revue.org, Sudoc;
- guides, manuals and other technical documents intended to assist in carrying out restoration work;
- official forms for financial aid granted by the Loire-Bretagne, Rhin-Meuse and Rhône-Méditerranée-Corse Water agencies to water managers for the purpose of river restoration;
- feedback from finished projects containing detailed information on river-restoration work.

A number of textual methods were used to analyse these sets of documents (see Figure 5) and characterise restoration definitions and techniques:

- bibliometrics consists of counting the number of scientific and operational documents produced and published (Rostaing, 1996);
- textual statistical analysis involves counting words (Lebart and Salem, 1994) and subjecting the results to statistical and probabilistic analysis. The TXM[5] software is used to run the analyses;
- content analysis is based on qualitative classifications and coding that are subsequently used for counting and quantitative analysis. For this project, content analysis was carried out manually;
- qualitative analysis proceeds by producing summaries and extracting quotations.

5a



5b

(a) © E. Milcent, (b) © B. Morandi, 2010

Figure 5. *Research in archives and documentation centres is an essential step in this type of scientific endeavour (a). The GénéaCapture system is used to digitally acquire the data contained in the documents (b).*

5. TXM, Heiden S., Decorde M. & Bertrand L., 2014. TXM manual, version 0.7, February 2014, 160 p. (textometrie.ens-lyon.fr).

2. Defining the concept of river restoration

2.1. The major French definitions of river restoration

With the exception of the documents published in conjunction with policies to restore mountain terrain (RTM policies) at the end of the 1800s (see the Results box 2), **the initial technical documents defining the concept of restoration in France were published in the 1970s**. Two different periods may be distinguished in the restoration field, corresponding to two different approaches to river restoration. **The first approach appeared in the 1970s and 1980s and addressed hydraulic and landscaping aspects. The second period, which began in the 1990s and continues today, corresponds to an ecological approach.** The study of 93 technical documents published over the four decades made it possible to characterise the two approaches and the corresponding restoration techniques.

2

Results box 2

What information is provided by the technical documents produced in the 1800s for the policies to restore mountain terrain?

The concept of restoration was developed in France in the 1800s and used in mountain regions by the engineers in the Water and Forestry Service in the framework of civil works that are today known as the mountain-terrain restoration (RTM) policy. The origin of the policy followed observations of increases in erosion on slopes, torrential flows in mountain regions and flooding in the lower areas downstream. **The RTM policy is commonly presented as a forerunner in soil restoration, however all the documents concur that its origins lie at least in part in work on mountain streams and rivers.** The text seen as the cornerstone for the policy is in fact the Study on torrents in the Hautes-Alpes department (1841) by A. C. Surell, an engineer in the Bridges and Roads Service. RTM work essentially addresses efforts against erosion and torrential flows (debris flows, floods, downcutting). A number of parallels may be drawn between this origin and more contemporary techniques of river restoration (see Figure 6), notably those concerning hydraulic and landscape restoration that were developed in the middle of the 1970s.

© Ville de Paris, 2008

Figure 6. *The links between current restoration techniques and the policies to restore mountain terrain (RTM) are revealed in certain contemporary documents intended for management purposes or for awareness raising. One example of the links is the highlighting of G. Demontzey, an emblematic engineer in the RTM field, presented as a pioneer in renaturation for an exhibition titled "A river, humans and systems", organised by the city of Paris in 2008.*

Similar to river restoration, the RTM policy places great importance on scientific and technical knowledge, which in turn raises the question of the links between knowledge and action. RTM work is defined by the forestry workers who implement it as policy based on proven facts. The policy takes into account regional studies and feedback from the field, the work undertaken brings technical know-how into play. The grounds provided by the scientific and technical knowledge are a major factor in justifying governmental action for public safety that is not particularly concerned with the socio-economic issues at hand in a given territory. That explains why it is often confronted with local opposition. The balance between national (and now European) policy and local needs is still difficult to achieve. Current guiding principles in the field of river restoration, though they foresee local participation, do not always avoid conflicts on the territorial level.

Scientific knowledge is also used in the framework of the debate surrounding RTM policy on the origins of the degradation and on the reference states used to characterise the degradation. However, the discussions that took place in the 1800s involved ethics as much as scientific knowledge and already raised the issues of the links between societies and their environment. Generally speaking, the RTM policy assigned human responsibilities to the problems confronted, even though it was fundamentally anthropocentric in its approach. Society was seen as a disturbing factor in a certain natural order and was also the first to suffer the consequences. By restoring mountain areas, forestry workers also restore the resources provided by these environments to society (that also contribute to regulating extreme hydrological phenomena), an approach that is not so different than that centring on ecosystem services that now lies at the heart of research into the management of aquatic environments.

The concept of river restoration appeared in the middle of the 1970s in technical documents published by the *Compagnie d'aménagement des côteaux de Gascogne*, a regional-development company holding a hydraulic concession for the farming sector. The concept spread to the national level in the 1970s and 1980s thanks to efforts by the Ecology and Agriculture ministries. **Restoration was defined in theoretical terms by hydraulic engineers and biologists.**

Restoration work, as presented in the documents from that time, was intended to counteract the absence of channel maintenance, mainly along the private river reaches, a situation observed over several decades and seen as a consequence of rural depopulation and the modernisation of agriculture. **The expressed objective of restoration was a return of the river to its status prior to being abandoned** (see Figure 7). That status was, however, poorly defined in the regulatory texts and the reference in guiding restoration was above all the return to a good relationship between the local residents and the river. In the documents from that time, restoration would appear to consist essentially of a return to bygone management and upkeep practices, rather than a return to the former status of the river. All the documents were in agreement on the fact that the causes of the abandon of rivers were profound and that the social customs ensuring upkeep had ceased to exist. In this analysis of the situation, there would seem to be a contradiction in efforts to return rivers to a status that resulted from a social context that no longer existed. According to those authors, **river restoration was possible only if non-profits and local governments stepped in to replace the local residents and took over the management of projects.** River restoration was therefore, from the moment it emerged among management techniques, a public policy.

7a

7b

© Lalanne-Berdouticq, 1985

Figure 7. *The concept of river restoration appeared in technical documents starting in the 1970s. At that time, the objective was to solve the problems caused by the fact that rivers were no longer maintained. This hydraulic and landscaping approach to restoration resulted in a shift from (a) abandoned rivers to (b) a maintained status to prevent flooding and to provide more attractive living conditions.*

The problems confronting restoration projects are well described in the technical documents of that time. **The main objective was to limit the risks of flooding and erosion caused by the closing in of the river environment due to the riparian vegetation and by obstacles in the river bed (snags, wood jams) that blocked the free flow of water** and notably flood waters. A further problem that the restoration project must solve was access to the river. The work had to recreate a visual and physical link with the river. Landscape perceptions and considerations were important factors that the authors linked to the concept of river restoration. They were also elements in the hydraulic aspects given that landscape quality, free flow and bank stability were all integral parts in the recommended work. Ecological aspects were not absent from these initial definitions of restoration. Though restoration work did not focus on ecosystems, the concern for environmental quality was very real (see Figure 8). It was recommended to intervene in rivers "while maintaining the biological and landscape environment" (Lalanne-Berdouticq, 1985, p. 16) and "disturbing as little as possible river configuration and the natural processes" (Cacas *et al.*, 1986, p. 11). **River restoration integrated the approaches resulting from the systematic use of impact studies made mandatory by the 1976 law on the protection of nature.** Ecological concepts, notably those concerning ecosystems and diversity, may be found in the documents produced in the second half of the 1980s. The underlying rationale, however, concerned development work for fish, seen as a resource, rather than an ecological approach taking into account the functioning of the river as a whole.

These environmental concerns may be seen as the starting point in changes in restoration techniques observed in the technical documents from the 1970s and 1980s. The authors expressed a desire to break away from the techniques used in the past in working on rivers. A notable change concerned the forestry techniques used to manage riparian vegetation. **The concept of selective intervention was recommended for all work on vegetation** (clearing, trimming, cutting back, planting, planting of cuttings), as opposed to systematic interventions (clear-cutting). Though advised for riparian and aquatic vegetation, selective intervention was not recommended for wood jams blocking the flow of water. Work on river morphology also changed in order to lessen the impact of work on the environment. **The concept of rational hydraulic interventions lies at the heart of the techniques** developed during the 1970s and 1980s. Even more than for the work on vegetation, the trend at that time was to "tread lightly", i.e. avoid massive interventions (channel rectification and reshaping) in favour of less intrusive techniques (removal of alluviation deposits, bank reprofiling). **Systematic channel cleaning and reshaping were no longer recommended, but were to be "limited" and "restricted to specific spots".** The softening of intervention techniques was also due to technological innovation. Though bank-protection systems involving stone banking, concrete and metal sheet piles were commonly recommended, the documents also mentioned bank-protection systems using plant material (wooden stakes, fascines and matting, plants and grass). **These techniques were the initial steps in the direction of bio-engineering as defined in the 1990s.**

© Arlot et al., 1987

Figure 8. *Hydraulic and landscape restoration do not focus on ecosystems, however environmental considerations are nonetheless an important factor. The work should be carried out in a manner designed to produce the least possible impact on the natural environment, as illustrated by this excerpt from a technical document encouraging readers to "Respect and take into account the complexity of river environments".*

During the decades of the 1990s and 2000s, the concept of river restoration gained in importance in the field of river management. The numbers of technical documents dealing with the topic rose sharply. In the 1990s, the Water agencies reinforced their role in the sector. Local governments, including the public entities for cooperation between townships (EPCI), began to produce their first documents on the subject in the beginning of the 1990s. In parallel, **the research sector participated more intensively in publishing technical documents and expanded its work to more diverse fields.** Hydrologists and hydraulics experts are still present in number, but the links with the ecological sector have been reinforced. New scientific disciplines, e.g. hydromorphology, are now active in producing technical documents. **The other category of authors that emerged in the 1990s is that of consultants and consulting firms, including a number of experts who became absolute references in the field of river restoration.**

These changes observed in the dynamics and publishing situation for technical documents took place in step with another change, that of the definitions of river restoration. There was, however, no radical break in the theories and though hydraulic and landscape restoration appeared to become less frequent in technical documents over the 1990s and 2000s, restoration was still often seen as an answer to the abandonment of rivers. **The issues of flow and erosion are still central elements in restoration as defined by a number of technical documents** (see Figure 9). Interventions to handle vegetation, manage wood jams and protect banks from erosion are still recommended as a part of river restoration. However, the Barnier law (1995) modified the objectives of maintenance and consequently of restoration, given that both were to be undertaken in order to "maintain the natural flow of water, ensure the stability of banks and preserve the fauna and flora while respecting the correct functioning of aquatic ecosystems". The techniques used for selective intervention were reinforced and often became more ecological in their approach. They were also used to remove jams, which had not been recommended in the technical documents from previous decades.

