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# River Restoration: Potential and limitations to re-establish riparian landscapes. Assessment & Planning.

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*The researcher investigates the river,*
*the engineer tames the river by means*
*of concrete and exponential equations.*

*But the rambler loves the river.*

*(Silvio Blatter, Wassermann, 1986)*

*Nicht in der Erkenntnis liegt das Glück,*
*sondern im Erwerben der Erkenntnis*

*(Edgar Allan Poe)*

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# Contents

## Summary

This study presents methods and indicators for the evaluation of restoration measures (river widening) along rivers (papers 1 and 2) and shows the results obtained from several case studies on Swiss rivers. This study also introduces an integrated search strategy for identifying promising areas (judged according to both ecological and socio-economic criteria) as a guide for future restoration planning (paper 3). The evaluation is based on a comparison between (i) river widenings, (ii) canalized rivers (regulated reference) and (iii) near-natural stretches (near-natural reference).

The findings about methods and indicators to evaluate restoration success can be summarized as follows:

<u>Indicators</u>

- Landscape metrics allow the restored landscape configuration and composition to be quantified. They are surrogates for landscape function and thus valuable indicators for assessing the potential of re-establishing riparian biocoenosis. The proposed core set of landscape metrics includes: Mean Shape Index, Median Patch Size, Mean Nearest Neighbour, Mean Proximity Index, Interspersion and Juxtaposition Indx, Edge Density, % Area, Patch Richness (paper 1).
- The degree of dependency of the plants found at a restored site on riparian habitats indicates the naturalness achieved by the restoration measures. A list of riparian (semi-) terrestrial plants is presented to guide future assessment procedures (Appendix).

Stencil technique

The application of landscape metrics is limited when comparing landscapes that differ in size (river widening, near-natural reference). Therefore the GIS-based "stencil technique", which can handle this problem was developed. It is described in detail in paper 1.

Computing of similarity indices

- Computing similarity indices allows quantifying the degree of naturalness achieved through restoration measures and thus a quick and clear rating of the performance of restoration projects.
- The degree of naturalness at the landscape level can be obtained computing the City Block Distance (= Manhattan Metric) between the landscape metric values of the river widening and its corresponding references (paper 1).
- Fuzzy ordination (multivariate statistics) revealed to be a useful method for computing and visualization of similarities between plant assemblages of the river widening and its corresponding references (paper 2).

The case studies (papers 1 and 2) revealed that:

- River widenings promote the re-establishment of pioneer habitats, mainly gravel bars and softwoods.
- River widenings increase habitat diversity. However, habitat diversity is lower than in corresponding near-natural reference sites due to the limited spatial extent of the widenings.
- River widenings show a more complex habitat mosaic than near-natural sites.

- River widenings provide habitats for riparian plant species, for example, *Phalaris arundinacea* and *Epilobium fleischeri*.
- Restoration success depends mainly on the spatial extent of the widening, distance to near-natural species pools and bed-load transport.

The identification of promising river reaches for restoration was based on a hierarchical filter process of spatially explicit information (multi criteria decision making (MCDM)-GIS analysis) (paper 3). The selection integrates ecological as well as socio-economic criteria and indicators to capture both ecological key processes (e.g. hydrology, bed-load transport, connectivity, etc.) and socio-economic aspects (e.g. flood protection, recreation functions, public attitude, etc.). The Ecological Restoration Suitability Index (ERSI) combines the ecological suitability factors in a single index. Weights and suitability functions for the MCDM-GIS analysis were obtained through expert interviews (modified Delphi process).

The results show, that (paper 3):

- Most of the catchments in Switzerland are ecologically very suitable for restoration. They are mainly located in the Swiss plateau because restoration suitability of Alpine rivers is limited due to hydropower production.
- The acceptance of future restoration projects by the public can be estimated on the basis of public votes, which serve as surrogate for the public attitude towards environmental policies.

In a nutshell, widening rivers is an appropriate measure for promoting riparian biocoenosis and there are many river reaches in Switzerland where such restoration measures would be worthwhile.

# Zusammenfassung

Inhalt dieser Arbeit ist eine Wirkungskontrolle bisher durchgeführter Revitalisierungsmassnahmen (Gerinneaufweitungen) an ausgewählten Schweizer Fliessgewässern (paper 1 und 2) und die Lokalisierung von Vorranggebieten für zukünftige Revitalisierungsmassnahmen (paper 3).