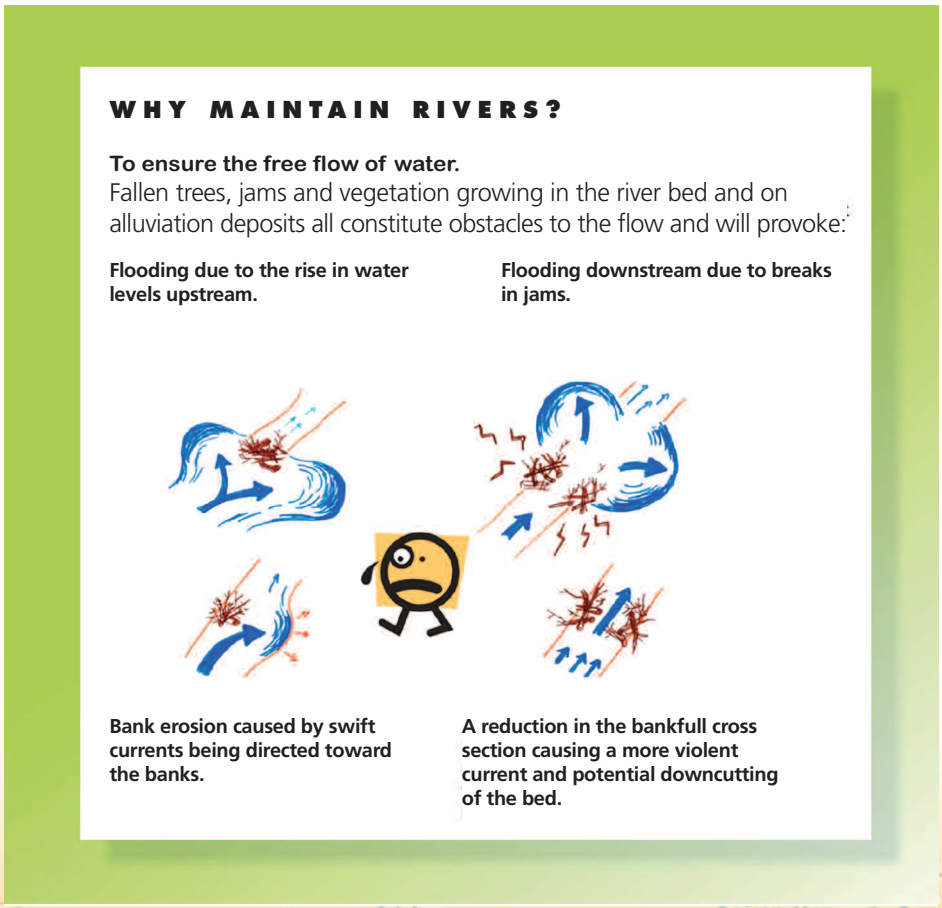


Figure 9. *The ecological approach in river restoration appeared in technical documents at the end of the 1980s, but did not replace the hydraulic notions concerning the free flow of water, which remained in certain technical documents published in the 1990s and 2000s.*

The hydraulic and landscape approach, developed during the 1970s and 1980s, continues today, but is accompanied by a new approach to river restoration. **Starting in the beginning of the 1990s, technical documents contained criticism of development work, going beyond bed reshaping and/or rectification to criticise the basic principles of the work.** The objective was not only to halt development methods that had come to be seen as mutilating rivers, but also to repair the mutilations, notably ecological damage, caused by past work and viewed with increasing disfavour since the 1970s. **Restoration thus became a form of corrective action based on ecological and functional criteria. A firm scientific basis is one of the main characteristics of this new approach to river restoration.** In step with observations on the degradation of aquatic environments, significant progress was made during the 1970s and 1980s in knowledge on rivers and concepts were developed that became, in the 1990s and 2000s, essential building blocks for restoration in France. The notions of diversity, sustainability and functionality in particular had a major impact on the concept of restoration and on the context for interventions discussed in technical documents. **Though most documents cite "good functioning" or "balanced functioning" as the objective of the restoration work, very few define those terms precisely.** In some technical documents, ecological functioning is determined by the species richness and, consequently, the biodiversity of the environment.

These different definitions focus on river functioning and constitute a basis in questioning the notion of the reference points used for restoration work. The status of the river prior to any degradation is often the selected reference point in defining good functioning. Most of the time however, this "past" reference point is not situated in time. The two adjectives most frequently used are "natural" and "original". Certain definitions add to the notion of natural that of stability, to the point that in certain French technical documents, the notion of stability has in itself become a reference that is no longer necessarily linked to the past of the river. However, not all definitions are based on stability. The notions of trajectory and resilience have become central features in dynamic approaches to references. Resilience is the capacity of a river to return, on its own, to its functional status that existed prior to the disturbance. This idea is expressed in technical documents when they discuss a degree of functional autonomy of the river not requiring any renewed interventions. The concept of passive restoration is also based on the notion of resilience. These different definitions of reference points make it clear that ecological restoration is essentially focussed on ecological criteria. **However, it is apparent in a number of technical documents that social concerns were not absent in the ecological approach to river restoration.** It is worthwhile to monitor the changes in the wording employed in definitions in order to understand the positions of the authors. In the 1990s and 2000s, the term "use" was replaced by "service" and/or "function". **Rivers were no longer there to be used, but to provide services and functions.**

These conceptual changes were accompanied by modifications in the techniques for river restoration recommended in technical documents, according to the principle of adaptive management. The projects were generally organised as a succession of steps, starting with the preliminary studies, going through the definition of objectives and actual execution, and ending with monitoring and post-work assessments. Within this project framework, the work done also changed. **Over the two decades from 1990 to 2010, bio-engineering techniques became common in parallel with the publication of several technical documents specifically devoted to the topic.** At the same time, restoration techniques became more specialised and numerous documents were published on certain types of watercourse (streams, gravel-bed rivers), on specific river compartments (riparian vegetation, side channels) and on specific types of degradation (farmland streams, underground rivers, dams and weirs). The restoration work proposed in the technical documents dealt with the river bed and targeted a diversification of aquatic habitats (flow velocities, water depths, types of substrate). Recommended work also included modifying the river planform (notably meanders) and the cross profile. This work was often intended to counteract previous reshaping and rectification projects. Ecological restoration techniques also addressed the hydromorphological processes that produce the river-bed shape and dimensions. Interventions on hydrology and sediment transport were in some cases direct, e.g. in the form of sediment reloading, but also included the removal of certain hydraulic structures disturbing the flows. The work proposed in the technical documents concerned, on the one hand, lateral processes in the river (elimination of bank-protection systems and dikes), where the objective was to reconnect the river bed and the floodplain, e.g. by restoring side channels. On the other hand, the proposed restoration work dealt with longitudinal connections in order to ensure sediment transport and ecological continuity.

2.2. The international scientific definitions of river restoration

River restoration and notably the ecological approach to restoration is based on scientific research. Researchers participate intensely in the conceptual work. Content analysis of 288 definitions found in the international literature published between 1976 and 2011 revealed the many scientific concepts and definitions concerning restoration. These concepts are expressed in terms of the references used to set the objectives targeted by the restoration work. **Starting right from the first definitions, past references (sometimes called original references) were frequently used, i.e. the status of the river prior to any degradation** (see Figure 10). This type of reference was used in 32% of the studied definitions. However, the position of scientists with respect to these references is not entirely clear. Most authors agree that a complete return to the status of a river prior to the disturbances is difficult, if not impossible, but they continue to use the reference as the ideal situation. In 64% of the cases where past references were used, they were employed in conjunction with other references, which may be an indication that past references are not in themselves sufficient. **References to the naturalness of a river, untouched by human activities, were just as frequent as past references.** They were also used in the very first definitions and occurred in 33% of all the studied definitions. However, some authors are very careful in using natural references and speak of restoring a river to "nearly natural" or "quasi-natural" conditions. Even more than past references, natural references are backed up 89% of the time by further references, often ecological references.

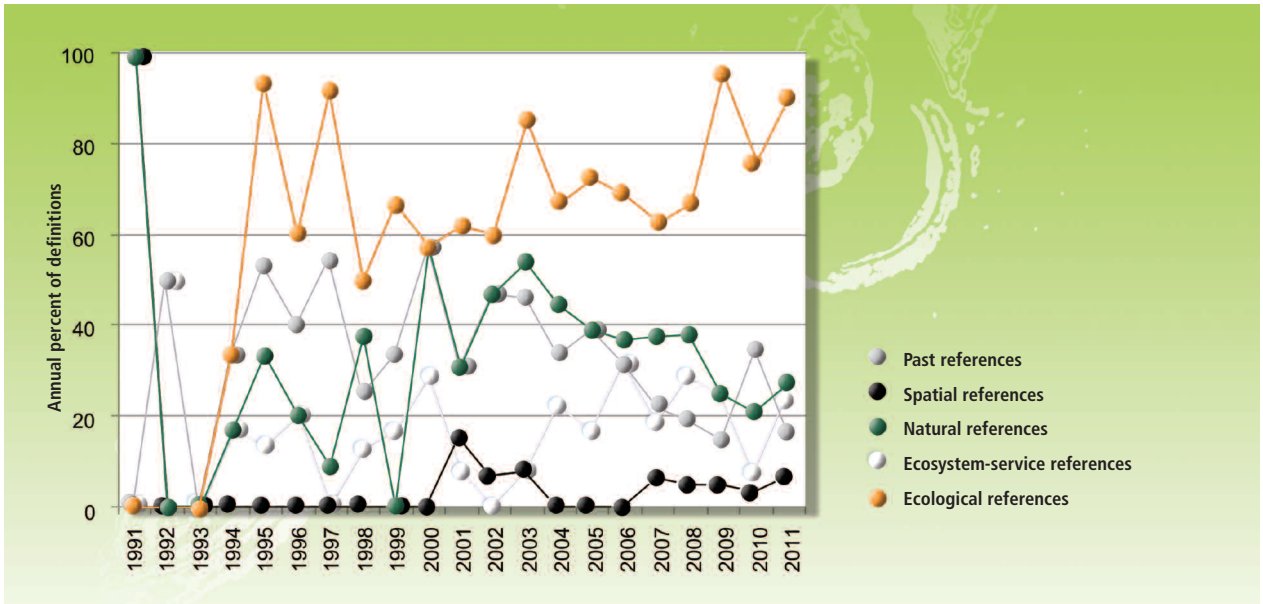


Figure 10. *Scientific definitions of restoration call on different types of references used to set restoration objectives. These references have evolved over time.*

Ecological references, i.e. those based on ecological concepts and more generally on the environmental sciences, are used in 72% of the studied definitions. **Restoration objectives expressed in scientific publications is not limited to an ideal past or to any positive values accorded to naturalness. As early as the 1990s, ecological references were frequently based on the concepts of the "structure" and "functions" of ecosystems** (see Figure 11). The concept of ecosystem structure, which may be linked to that of biodiversity, was used in 52% of the definitions based on ecological references. Ecosystem functions may be defined as all the interactions between the various elements of an ecosystem. This concept was used in 44% of the definitions based on ecological references. **The restoration of ecosystem structures and functions should enable a river to restore itself or at least to maintain its status following the restoration without any further human intervention.** In this case, the restoration work is seen as a form of assistance for nature. This approach, expressed in terms of "sustainability" and "resilience", was mentioned in 15% of the definitions based on ecological references. Some definitions perceive the river not as an object, but as an active subject. The objective is to "work with nature, not against it" or to consider "nature as a partner".

References tend to evolve over time. **Past references, though widely discussed over the last decade, appeared increasingly infrequently during the 2000s** (see Figure 10). This shift would also appear to apply to natural references, whereas in parallel, spatial references, i.e. references to an existing river taken as a model, increased. References based on ecosystem services were common in some definitions as early as the 1990s and would seem to have maintained their frequency at least up to 2011. **Ecological references were virtually omnipresent, but a change occurred at the start of the 2000s. They initially took the form of an historical and natural reference, but then changed and were subsequently expressed in terms of ecological improvements**, based on an optimum situation that remained to be defined, i.e. targeting an improvement rather than a condition in the past. An analysis of the different types of ecological reference confirmed this observation. Gradually over time, the notions of ecosystem structures and functions were increasingly described, but were no longer used as such in definitions. New notions came into play, such as stability, health, integrity and connectivity. **The emergent idea at that time was that a restored system should be stable, diversified in terms of its habitats and species, connected and capable of maintaining itself via its hydromorphological processes.**

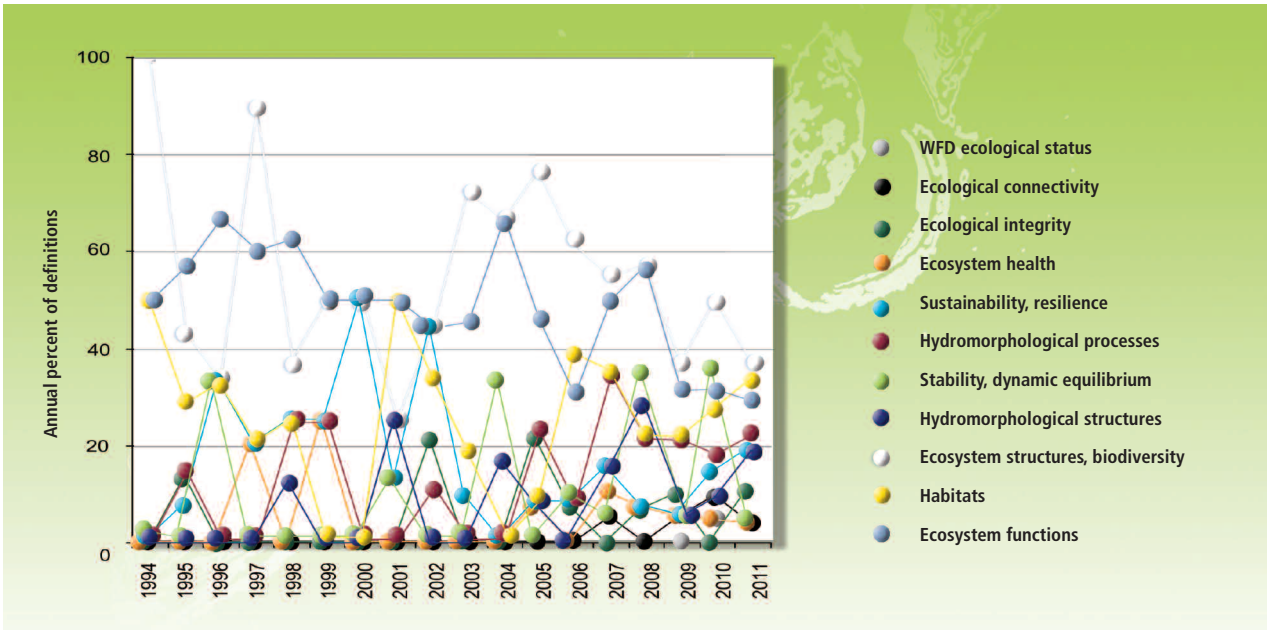


Figure 11. *Ecological references for restoration work are based on different concepts drawn from the environmental sciences. The manner in which these references are used has evolved over time.*

Some definitions focussed on habitat diversity, a notion that gained in importance as an ecological reference in the middle of the 2000s because it injected meaning into the notion of structure. This interest is due notably to what certain authors call the "field of dreams" hypothesis, which states that habitat restoration will result in a return of the species. The phrase generally used to sum up this hypothesis is that "If you build it, they will come". This hypothesis has been intensely debated in the scientific community, notably due to the fact that it has never been seriously validated. That being said, it serves as one of the basic guidelines for many restoration projects. **Habitat restoration is often thought to be based on a static vision of rivers,** of their "structures" and " functions". However, this perception should not be exaggerated. In most cases, the vision of the river was not static. It was rather a question of a dynamic equilibrium, to cite a restoration principle found in a number of definitions. **Hydromorphological processes were increasingly mentioned in ecological references and gained further in importance starting in the middle of the 2000s.** These references are linked to the concepts of ecological integrity and connectivity. This approach differentiates between restoration of river morphology and habitats, in a sense the structures of a river, and restoration of dynamic processes, of the connections that ensure the stability of the restored ecosystems, their resilience and sustainability.

But whether the restoration references are past, natural or ecological, **the underlying idea in many scientific definitions is that the human factor is synonymous with an altered environment.** The scientific discussions on "novel ecosystems" have not yet permeated the debates on restoration.

That being said, criticism of the natural ideal may certainly be found in the scientific literature. The question is no longer "can we restore a river to a natural or original state", but rather "is a natural or original state desirable". A number of authors have questioned the natural ideal even more directly by developing the idea of an ideal condition based on perceptions and collective representations, i.e. not exclusively on scientific knowledge. **Another idea put forward suggested that the reference is a river that provides a certain number of services for people or entire societies.** This approach to river restoration, that was developed during the 2000s, was noted in 17% of the studied scientific definitions. Whereas the natural ideal may be interpreted as expressing the intrinsic value of a river, the services approach brings to the fore its utilitarian value. However, that does not represent a reversal of the natural ideal in that the services approach does not replace the natural ideal, but rather often complements it. The utilitarian value is a positive factor and an argument used to justify the restoration work.

2.3. Going beyond the definition, the words used by researchers and managers for river restoration

The work on definitions resulted in increased levels of conceptual work and in a diversification of the terminology used in the restoration field. The concept of rehabilitation is a prime example that appeared in the scientific definitions starting in the early 1990s. In 59% of the scientific publications using both terms, no distinction was made between the two and each was used in defining the other. The two concepts, restoration and rehabilitation, were used in fairly similar proportions in the different references used for the definitions (see Figure 12). When a clear distinction is made, it refers to the scope of the work, i.e. whether it targets a complete or partial solution. **Whereas restoration is seen in the definitions as an ideal solution, a complete return to the river as it was prior to any degradation, rehabilitation is perceived as more partial.** The objectives of a rehabilitation are more feasible, more realistic, they take into account external factors limiting the scope of the project. **It is portrayed as a best possible solution under the circumstances, in contrast to an ideal restoration, a "complete restoration", which explains why the latter concept is more often linked to a past reference than is the concept of rehabilitation.** The concepts of renaturation and revitalisation appear infrequently in the scientific literature and remain poorly defined. However, renaturation does not refer to complete restoration and ideal conditions, as its etymology might suggest, and definitions do not place any particular stress on nature. On the contrary, the term refers to a targeted approach, focussing on certain river compartments, on its structure and habitats, whereas revitalisation is more concerned with functional aspects and processes. These terms are also used in a specific geographic context, i.e. primarily in the German-speaking countries.

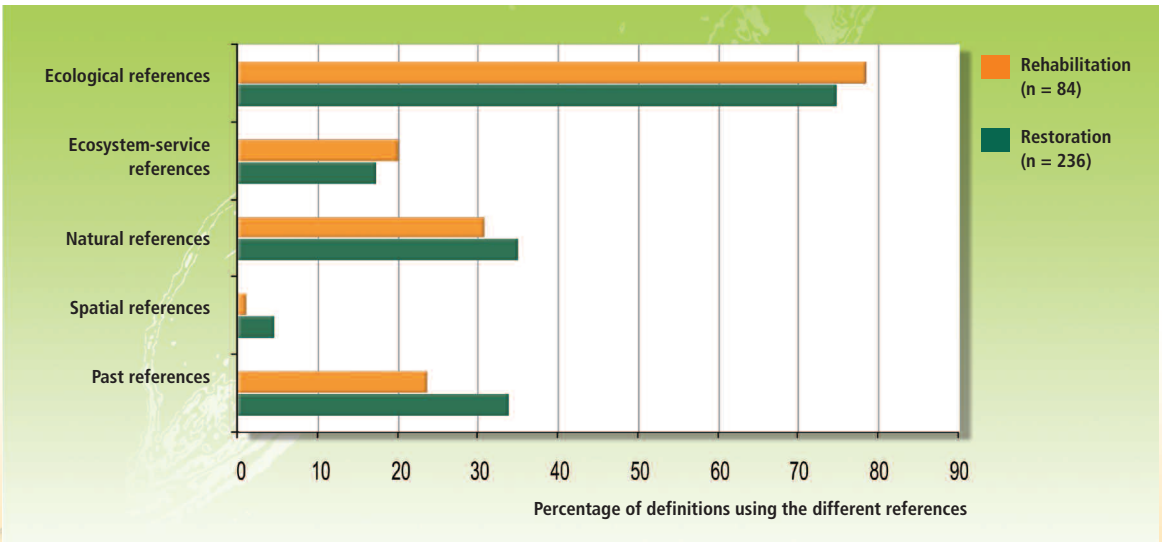


Figure 12. *There is little difference between the ecological references linked to the concept of restoration and those linked to that of rehabilitation.*

Contradictions may occur between the definitions used in a rigorous, theoretical context and those that appear in various documents, whether scientific or administrative. The distinction between the notions of restoration and rehabilitation does not exist purely on the conceptual level in the international scientific literature. An analysis of the frequency of the two in scientific publications revealed a spatial factor in their use. European publications use the concepts of restoration and rehabilitation, as well as those of renaturation and revitalisation. **The concept of restoration is much more frequently used in North America whereas the use of rehabilitation is specific to publications from Oceania and certain European countries. Strict distinctions are generally made between the two concepts in North-American publications, however in European publications, they are fairly commonly used as synonyms** (see Figure 13). Within Europe, differentiated usage would appear to be well established. Ireland, the U.K. and the Netherlands tend to use the term rehabilitation, in Germany and the German-speaking countries (Austria, Switzerland), the term renaturation is more frequently used and the term revitalisation stands out for its use in the Czech Republic (see Figure 14). Use of the term restoration would appear to be specific to Sweden, Denmark and France. In Germany, it co-exists with the term renaturation. **The analysis thus revealed a dynamic, changing and multi-faceted scientific debate, in which regional specificities nonetheless existed.** The scientific community has not become globalised, as is demonstrated by the vigour of the debates and schools of thought that exist in the different linguistic zones and political units. The latter may be a key factor in explaining the different scientific standpoints observed in the international literature..