Die Wirkungskontrolle basiert auf einer vergleichenden Untersuchung zwischen (i) Gerinneaufweitungen, (ii) kanalisierten Strecken (regulierte Referenz =Nullzustand) und (iii) naturnahen Abschnitten (naturnahe Referenz = Zielzustand), welche die Beurteilung der durch die Revitalisierung erreichten Naturnähe ermöglichen soll.

Im Rahmen dieser Arbeit wurden folgende methodische Erkenntnisse zur Durchführung einer Wirkungskontrolle gewonnen:

Indikatoren

- Landschaftsstrukturmasse (landscape metrics) eignen sich zur Quantifizierung der wiederhergestellten Landschaftskomposition und -konfiguration und damit als Indikatoren für das Potential zur Wiederherstellung auetypischer Biozönosen. Das vorgeschlagene Indikatorenset setzt sich zusammen aus: Mean Shape Index, Median Patch Size, Mean Nearest Neighbour, Mean Proximity Index, Interspersion and Juxtaposition Indx, Edge Density, % Area, Patch Richness (s. paper 1).
- Die Anzahl und Habitatbindung (Stenökie) der einzelnen, in einem revitalisierten Abschnitt angetroffenen Arten sind Zeiger für den Revitalisierungserfolg. Für die Durchführung zukünftiger Erfolgskontrollen wurde deshalb eine Liste auetypischer, (semi-)terrestrischer Pflanzenarten unterschiedlicher Habitatbindung erstellt (s. Anhang).

Stencil technique

Der Vergleich der Landschaftsstruktur unterschiedlich grosser Untersuchungsgebiete (Aufweitung, naturnahe Referenz) mittels landscape metrics ist nur bedingt zulässig. Um einen solchen Vergleich dennoch zu ermöglichen, wurde die GIS-basierte „Stencil technique“ entwickelt, welche im paper 1 detailliert beschrieben wird.

Ähnlichkeitsrechnungen

- Die durch die Revitalisierung erreichte Naturnähe lässt sich mittels Ähnlichkeitsrechnungen quantifizieren.
- Auf der Ebene der landscape metrics eignet sich hierfür die Berechnung der City Block Distance (= Manhattan metric) zwischen den Werten der Gerinneaufweitung und den Werten der regulierten bzw. naturnahen Referenz (paper 1).
- Für die Berechnung und visuelle Darstellung der Ähnlichkeit zwischen den Vegetationsaufnahmen der Gerinneaufweitungen und jenen der entsprechenden Referenzgebiete, erwies sich die Fuzzy Ordination, eine Methode aus dem Bereich der multivariaten Statistik, als besonders geeignet (paper 2).

Die Anwendung der oben vorgestellten Methoden zur Wirkungskontrolle von Revitalisierungsmassnahmen führte zu folgenden Ergebnissen (paper 1 und 2):

- Gerinneaufweitungen ermöglichen vor allem die Wiederherstellung von Pionierlebensräumen wie z.B. Kiesbänke u. Weichholzgebüsch.

- Gerinneaufweitungen erhöhen die Habitatdiversität. Diese liegt jedoch aufgrund der geringen Flächenausdehnung der Aufweitungen unter jener der naturnahen Strecken.
- Gerinneaufweitungen weisen ein komplexeres und kleinteiligeres Habitatmosaik auf als entsprechende naturnahe Bereiche.
- Gerinneaufweitungen leisten einen wichtigen Beitrag zu Schutz und Förderung auetypischer Pflanzenarten, z.B. von Rohrglanzgras (*Phalaris arundinacea*) oder Fleischers Weidenröschen (*Epilobium fleischeri*).
- Der Erfolg von Massnahmen zur Gerinneaufweitung ist im Wesentlichen abhängig von der Grösse der Aufweitung, der Nähe zu naturnahen Bereichen und dem Geschiebehaushalt.

Für die Ermittlung der Vorranggebiete für zukünftige Gerinneaufweitungen (paper 3) wurden räumlich explizite Daten in ein GIS eingespiesen und mittels eines hierarchischen Filterprozesses ausgewertet (multi criteria decision making (MCDM)-GIS- Analyse). Der Auswahlprozess integriert:

- ökologische Kriterien und Indikatoren zur Erfassung ökosystemarer Schlüsselprozesse (z.B. Hydrologie, Geschiebe, Vernetzung) und
- sozio-ökonomische Kriterien (z.B. Hochwasserschutz, Naherholung, Einstellung der Bevölkerung gegenüber Umweltbelangen), womit der gesellschaftlichen Relevanz von Revitalisierungsprojekten Rechnung getragen wird.

Die Eignung aus ökologischer Sicht wird in einem „ecological restoration suitability index“ zusammengefasst. Die Gewichtung der Kriterien und Wertfunktionen für die MCDM-GIS-Analyse wurden im Rahmen einer Expertenumfrage (Delphi-Prozess) ermittelt.

Die Ergebnisse zeigen, unter anderem, für die Schweiz (paper 3),:

- dass die überwiegende Mehrheit der Einzugsgebiete sehr gute, ökologische Rahmenbedingungen für Revitalisierungsmassnahmen aufweist. Diese liegen mehrheitlich im Mittelland, da das Revitalisierungspotenzial der Berggewässer durch die Wasserkraftnutzung stark eingeschränkt ist und,
- dass eine Auswertung des bisherigen Abstimmungsverhaltens der Bevölkerung eine Abschätzung der Akzeptanz zukünftiger Revitalisierungsprojekte ermöglicht.

Grundsätzlich zeigt sich, dass Gerinneaufweitungen geeignete Massnahmen zur Förderung u. Wiederherstellung auetypischer Arten- u. Lebensgemeinschaften darstellen, deren Potenzial in der Schweiz bei Weitem noch nicht ausgeschöpft ist.

## Résumé

Cette thèse traite de la surveillance de l'efficacité des mesures de revitalisation des cours d'eau (l'élargissement local de rivières); ceci à travers une méthode de localisation des lieux prioritaires pour des mesures de revitalisation. La surveillance s'est effectuée sur une comparaison des (i) élargissements avec (ii) des rivières canalisées (référence corrigée) et (iii) des rivières naturelles (référence naturelle = état-but). Cette comparaison rend possible la quantification du caractère naturel réalisé par la mesure de revitalisation.

Les résultats concernant les méthodes de l'exécution de la surveillance de l'efficacité des mesures de revitalisation sont les suivants:

<u>Indicateurs</u>

- Les « landscape metrics » sont adéquats pour quantifier la composition et la configuration du paysage rétabli. Ce sont des indicateurs permettant d'évaluer le potentiel de reconstitution des habitats et espèces alluviales. Les indicateurs proposés sont : "Mean Shape Index", "Median Patch Size", "Mean Nearest Neighbour", "Mean Proximity Index", "Interspersion and Juxtaposition Index", "Edge Densitiy", "% Area", "Patch richness" (article 1).
- Le nombre d'espèces trouvées dans l'élargissement et la liaison des espèces avec la diversité des habitats démontrent le succès de la revitalisation. Une liste des plantes alluviales (semi-) terrestres est présentée (Appendice).

"Stencil technique"

La comparaison de la structure du paysage avec des « landscape metrics » est limitée dans le cas de zones de recherches offrant des surfaces différentes. Pour faciliter cette comparaison la « stencil technique » (effectué dans un Système d'Information Géoréféré, SIG) est presentée et developée en détail dans l'article 1.

Calcul des similarités

- Il est possible de quantifier le caractère naturel obtenu à l'aide de calculs de similarités.
- Quant à l'état des « landscape metrics » le calcul de la « City Block distance » (="Manhattan metric") est idéal pour indiquer la similarité entre les valeurs obtenues pour les élargissements et les références correspondantes (canalisées et naturelles) (article 1).
- La "Fuzzy Ordination" (une méthode d'analyse statistique multivariée) est judicieuse pour le calcul et la visualisation des similarités entre les relevés de végétation obtenus dans les élargissements et les références correspondantes (article 2).

L'exécution de la surveillance de l'efficacité des mesures de revitalisation des cours d'eau montre les résultats suivants (articles 1 et 2) :

- Les habitats pionniers, par exemple les bancs de gravier brut et les saulaies buissonnantes, sont les habitats qui se reconstituent les premiers.
- Les élargissements locaux de rivières augmentent la diversité des habitats. Mais la diversité des élargissements est moindre que la diversité trouvée dans les zones alluviales naturelles du fait que les élargissements réalisés sont trop petits.

- La mosaïque des habitats des élargissements est plus complexe que celle des zones alluviales naturelles.
- Les élargissements représentent une contribution importante pour la protection et le développement des plantes alluviales, par exemple *Phalaris arundinacea* ou *Epilobium fleischeri*.
- Le succès des mesures dépend de la surface de l'élargissement, de la proximité des zones alluviales naturelles et de la régime du dépôt sédimentaire.