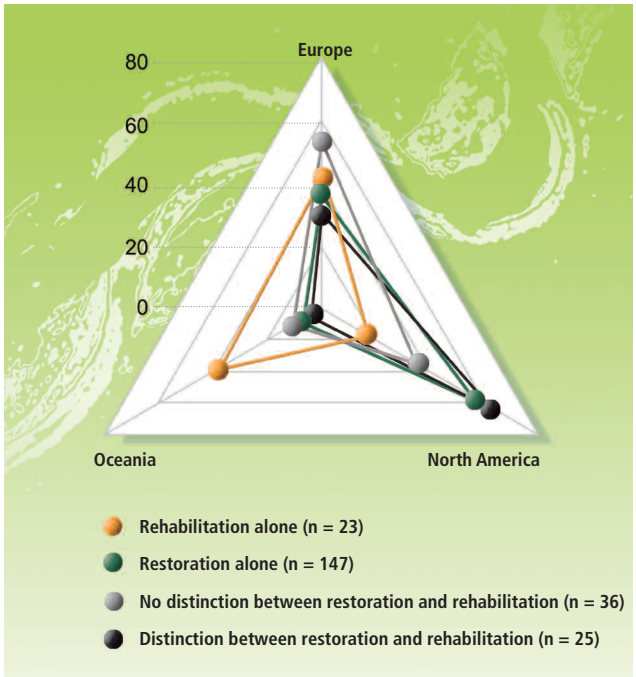


Figure 13. *The distinction made in scientific definitions between the concepts of restoration and rehabilitation corresponds to geographic contexts. The distinction is made essentially by scientists in North America whereas in European publications, the terms are frequently used as synonyms.*

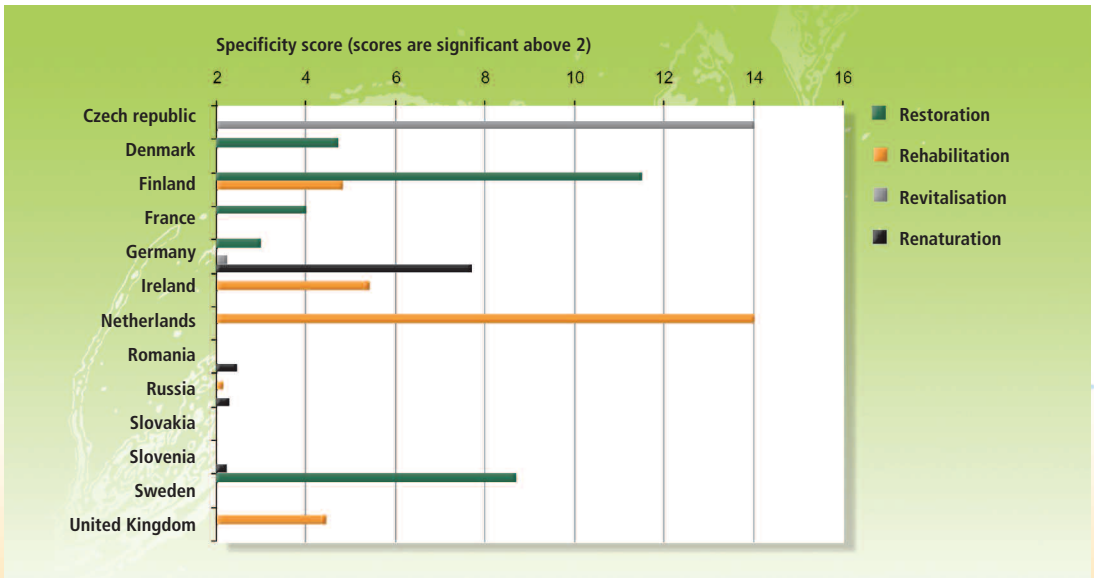


Figure 14. *The use of concepts in the abstracts of European scientific publications is largely specific to the different countries. The higher the specificity score, the more the country tends to use the concept.*

Water agency financial-aid procedures from the definition of funding programmes to the application forms for river-restoration work

As foreseen by the 1964 Water law, a Water agency "grants subsidies and loans to private and public entities for work in the general interest of the river basin or group of basins, said work being undertaken directly by the recipients, on the condition that the work will subsequently reduce the expenses of the Water agency". **Analysis of the subsidies granted is a valuable means to examine public policy in the field of river restoration.** Applications for subsidies or financial aid must go through a series of steps within an administrative procedure (see Figure 15) and the forms are archived by the Water agencies.

Textual statistical analysis was run on 4 089 occurrences of key words (restoration, renaturation or rehabilitation) in application forms processed by the Loire-Bretagne, Rhin-Meuse and Rhône-Méditerranée-Corse Water agencies from 1987 to 2011. Among those forms, 364 contained all the documents submitted during the various steps of the processing procedure and were subjected to an in-depth analysis of their contents.

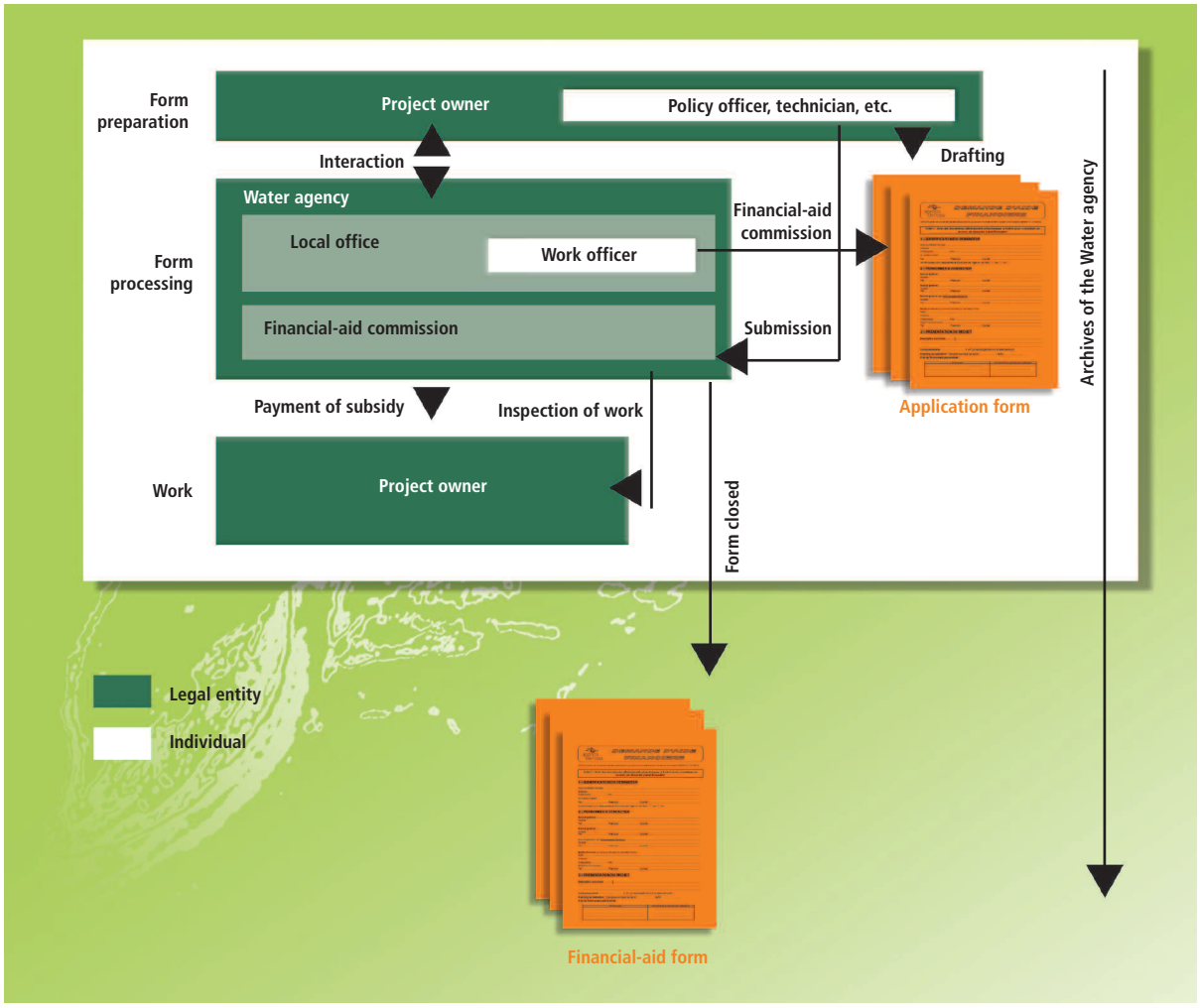


Figure 15. *Applications for financial aid go through an administrative procedure in the Water agency and the result is an application form. The form is not prepared by a single person or entity, but is generally the result of a consensus and interaction between the project owner and the Water-agency personnel.*

On the national level, an analysis of the financial-aid forms processed by the Loire-Bretagne (LB), Rhin-Meuse (RM) and Rhône-Méditerranée-Corse (RMC) Water agencies between 1987 and 2011 (see Methods box 2) also revealed a geographic distribution in the use of concepts (see Figure 16). **The concept of renaturation is specific to the documents produced by the RM Water agency. The RMC Water agency, on the other hand, uses the concepts of restoration and rehabilitation.** Geographic differences are also observable among the local offices within a given Water agency, notably within the RMC river basin. For example, the forms processed by the Besançon local office tend to use the concept of rehabilitation whereas the other local offices use the term restoration more frequently.

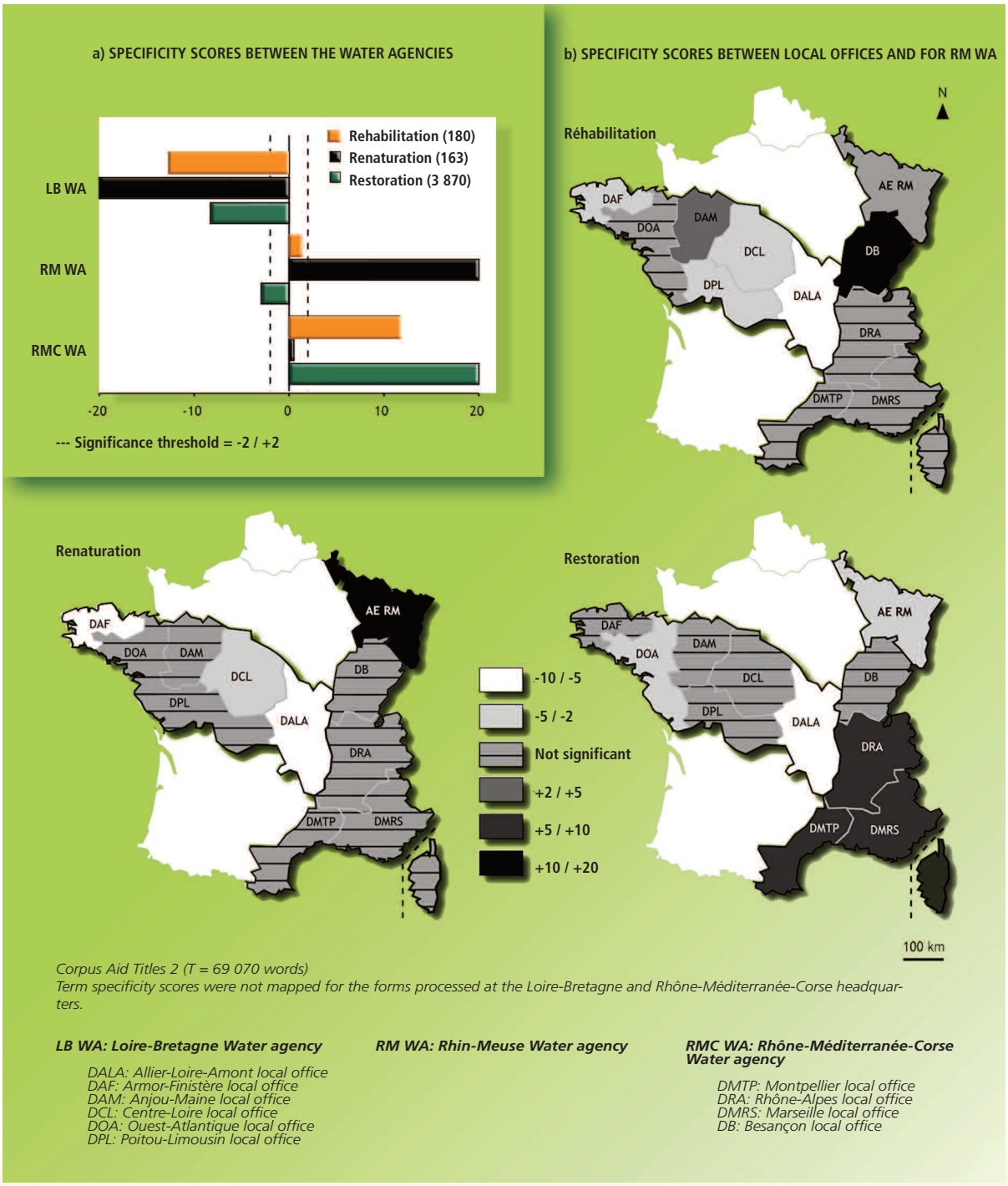
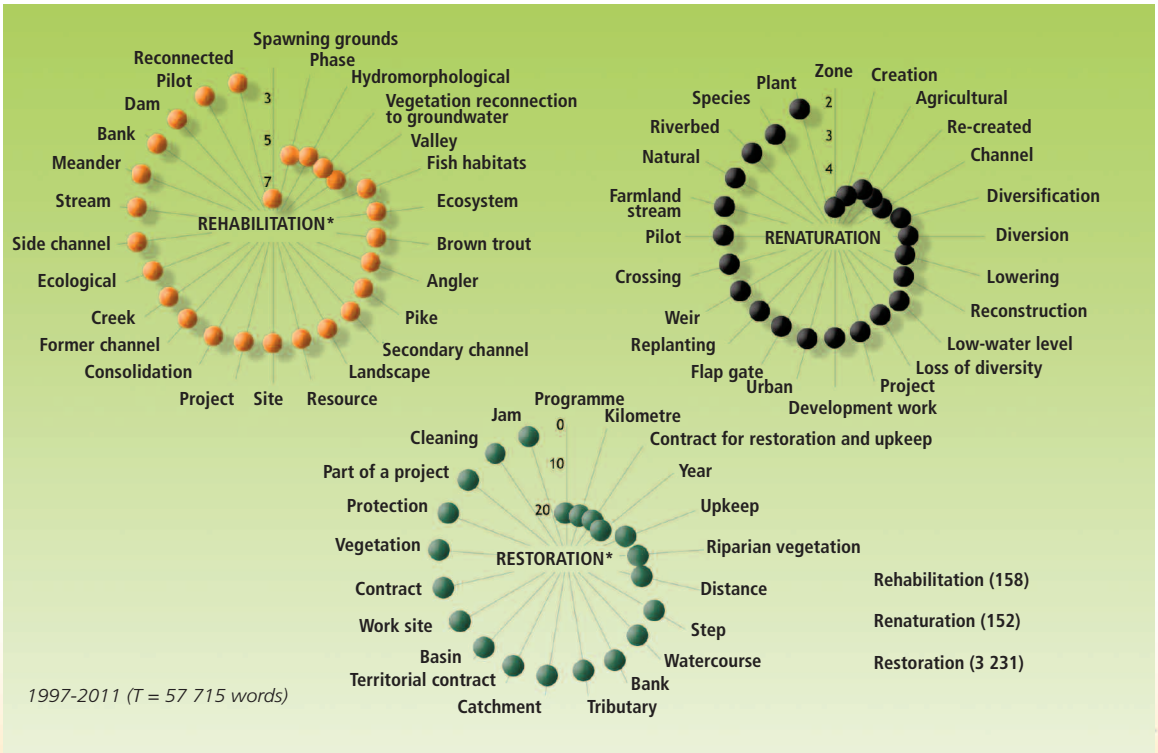