Le choix des lieux prioritaires pour de futurs élargissements (article 3) a été effectué à l'aide d'un SIG. Les données spatiales sont analysées avec une procédure-filtre hiérarchique ("multi criteria decision making (MCDM)-GIS Analysis"). Cette procédure de sélection intègre :

- des critères et indicateurs écologiques pour comprendre les processus clés de l'écosystème alluvial (hydrologie, régime des sédiments, connectivité etc...) et
- des critères socio-économiques (par exemple: la protection contre les crues, offre d'activités récréatives, opinion publique face aux mesures de gestion de l'environnement).

Les critères écologiques sont réunis au sein de l'« Ecological Restoration Suitability Index (ERSI) ». L'importance des critères et des fonctions de valeurs des critères pour l'Analyse MCDM-SIG " sont mis en place par un groupe d'experts dans le domaine (processus-delphi).

Pour la Suisse les résultats sont les suivants (article 3):

- La majorité des bassins hydrologiques ayant des conditions-cadre favorisant des mesures de revitalisation de cours d'eau (l'élargissement local des rivières) sont situés sur le plateau Suisse et non pas en région de montagne. En effet, dans ces régions, les revitalisations potentielles sont limitées par la présence des usines hydrauliques.
- Une analyse des résultats de votations montre l'intérêt du public pour les mesures environnementales et rend possible l'estimation de l'acceptation de l'opinion publique envers de futurs projets de revitalisation des cours d'eau.

Pour résumer les résultats, on peut dire que les élargissements locaux de rivières sont des mesures appropriées pour l'encouragement et la reconstitution des habitats et espèces alluviales. De plus, en Suisse le potentiel de revitalisation des cours d'eau n'est pas encore épuisé.

# General introduction

## Rivers and their multiple roles in the human environment – an overview

Rivers are more than just flowing water. They are prominent features in the environment that have a major impact on human society and culture as people have always been attracted to water courses. Thus religion and mythology, as well as art and economics, have been affected by rivers. The following chapter aims to give a glimpse of the many different ways rivers have touched and still touch people's lives and environment.

Water is a major resource for humans. Thus settlements were often made near rivers. On the Swiss plateau, for example, settlements have since Neolithic times occured mainly along rivers and lakes. Rivers have often defined the borders between estates, communities, shires and states. For instance, the Rhine is still a major border between several European countries. Districts were often named after rivers. In Switzerland, for example, the names of the cantons Thurgau and Aargau came from the rivers Thur and Aare.

The water courses themselves have been used for multiple purposes: fishing, drinking water, irrigation, waste disposal, transport and industry. Early watershed industries included logging, mining, milling, tanneries and agriculture. In Switzerland, for example water power was used as early as the 3$^{rd}$ century (Schnitter 1992). Water courses have also allowed the transport of mainly timber and firewood, but also of salt, wine and ore, and thus promoted commerce. Some settlements along rivers became major trading centres. In the 16th century Zurzach, for example, near the junction of the navigable Rhine and Aare became a widely known market town. Traders from Italy, France, The Netherlands and Poland came to trade leather, textiles and horses. Other settlements obtained considerable income from tolls on bridges, for example, Brugg on the Aare river. Today, rivers have become popular for recreational purposes (canoeing, walking, etc.) but they are still important commercially, especially for transport (e. g. the Danube, Rhine, Elbe and Weser), cooling water and hydropower. In Switzerland, for example, hydropower produces 56% of Switzerland's electricity and covers about 65% of its electricity consumption (BWG 2003, http://www.bwg.admin.ch).

Rivers have contributed to economic development through the exchange of goods, but also enable travel and thus the exchange of knowledge. Thus rivers have markedly influenced cultural development and have often been a source for artistic inspiration. One of the most famous examples is the music by Bedrich Smetana (1824 – 1884) which describes the course of the river Moldavia from its springs to where it flows into the Elbe river. Rivers are also the subject of works of Franz Schubert (1797-1828) in his Lieder " Am Flusse" (1822, text by J. W. Goethe) and "Der Strom" (1817, text by A. Stadler). Rivers have also been popular themes with painters. In his painting "The Flood" (Figure1) Wassily Kandinsky, for example, expressed the destructive force of rivers, whereas Claude Oscar Monet (1840-1926), the leader of the Impressionist movement in France, painted many rather romantic river scenes of the Epte and Seine. The most famous one "The Seine at Port-Villez. Harmony in Blue" (1894) can be seen at the Tate Gallery in London (Figure 2).

Figure 1. Wassily Kandinsky (1866 – 1944): Komposition VI (The Flood) 1913; Hermitage, St. Petersburg.

An art époque, the "Rheinromantik", was even named after a river. In 1802 the poet and philosopher Friedrich Schlegel explored the Rhine valley. His travelogues launched the beginning of the “Rheinromantik”, which influenced many artists, amongst them Clemens Brentano (1778-1842) and Heinrich Heine (1797-1856) whose poems were inspired by the Rhine as well as the English painter William Turner (1775-1851) and the Swiss painter Johan Ludwig (Louis) Bleuler (1792-1850), who created a series of paintings of the Rhine between 1820 and 1850.

Figure 2. Claude Monet. *The Seine at Port-Villez. Harmony in Blue*. 1894. Oil on canvas. Tate Gallery, London.

Rivers also have played an important role in religion and mythology. In India, for example, the Hindus worship the river Ganges as the water of the Goddess Ganga. Every year millions of pilgrims go there for a ritual bath. Another example is the old creation myth of native Americans which describes the origin of rivers:

> *“Long time ago the moon-woman and the sun-god fell in love with each other. But marriage would be the world’s end as the fiery love of the sun-god would burn the earth and the tears of the moon-woman would flood the earth. So they decided not to marry. They split, but the moon-woman cried day and night. Her tears poured down to the earth and filled rivers flowing down to the sea…”*

Before regulation took place, rivers were amongst the most dominant driving forces in the landscape. The interplay of erosion and sedimentation formed the landscape. The dynamics of these processes led to an ever changing scenery of deep valleys and wide flood plains with sand bars, islands and woodlands. Hydrogeomorphic processes create a shifting mosaic of different successional stages and the mosaic of water, bare ground, pioneer vegetation up to mature woodland provides habitat for many different species. Therefore rivers and their flood plains are widely acknowledged as biodiversity hotspots. For example, nearly 40% of all vascular plants to be found in Switzerland occur along rivers (Huber et al. 2002, Roulier 2002). Thus today the remnants of natural rivers play a major role in the conservation of biodiversity and rivers provide important corridors for species dispersal (e.g. Bonn and Poschlod 1998).

This brief overview shows that rivers have influenced human life in many different ways. However, the influence has also been vice versa as humans have altered the appearance of many river corridors drastically with engineering works and regulation.

## River regulation in Switzerland and its consequences

In many areas rivers have undergone progressive changes away from their natural state. Changes began with human settlement along rivers. As the population grew, many areas that previously had been flooded during high water became more and more densely populated. As a result measures were taken for flood protection. However, until the $18^{th}$ century these measures had only local effects (Vischer 1986). Local measures were, for example, the meander cutoffs at the Reuss between Ottenbach and Birri-Merenschwand in 1415 and between Buchrain and Inwil in 1594 (Vischer 2003).

Things changed when there was a marked increase in severe flooding in the $18^{th}$ and $19^{th}$ century due to climate changes and deforestation (Pfister 1999). Growing populations and industries led to extensive clearing, for example, in the Emme valley, which provided wood and timber for the growing industries of the city of Solothurn. As a result water retention decreased and erosion and sediment transport increased. Larger quantities of sediment caused the river beds to progressively rise, with consequent flooding. As a result many people and livestock died, settlements and agricultural land were destroyed and the land became marshy with malaria becoming an additional threat. At this time many people suffered as a result from hunger and disease and there were increasing calls for effective flood protection. This was the beginning of the first major river training works (Table 1).

Table 1. Major river correction projects in Switzerland (HLS 2002)