Figure 16. *The concepts of restoration, rehabilitation and renaturation are not used uniformly throughout France. Analysis of the geographic distribution of the concepts reveals different uses (a)* ***between the Loire-Bretagne, Rhin-Meuse and Rhône-Méditerranée-Corse Water agencies****, and (b) between the local offices within a given Water agency over the period 1987 to 2011. A positive specificity score indicates that a concept is frequently used in the given area. See B. Morandi et al, 2014.*

Over the period 1997 to 2011, the main terms associated with the concepts of restoration, rehabilitation and renaturation referred to different fields (see Figure 17). **The concept of restoration was more frequently associated with the notions of upkeep and cleaning.** In this context, the terms riparian vegetation, bank, vegetation and jam appeared often. Restoration often entailed terms referring to large-scale interventions on entire river basins, rivers, streams, tributaries. The work would appear to be divided into steps over time, in the framework of programmes or plans where significant importance is paid to the distances (length of river) covered. **The concept of renaturation often appeared in conjunction with terms pertaining to pressures and anthropogenic degradation,** e.g. agricultural, urban, flap gates, loss of diversity, weir. The concept was also closely linked to the term "project", which would suggest that the work targets precisely delimited areas. This impression is reinforced by the choice of terms concerning the hydrosystem compartments (side channels, river bed, etc.) targeted by renaturation work. Other terms used (creation, reconstitution, execution, detouring) concerned work requiring greater resources and equipment. **Finally, the concept of rehabilitation was specifically linked to terms concerning fish, e.g. spawning grounds, fish habitats, brown trout, anglers, pike.** Terms from the fields of hydromorphology and ecology were also noted (ecosystem, ecological) and types of environment were clearly identified, e.g. side channels, meanders, banks. Similar to renaturation, the work is closely linked to terms that evoke clearly delimited areas (site, project), even though they would appear to be spread over time (steps).

Via the terms selected, the persons involved tend to distinguish the various rationales and the approaches to the work that emerged over the period, notably concerning hydraulic and landscape restoration, as well as ecological restoration. The use of the term naturalisation, which suggests the ecological conception of restoration, is probably due to the influence of the German work in the field, which began earlier than in France and most likely filtered into the eastern sections of France. These analysis results on the use of concepts highlight **the divergence between scientific discourse which tends to use the term restoration in the ecological sense, whereas other people prefer the terms renaturation and rehabilitation, and reserve the concept of restoration for the hydraulic and landscape work done in the past.** This divergence is most likely due to the lack of interaction between the vocabularies used by scientists and water managers, even though the actual situations covered by the same term, restoration, may be contradictory. That is why it would appear important to encourage dialogue and better define the concepts underlying public policy.



** Terms for which the specificity score is > 2 and the co-frequency with the central term is > 2. Not included in the diagrams are punctuation, proper names and the following terms for 1) rehabilitation: view, their, iibsn, network, enable, coastal, cper, this, the, intermunicipal association, 2) renaturation: 1bl1, now, in, at, different, small, with, by, new, and 3) restoration: and, of, work, on, the, its, upstream.*

Figure 17. *Analysis of the terms used in conjunction with the concepts of rehabilitation, renaturation and restoration reveal different approaches to work on rivers. The more often a term is used in conjunction with a concept, the closer the term is to the centre of the spiral. See B. Morandi et al, 2014.*

3. Techniques of river restoration

3.1. Diversity of river-restoration techniques in France

Analysis of the financial-aid application forms processed over the period 1997 to 2011 by the Loire-Bretagne, Rhin-Meuse and Rhône-Méditerranée-Corse Water agencies (see Methods box 2) highlighted the diversity of river-restoration techniques employed in France.

The most frequent type of work dealt with riparian vegetation (see Figure 18) and represented 86% of all forms processed by the three Water agencies. On the other hand, the average amount of financial aid for this type of work was among the lowest (34 000 euros). It consisted essentially of upkeep on vegetation, e.g. trimming or more severe cutting back. In the RM river basin, this work on the riparian vegetation included planting along the river in 76% of the cases. **The second most frequent type of work dealt with the river bed itself.** The average amount of financial aid was roughly equivalent to that for the riparian vegetation (34 000 euros[6]). The objective of this work was to clear jams and obstructions in the river bed (76% of financial forms) and to remove alluviation deposits (21%). This work in the river bed also consisted of creating aquatic habitats, notably for fish, by installing large rocks and setting up shelter areas along the banks (24%). For the Water agencies, this work was the most expensive among that undertaken in the river bed given that the average amount of financial aid amounted to 55 000 euros. The RM Water agency carried out less work in river beds than the other two Water agencies.

The other types of work are less frequent (15% of financial forms). They dealt with the floodplain, consisting essentially of interventions on side channels (notably reconnection with the river bed) and on the erodable corridor. Other aspects included work on transverse structures (13% of financial forms). Projects dealing with the landscape, recreational features and river usage represented a very small proportion of the forms processed (8%). Generally speaking, these types of work were less frequent, but received higher levels of financial aid, notably those projects on the floodplain and on weirs and dams. Only one project mentioned work on hydromorphological processes (restoration of hydrology and sediment transport in the Rhône River) and it was this project that received the largest amount of financial aid (297 000 euros).

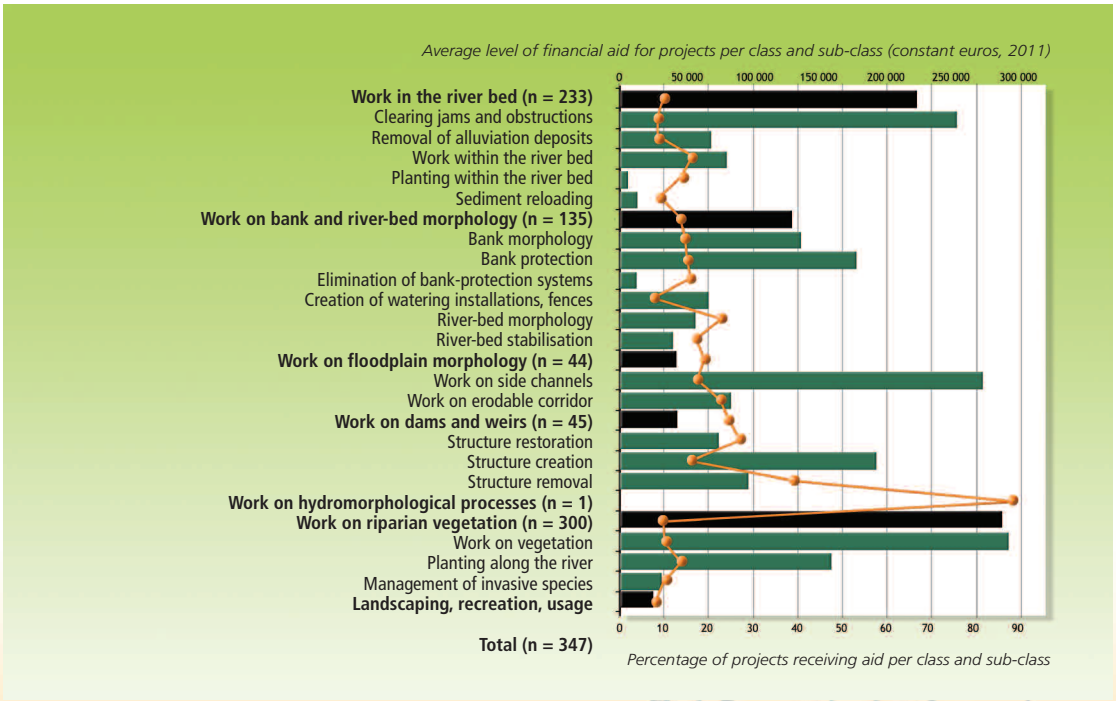


Figure 18. *River-restoration work with funding from the Loire-Bretagne, Rhin-Meuse and Rhône-Méditerranée-Corse Water agencies from 1997 to 2011. Projects addressing riparian vegetation and the river bed were the most frequent, but also those that received the lowest amounts of financial aid per project, whereas projects on river morphology or transverse structures were less frequent, but received higher levels of subsidies. See B. Morandi et al, 2016.*

6. 2011 constant euros, rounded.

Underlying these interventions are two conceptions of river restoration similar to those revealed previously by the analysis of the technical documents. **It is possible to distinguish between the work linked to hydraulic and safety objectives (as well as those addressing the cultural heritage, river usage and educational activities to raise public awareness) and that linked to ecological, hydro-morphological and physical-chemical objectives.** The first type of work concerns landscaping, interventions on vegetation, removal of jams, obstructions and alluviation deposits, restoration of dams and weirs and work to stabilise the river bed and banks. The second type concerns the elimination or modification of structures seen as constituting pressures (e.g. bank-protection systems, dams and weirs), development of the floodplain and the restoration of hydrological and sedimentary processes. The hydraulic and landscaping conceptions on the one hand and the ecological conceptions on the other are clearly identifiable in the implementation of the financial-aid policies by the Loire-Bretagne, Rhin-Meuse and Rhône-Méditerranée-Corse Water agencies.