| Period | River | Regulation | Length (kn |
|---|---|---|---|
| 1711-14 | Kander | Kanderdurchstich | 1 |
| 1807-16 | Linth | Walensee-Zürichsee | 15 |
| 1855-65 | Gürbe | Wattenwil-Aare | 16 |
| 1856-90 | Nozon/Orbe | Orny bzw. Orbe-Neuenburgersee | 9+11 |
| 1860-90 | Alpenrhein | Landquart-Rüthi (SG) | 40 |
| 1863-84 | Rotten/Rhone | Brig-Genfersee | 103 |
| 1866-75 | Aare | Meiringen-Brienzersee | 13 |
| 1868-91 | Zihl | Bielersee-Büren an der Aare | 12 |
| 1871-1920 | Emme | Räbloch (Gem. Schangnau)-Aare | 61 |
| 1874-93 | Thur | Bischofszell-Hochrhein | 62 |
| 1878-95 | Glatt | Greifensee-Hochrhein | 41 |
| 1881-1910 | Töss | Fischenthal-Dättlikon | 42 |
| 1888-1912 | Tessin | Bellinzona-Langensee | 14 |
| 1895-1923 | Alpenrhein | Rüthi (SG)-Bodensee | 25 |
| 1911-1926 | Muota | Hinterthal (Gem. Muotathal)-Vierwaldstättersee | 9+6 |
| 1917-87 | Saane | Montbovon-Lac de Gruyère | 16 |
| 1949-55 | Areuse | Travers-Couvet | 14 |

The very first was the Kander correction conducted from 1711 to 1714. The pristine course of the Kander went through the lake and city of Thun and joined the Aare river downstream from Thun. The floods along the Kander regularly destroyed neighbouring settlements. Additionally, the huge deposits of sediment constricted the channel of the Aare, which also made the city of Thun prone to flooding. Relief was gained by diverting the water course of the Kander into Lake Thun, resulting in the so-called "Kanderdurchstich", and associated engineering works (Grosjean 1962).

Devastating floods, such as the "Wassernot" of 1762 and 1784 in the Linth valley and the cities of Walenstadt and Weesen, were stopped by diverting the Linth into Lake Walen. The Linth correction was a major hydraulic engineering feat and celebrated over the generations as "heroic deed". The main constructor was Johann Gottfried Tulla who also carried out the major river training works on the Upper Rhine in Germany. Hans

Conrad Escher promoted the Linth correction, which took nearly 10 years to complete (1807-1816). He also led the engineering works together with Conrad Schindler (Speich 2002).

The third major river correction in Switzerland was the "1st correction of the Jurassic water courses" which took place from 1868 to 1891. It was the largest of all the river correction projects and a key figure behind it was the doctor Johan Rudolf Schneider (Vischer 2003). This project included the construction of the Hageneck Canal which redirected the Aare from Aarburg directly into Lake Biel. The effluent of Lake Biel was increased with the construction of the Nidau-Büren Canal. These measures stopped the regular flooding and the marshland became dry. As a consequence large-scale subsidence of the terrain took place which made further measures necessary. Around seventy years later, the "2nd correction of the Jurassic water courses" (1962-73) took place.

Most of the following river training works did not aim to direct flow but rather to increase drainage capacity. The natural water courses were canalized and contained in a double trapeze profile. The correction of the Rhone from Brig to Lake Geneva is a typical example. Here the water course was straightened and the river profile was defined by flood levees at a distance of 70m to 120m, accompanied by groins 20m to 30m long. By the beginning of the 20th century nearly all the rivers in Switzerland had been corrected.

These river corrections also led to land reclamation due to improved drainage and melioration. During the "1st correction of the Jurassic water courses", for example, 400 $km^2$ of wetlands were converted into agricultural land. This land reclamation, also called "inner colonisation", was necessary as the population was growing rapidly with industrialization. River training works and melioration replaced meandering and free-flowing streams and their floodplains with diked canals and agricultural land (Figure 3).


Figure 3. W. L. Kozlowski. Entwässerung, Regulierung, Drainage. 1932

A study of the International Commission for the Protection of the Alps (CIPRA) showed, that only around 10% of the most important rivers of the entire Alpine region are still “pristine” or in a “near-natural” condition (Martinet and Dubost 1992). The landscape changes from natural to cultural land were originally perceived as improvements. But the decisions were solely based on technical and economic considerations and no attention was paid to possible ecological and social consequences. The most striking was the severe loss of natural habitat, which led to a massive decline in plant and animal diversity, and even the extinction of many species. In Switzerland, for example, the fish species salmon (*Salmo salar*), sturgeon (*Acipenser sturio*) and lamprey (*Lampetra fluvialis*) were lost (BUWAL 2002). The changes affected the aesthetic value of the landscape as well: winding water courses, with their charming contrast of open water, islands and woodlands, have been replaced by monotonous canals.

In the long run, river corrections have also had some negative economic consequences. These are increased bed shear stress due to channel straightening and bank protection which causes river bed erosion. This puts bridge foundations and other constructions at risk and decreases land productivity due to lowered water tables.