These two conceptions of river restoration co-existed in the projects carried out from 1997 to 2011. Objectives and techniques did not change, but rather became more diverse. What is more, the different objectives are not mutually exclusive. In fact, 57% of the projects citing an ecological objective and 67% of those citing a hydraulic objective also mentioned the other objective. The two types of objective were closely related up until 2007 (see Figure 19). Starting in 2008, the ecological objective tended to dominate, but the absence of complete data for the year 2011 made it impossible to confirm this trend. Trends are even less clear in the work actually done because the latter has become more diversified, in parallel with the objectives. **In addition to work on removing jams and alluviation deposits that was carried out fairly regularly up until 2011, projects to develop aquatic habitats increased considerably in number starting in 2003.** Sediment reloading and planting in river beds increased starting in 2006. Similarly, efforts against invasive species in riparian vegetation started only in 2003, whereas general work on vegetation and planting was undertaken regularly from 1997 to 2011. Finally, whereas initial projects on dams targeted their restoration, **projects to modify dams, e.g. fish passes, did not become frequent before 2006, similar to efforts to remove dams which took place for the first time in 2003,** before becoming much more frequent starting only in 2009. Generally speaking, the first restoration projects dealt with hydraulics and landscaping, to which projects focussing on ecological aspects were added, but without replacing or reducing the first.

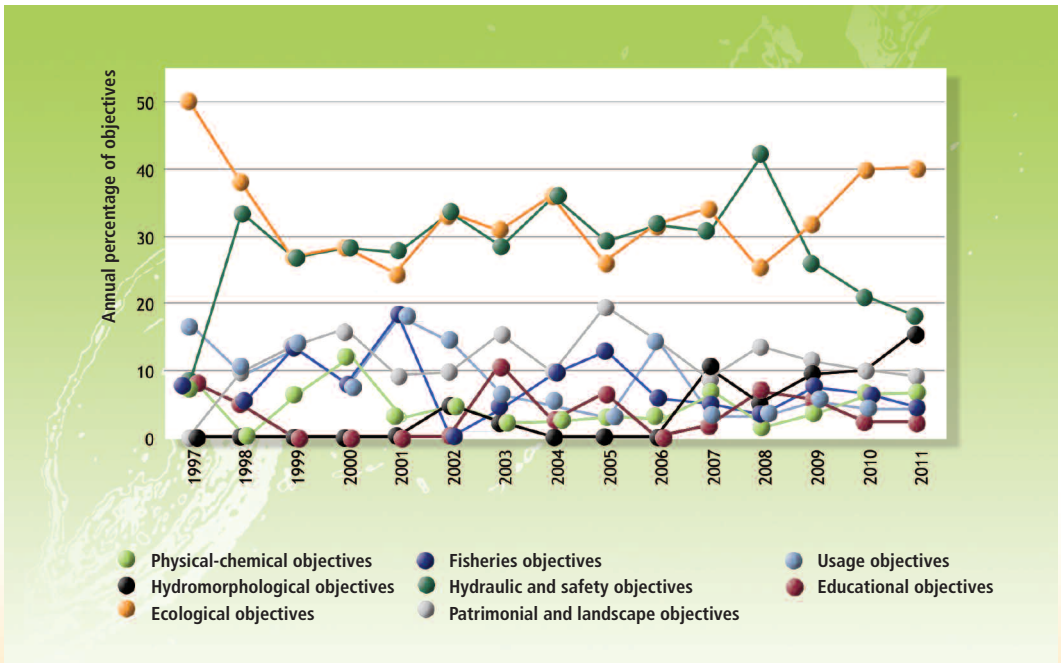


Figure 19. *The objectives for river restoration presented in financial-aid applications changed relatively little from 1997 to 2011. Ecological and hydraulic objectives co-existed perfectly until 2007. Then, starting with the ninth funding programmes, a notable change in objectives occurred, even though the data for 2011 are incomplete. See B. Morandi et al, 2016.*

3.2. Ecological-restoration techniques in the WFD context

A total of 102 French restoration projects, identified via a national inventory (see Methods box 3), were analysed to determine the techniques specific to the ecological conception of river restoration. The French restoration projects were also compared to 270 projects conducted in Germany (Morandi *et al.*, 2017).

3

Methods box 3

Inventorying ecological river-restoration projects in France and Germany

Starting in the 2000s, water managers and researchers started to inventory ecological restoration projects for rivers in order to assess the work (Pierron, 2005; Adam *et al.*, 2006; Malavoi *et al.*, 2007; Morandi, 2010; Onema, 2010; Morandi & Piégay, 2011) (see Figure 20). The data was reused to propose an updated summary for the current research project. The list of projects is not complete. It contains primarily those projects deemed outstanding by the authors compiling the list.

A standard format was used to characterise each project:
- the geographic position and administrative context;
- a list of pressures identified and declared by the stakeholders involved in the project;
- a list of degradation identified and declared by the stakeholders involved in the project;
- the length of river affected by the work;
- a general chronology of the project, comprising four major waypoints, namely the beginning and end years of the work and of the measurement campaigns to assess the project;
- a list of objectives declared by the stakeholders involved in the project;
- a list of the work carried out.

The results of this summary were compared to those of an inventory of restoration projects carried out in Germany, using the same data format (Morandi *et al.*, 2017).

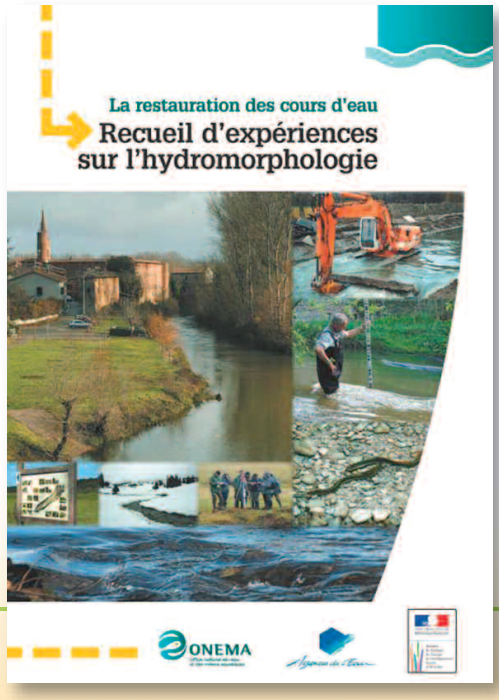


Figure 20. *The collection of data sheets on hydromorphological projects for river restoration, intended for water stakeholders and local partners, presents over 80 examples of projects carried out over the past 20 years in continental France. It is currently the main summary of data for France in this field.*

Changes in the numbers of ecological-restoration projects launched correlated with the numbers of requests for financial aid for restoration work noted earlier. **The first projects emerged in the beginning of the 1990s, when a major shift from "hydraulic and landscape restoration" to "ecological restoration" occurred in the scientific and technical sphere and in the guidelines for public policy.** The number of projects rose steadily over the studied period.

The geographic differences in the numbers of projects launched were greater than they were in the intervention policies of the various Water agencies. **In terms of the major river basins, project densities with respect to the total length of hydrographic networks indicated that the highest levels of activity were in the Rhin-Meuse and Rhône-Méditerranée-Corse basins.** In terms of the administrative regions[7], the Rhône-Alpes region alone represented 25% of all projects in France. The regions in eastern France, namely Lorraine (10%), Alsace and Franche-Comté (8%), were the next most active regions in terms of the number of projects. These four regions were also those that had the highest project densities with respect to the total length of their hydrographic networks. The regions with the lowest project densities were Corse, Aquitaine, Provence-Alpes-Côte-d'Azur and Auvergne.

The comparison between the number of projects in France and Germany over the period from 1960 to 2009 revealed a number of projects in Germany almost twice that in France (see Figure 21). Approximately 576 kilometres of river were restored in Germany, compared to only 401 km in France, which corresponds to 0.6% and 0.2% respectively of the national hydrographic networks[8]. There are a number of hypotheses to explain this difference in the two situations. One is the greater degradation of German rivers which require more numerous restoration projects. German river basins are among those most severely impacted by hydromorphological pressures in Europe. The quantitative difference may also be explained by differences in the perception of degradation, linked to differences in how societies see their relationship with nature. This idea must be studied further because the differences are not necessarily related to environmental perceptions, but to different political reactions to the perception of ecosystem degradation (Morandi *et al.*, 2017).

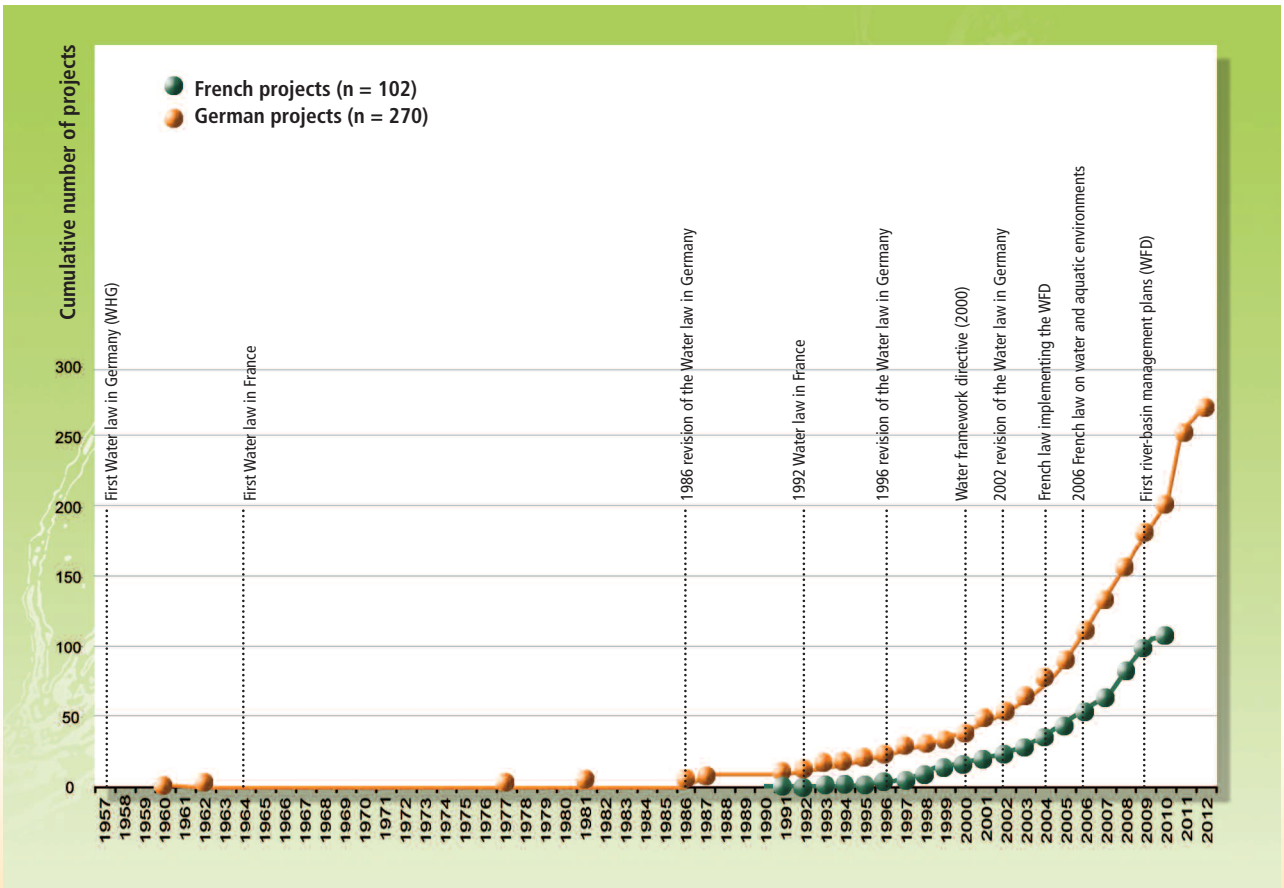


Figure 21. *Numbers of ecological river-restoration projects in France and Germany from 1957 to 2012. See B. Morandi et al, 2017.*

7. The names of regions used here are those in effect at the time of this study (2011 to 2014), prior to the reform adopted in 2015.
8. European Environment Agency (EEA), 2012. Catchments and Rivers Network System ECRINS v1.1. Rationales, building and improving for widening uses to Water Accounts and WISE applications. Technical report, 7/2012.

Most of the ecological-restoration projects studied in France and Germany took place in areas that were agricultural or partially agricultural in nature (see Figure 22). The only notable discrepancy between the two countries concerned projects in urban areas, of which there were a greater number in Germany. **Morphological pressures were the main issue for the restoration projects in both countries,** respectively 76% in France and 94% in Germany. Problems dealing with channelisation and habitat damage were noted more frequently for projects in Germany. Conversely, river fragmentation and sand and gravel mining were more frequently mentioned in French projects. Other pressures such as pollution, abstractions and discharge management constituted secondary issues in restoration projects in both countries.

Mirroring the high importance placed on river fragmentation in France, breaks in ecological continuity were the main degradation reported (12% of all mentioned degradations). The second most cited degradations concerned damage to or loss of aquatic and river-bank habitats (10%), followed by greater environmental uniformity in river beds and clogging (9%). Damage caused to living beings would appear to often be the reason for restoration work, primarily the negative effects of pressures on animals and to a lesser degree on plants. Morphological degradations were declared less often, for example breaks in the continuity of sediment transport were mentioned less frequently than breaks in ecological continuity. River-bed downcutting and bank erosion were the morphological degradations most commonly noted, followed by the disconnection of side and secondary channels. **Alterations in hydrological processes were cited infrequently.** Degradations cited as the reason for projects targeting ecological restoration included effects on landscapes and the safety of life and property, however these topics represented a small minority.

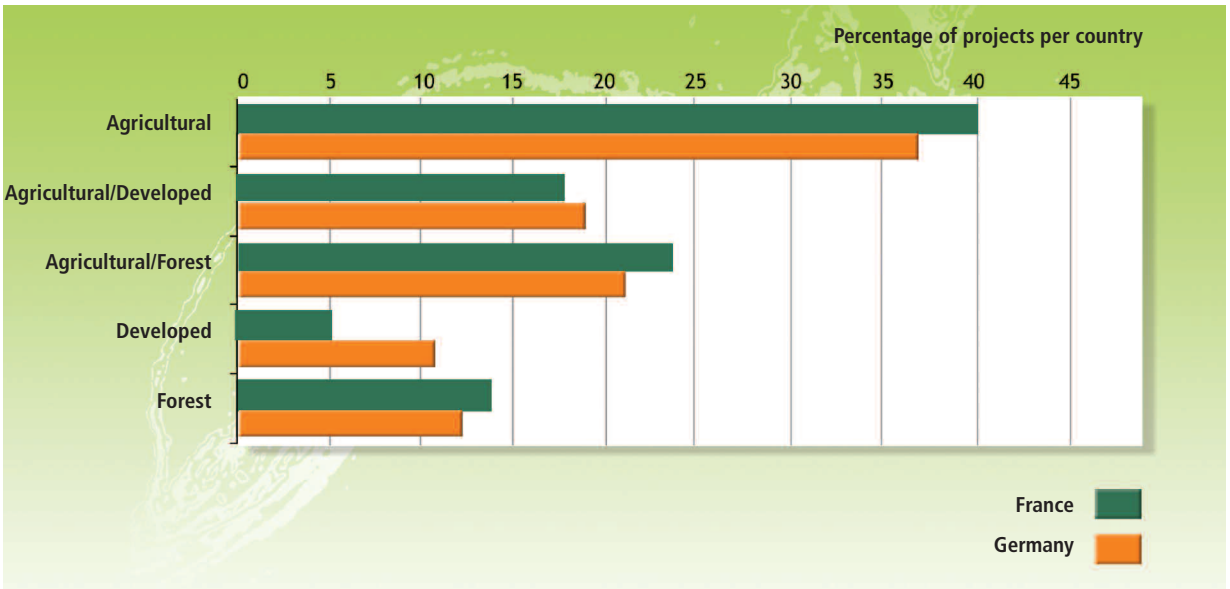


Figure 22. *Most projects for ecological restoration took place in France and Germany in agricultural or partially agricultural areas. See B. Morandi et al, 2017.*

In France, the objectives set by project owners prior to launching restoration projects are ecological 37% of the time. It should be noted, however, that in some cases the ecological objectives for river projects refer to a level of ecological quality that is not defined. Among those cases, a majority focus on the restoration of aquatic habitats and on ecological continuity. Conversely, other objectives zoom in on the fish compartment and even on certain "target" species. Objectives can also be hydromorphological in nature (23% of objectives), however it is not always clear how they differ from objectives concerning the restoration of aquatic habitats. Some more specifically target the restoration of sedimentary and hydrological processes. Mention must be made of the importance placed on social objectives, notably landscape quality, flood control, the safety of life and property and recreational activities. Finally, other objectives concern educating and raising the awareness of the public and water stakeholders.

The work done in the framework of restoration projects differs significantly between France and Germany (see Figure 23). Work on the morphology of rivers is the most common and is a component in 97% of projects in Germany and 72% of projects in France. **Work in the river bed is particularly frequent.** The results indicate that there is a clear link between the pressures and degradations declared and the work done to correct the situation (Morandi, 2014). Only a small proportion of projects, in both France and Germany, include work addressing hydromorphological processes (hydrology and sediment transport). **The main differences noted between France and Germany concern the different types of work in the river bed.** German projects comprise a highly diverse set of measures in the river bed such as the elimination of structures stabilising the river bed or bank-protection systems, the introduction of dead wood and gravel, and the creation of shelters for fish. French projects, on the other hand, deal essentially with the gravel reloading and large stones to initiate natural dynamics in the river bed. **The introduction of dead wood was not noted in any of the French projects.** The absence may be explained by differences in perception and management approaches to wood in rivers, in conjunction notably with work to restore the free flow of water that is still very common in French policies for river management (Morandi *et al.* 2016). In addition to the issue of work in the river bed, German projects also implement various measures concerning the river planform (re-creating meanders, braiding, restoration of lateral dynamics), whereas French projects focus essentially on re-creating meanders. **Finally, a notable difference concerns ecological continuity** with 35% of French projects addressing this topic, compared to only 18% of German projects. It should, however, not be forgotten that **the comparison between France and Germany revealed a far higher level of restoration activity in Germany than in France.**

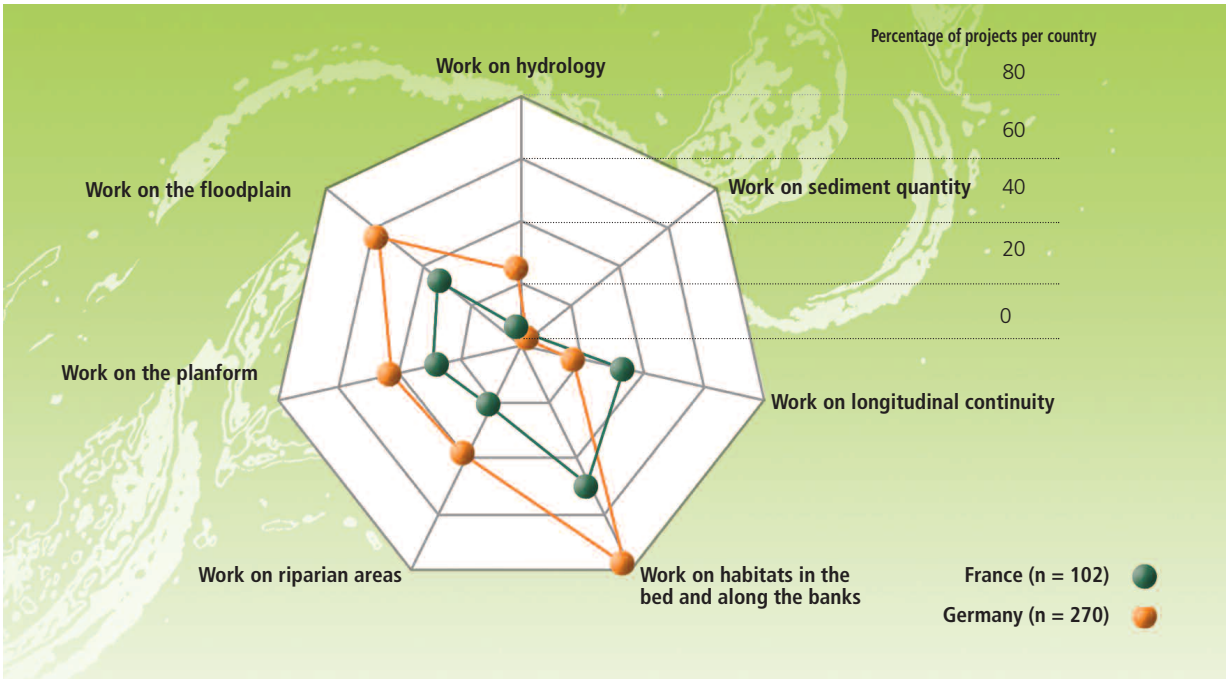


Figure 23. *The types of ecological restoration of rivers differ significantly between France and Germany. The main differences concern work on longitudinal continuity, a dominant sector in France, and work on habitats in the river bed, a dominant sector in Germany. See B. Morandi et al, 2017.*

4. Current issues and strategies for river restoration

The 1990s and 2000s are presented by river managers as an experimental period in ecological restoration that has now given way to assessments and prospective studies (see for example Roux-Michollet *et al.*, 2013; Sala *et al.*, 2013).

The results of this study indicate that the knowledge and experience gained by stakeholders in the water and aquatic-environment fields over the past decades reveal the increasing importance of river restoration within public policy and explicitly raise the question "Which rivers do we want to restore?".

The old questions raised by researchers via intentionally controversial formulations such as "Recreating nature" (Barnaud & Chapuis, 1999) or "Which natures do we want?" (Lévêque, 2003), would seem to have had little impact on public policy in the field of river restoration. Now, at a time when biophysical-restoration values are increasingly accompanied by other values, notably economic and social values (Bouni, 2014), it would be worthwhile to relaunch the debate in a clear and open manner. By offering people an active and positive approach to river management, the concept of restoration encourages this process. Use of the restoration concept in effect acknowledges that rivers can be modified and that the modifications can lead to gains as well as losses of value (for all types of value). Use of the restoration concept also implies a responsibility for the losses of value, not in terms of guilt, but rather in terms of prudential concern and the assumption of that responsibility. This approach would seem to be conducive to a discussion, an explicit description and a definition of the values that should guide work. The objective is to launch an ethical debate, based on our knowledge of the environment and of society's relationship with the environment.

The strategic proposals made here contribute to this process of collective debate by providing analytical results for the discussion on the questions raised by river restoration.

This discussion would appear all the more necessary given that the WFD deadlines for 2021 and 2027 highlight the need to take action. The work for ecological restoration has increased significantly since 2006, notably on the part of the Water agencies that prepared the implementation of the river-basin management plans (RBMP) for 2015 and recently formulated the Eleventh funding programmes for 2018. These debates and discussions take on particular meaning in light of the recent Biodiversity, nature and landscapes law (2016) that created the French biodiversity agency (AFB) and assigned it the mission of contributing to preserving, managing and restoring the biodiversity of terrestrial, marine and aquatic environments. AFB is notably in charge of conducting and supporting research and prospective studies, contributing to identifying necessary research and undertaking conservation and restoration work.

4.1. Modifying the references used for river restoration

The topics discussed here also question the notion of the references on which river-restoration work is based and notably the notion of "good status" as defined by the WFD (2000). Ecological and physical-chemical references play an important role in implementing public policy, but there should be no reason, after 15 years of study and work in the WFD context, not to take a new look at them. Given a river-restoration project designed according to the integrated operational approach stipulated by the 1992 Water law, **it is worthwhile to raise the issue of new environmental references based on different types of values. These references must make it possible to address biodiversity and environmental functions in terms of their intrinsic value and the related benefits for society, as well as their safety, aesthetic, affective and economic aspects.** This implies looking into the very nature of the references. Those set up in the WFD framework are quantitative indicators based on an ecological references. The idea of creating social indicators in conjunction with the existing biophysical indicators is appealing, but raises further ethical and methodological questions.

It would seem important that an ethical debate on restoration references be public. The WFD is based on expert scientific input. In view of defining environmental references, a different, more open approach would appear necessary. The references should be socio-political in the sense that they would be the expression not of scientific truths, but of the objectives of society, based on scientific knowledge and promoted politically. Public consultations, such as those carried out in 2013 for the RBMP revisions, contribute to legitimising public policy in the field or river restoration, but would not seem to be suitable for setting guidelines. The issue here is not simply having a project accepted by the public. Public wishes and choices must also be taken into account. **Public discussions would appear, in principle, to be acceptable for creating references on the condition that all environmental stakeholders accept to participate.**

This necessarily leads to a second question concerning the spatial and temporal scales used in defining the references. It would be a good idea to devise references capable of evolving and adapting, given that the relationship between society and rivers will not necessarily be the same in the future. This implies organisations capable of bringing environmental stakeholders together for regular and long-standing discussions. In France, such organisations already exist thanks to the 1992 Water law, certainly the most innovative law in this field in France. It would perhaps be worthwhile to create the ways and means to **include the results of these discussions in the sub-basin management plans (SBMP) and the river contracts in order to gain a simultaneous overview of all the issues at hand, given that ecological restoration is but one field of action among others.** Environmental references cannot, however, be set up for the entire hydrographic network, but must take into account the different geographical contexts and the interactions between societies and rivers.

4.2. Restoration in the framework of the integrated management of water and aquatic environments

River restoration based on new environmental references can produce effective results only if it is one part of an integrated water-management system for water and aquatic environments. That principle was laid down by the 1992 Water law, but ecological-restoration work, generally designed with a specific project in mind, has strayed from the management guidelines. Today, it is important to work toward a new form of restoration that takes into account the various issues relating to rivers, by basing that work on clearly stated values and defining the terms used in order to avoid misunderstandings and to converge toward options for which there is consensus.

To avoid potentially contradictory approaches, study must be put into better integrating ecological and usage objectives. The Management of aquatic environments and flood prevention policy (GEMAPI, 2014) would appear, in its approach to problems, to be an excellent example of an integrative policy. Ecological restoration and flow-capacity restoration are management objectives among others and must be integrated in a more comprehensive management strategy, in terms of both the concepts and the practical work. The analysis of the current situation produced by this research project leads the authors to recommend a reinforcement of the non-degradation principle and of the linked concepts of conservation and preservation. Ecological restoration, due to its active image, would tend to become the emblematic feature of public action in favour of the environment. Though important from the ethical and operational point of view, ecological restoration must be positioned as a second-order concept, as noted in the first article of the WFD (2000). The expression "when conservation is not enough" has become common. It is necessary to firmly add "when restoration cannot do everything".

River restoration must be coordinated with the other policies for territorial management. Above and beyond the multi-faceted approach, it is essential to take into account the diversity of the territories in which the work will be carried out. The objective is to rethink the links between restoration and the concepts and tools of territorial management. Most restoration work is undertaken in agricultural settings. Given that factor, it may be worthwhile to design the work in conjunction with the sector policies, notably in terms of the necessary study on the issue of the land required for restoration work and, more generally speaking, agri-environmental incentives. The land issue is also important in urban areas where coordination with urban-development instruments is all the more necessary that pressures on real-estate are high. Inclusion of ecological restoration in the preparation of local urban planning documents (PLU), which already take into account flood risks, would be a first step. **Justification for this approach in view of achieving integrated restoration is even greater in that urban planners have already developed other concepts to recover, renovate and renaturalise river banks** focussing more on social objectives than on ecological objectives.

4.3. Learning to adapt restoration techniques

It is also worthwhile to draw the lessons from the comparison between restoration techniques used in France and Germany. The comparison demonstrates that **an identical regulatory framework does not always produce identical techniques.** Differences in restoration practices are observable notably in terms of ecological continuity and the placing of dead wood in the river bed. Environmental factors specific to each country and diversity in the types of pressures weighing on environments may partially explain national differences, however other factors are also certainly involved. For example, **the perceptions and uses of rivers, dissemination of knowledge and the manner in which public policies are implemented may influence management decisions, including the technical aspects of those decisions.** Has scientific research in France on restoring river continuity for fish and in Germany on placing wood in rivers contributed to influencing public policies in this field?

These questions are difficult to answer, but they highlight the fact that the study of techniques is a means to put into perspective the scientific foundation on which they are based, to point out the uncertainties in the implementation of these policies and to adapt techniques in step with our understanding of the social and environmental responses to the policies and of the mechanisms involved. **It is important to receive feedback on techniques, to benefit from external and varied opinions made possible by the contacts between communities in Europe, in order to adjust those techniques and to better define them with respect to references established in a framework designed for balanced and associative management.**

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The results presented in this *Knowledge for action* document are drawn from an exploratory research project (Overall approach and review of river restoration in France and Germany[1]) examining the definitions and techniques used for river restoration. What does river restoration consist of? The objective was to address this question in the French and foreign contexts, by assessing existing definitions and techniques. The results served as the basis for operational discussions carried out with AFB and the Water agencies in view of facilitating implementation of public policy in this field.

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Bibliography

- Adam P., Debiais N. et Malavoi J.R., 2006. Retour d'expérience d'opérations de restauration de cours d'eau et de leurs annexes, menées sur le bassin RMC, Agence de l'Eau Rhône-Méditerranée & Corse, 129 p.
- Barnaud G. et Chapuis J.L., 1999. De l'écologie de la restauration à l'ingénierie écologique, où en est-on ? Courrier de l'environnement de l'INRA, No. 36, pp. 117-123.
- Bouni C., 2014. Comment développer un projet ambitieux de restauration d'un cours d'eau ? Retours d'expériences en Europe, un point de vue des sciences humaines et sociales, Onema - Collection Comprendre pour agir, 28 p.
- Cacas M., Degoutte G., Dutartre A., Gross F. et Vuillot M., 1986. Aménagement de rivières : trois études de cas. Ministère de l'Environnement, délégation à la qualité de la vie, direction de la prévention des pollutions et ministère de l'Agriculture, direction de l'aménagement, 68 p.
- Clewell A. F. et Aronson J., 2010. La restauration écologique. Principes, valeurs et structure d'une profession émergente. Actes Sud, 340 p.
- Lalanne-Berdouticq G., 1985. Aménagement et entretien des rivières en milieu rural. Méthode d'étude et technique de travaux. Ministère de l'Agriculture, direction de l'aménagement, service de la mise en valeur, de l'hydraulique et du développement rural, 154 p.
- Lebart L. et Salem A., 1994. Statistique textuelle, Dunod, Paris, 342 p.
- Lévêque C., 2003. Quelles natures voulons-nous ? Quelles natures aurons-nous ? in Lévêque C. et Van Der Leeuw G., Quelles natures voulons-nous ? Pour une approche socio-écologique du champ de l'environnement. pp. 13-21.
- Loupsans D., 2014. La compétence « Gestion des milieux aquatiques et prévention des inondations » (Gemapi). Onema, coll. Comprendre pour agir. 4p.
- Malavoi J.R., Adam P. et Debiais N., 2007. Manuel de restauration hydromorphologique des cours d'eau. Agence de l'eau SeineNormandie, 168 p.
- Mettoux-Petchimoutou AP., 2015. Synthèse Carteau-Eaux et milieux aquatiques : panorama des acteurs de la Recherche et Développement en France. OIEau, Onema, mai 2015, 47 p.
- Morandi B., 2014. La restauration des cours d'eau en France et à l'étranger : de la définition du concept à l'évaluation de l'action. Éléments de recherche applicables. Thèse de doctorat, ENS de Lyon, 430 p. (https://tel.archives-ouvertes.fr/tel-01126880).
- Morandi B., Kail J., Toedter A., Wolter C., Piégay H., 2017. Diversity of approaches in implementation and monitoring of river restoration. A comparative perspective in France and Germany. Environmental Management, 60, 5, pp. 931-946.
- Morandi B., Piégay H., Johnstone K. et Miralles D., 2016. Les agences de l'eau et la restauration : 50 ans de tension entre hydraulique et écologique. Vertigo, 16-1 (https://vertigo.revues.org/17194).
- Morandi B., Piégay, H., Lamouroux, N. et Vaudor, L., 2014. How is success or failure in river restoration projects evaluated? Feedback from French restoration projects. Journal of Environmental Management, 137, pp. 178-188.
- Morandi B. et Piégay H., 2011. Les restaurations de rivières sur Internet : premier bilan, Natures Sciences Sociétés, Vol. 19, pp. 224-235.
- Onema, 2010. La restauration des cours d'eau - Recueil d'expériences sur l'hydromorphologie, Onema, MEEDDM, agences de l'eau (http://www.onema.fr/Hydromorphologie,510).
- Pierron F., 2005. Restauration physique des cours d'eau dans le Nord-Est de la France, CSP, 18 p.
- Rivière-Honegger A., Cottet M. et Morandi B. (coord.), 2014. Connaître les perceptions et les représentations : quels apports pour la gestion des milieux aquatiques ? Collection Comprendre pour agir, Onema, 180 p.
- Roni P. et Beechie T., 2012. Stream and Watershed Restoration: A Guide to Restoring Riverine Processes and Habitats, John Wiley & Sons, ltd, Chichester, UK.
- Rostaing H., 1996. La bibliométrie et ses techniques, Sciences de la Société, Centre de Recherche Rétrospective de Marseille, Toulouse, Marseille, 131 p.
- Roux-Michollet D., Clémens A., Montuelle B. et Marmonier P., 2013. Prospective sur les actions de recherche sur la restauration et la remédiation écologique des milieux aquatiques - Document de synthèse à destination de l'Onema - Journées d'étude les 11 et 12 mars 2013, Juin 2013, CNRS, INEE, Zones Ateliers, 56 p.
- Sala P., Jannes-Ober E. et Lamblin V., 2013. Eau, milieux aquatiques et territoires durables 2030 - synthèse de l'exercice de prospective. Commissariat général au développement durable, n°91, Août 2013, 52 p.

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