As the negative consequences of the traditional engineering practice became more and more serious, a paradigm shift took place towards a more sustainable river management.

## River widening: A new approach to river management

Public awareness of the limitations of traditional engineering practices and the imperative to conserve nature in the 20$^{th}$ century have led to changes in river management policies and to the development of numerous restoration projects. Changes in management policies have taken place at different political levels. At the international level the European Habitats Directive and the European Water Framework Directive represent the most important policy shift. At the Swiss federal level a network of floodplain reserves was established through legislation (Auenverordnung, 1992). Reserves now cover 289 floodplains of national importance and the Water Protection Law (GSchG 1991) regulates, among other things, the minimum flow discharge which has to be maintained in the river when it is used for hydropower production.

In recent years various river restoration projects have been planned or implemented. In Europe the various projects include creation of secondary channels along the Rhine (Simons et al. 2001), returning the straight, regulated river Skjern back to its former meandering state (Neilsen 2002), reconnecting the Danube side-arm system to the main channel (Tockner et al. 1998), re-allocating flood levees at the Elbe river (http://www.burg-lenzen.de/deichrueckverlegung/) and widening rivers in Switzerland and Austria (e.g. Drau river: http://panda.wwf.at/spittal.html). In North America many projects have focused on dam removal (Bednarek 2001, Hart and Poff 2002) to re-establish the river continuum.

In Switzerland many rivers face progressive river bed erosion due to river training (Schilling et al. 1996). Traditionally, sills, chutes or block ramps were installed to stabilize the river bed. But these measures disrupt the river continuum and impair species movement. An alternative management option is the construction of river widenings. The first river to be widend in Switzerland was along the Emme river in

1992. Several other widenings followed along the Thur, Alpenrhein, Rhône, Moesa, Reuss, Inn and Calancasca.

Local widening of a river bed seeks to meet hydraulic and ecological demands. River widening decreases the transport capacity of a river and causes retention of sediment within the widening so that the mean bed level rises. At the same time river widening allows river braiding which increases the variability of flow parameters and the diversity of in-stream habitats.

The morphological changes along the longitudinal profile of a river widening are, according to, Hunzinger (1998):

- The mean bed level in the widening is stepped vertically relative to the bed level in the upstream and downstream channel to ensure continuity and energy conservation.
- A new equilibrium slope becomes established. This is steeper than the slope of the original narrow streamway. In the case of long river widenings, this effect increases the upstream bed level.
- Bars are formed, creating a more diverse flow pattern. At the same time cross flows and scouring lead to an increased hydraulic load on the river banks.
- The flow is concentrated, causing intense scouring at the constriction.
- Sediment is retained within the widening, causing temporary downstream erosion.

The morphological processes occurring in river widenings are pretty well known and documented and can be quantified in hydraulic experiments and numerical simulations. So far research has concentrated mainly on aspects of river engineering and neglected the postulated aim of ecological river restoration. There have only been a few ecological studies on river widenings, all from Austria (Habersack and Nachtnebel 1995, Habersack et al. 2000, Petutschnig 1997). However, if river management is to be sustainable the contribution of river widenings to the restoration of river systems and riparian landscapes needs to be investigated and assessed.

## Restoration, Rehabilitation or Revitalization?

There is a growing literature on the philosophical and scientific dimensions of "restoration". Numerous terms have been used to describe river restoration, such as "rehabilitation", "revitalization", "renaturalization" and "enhancement". Adams and Perrow (1999) and Perrow and Wightman (1993) proposed the following definitions, which are similar to the definitions given by the CIPRA (Martinet and Dubost 1992):

Restoration: "The complete structural and functional return to a pre-disturbance state."
Rehabilitation: "The partial structural and functional return to a pre-disturbance state."
Enhancement: "Any improvement of structural or functional attribute".

Following these definitions I suggest the terms "renaturalization" should be considered an alternative term for "restoration" and "revitalization" should be considered an alternative term for "rehabilitation".

In recent years there has been a shift in meaning of the term "improvement". Traditionally, rivers have been "improved" for flood protection and land reclamation through canalization and regulation. A quote from Victor Hugo (1802-1885) underlines this traditional meaning: "When nature created the Rhine, there was chaos and void, however mankind turned it into a street". This "street" was celebrated as "improvement". More recently these traditional "improvements" have come to be recognized at least in part as losses and river "improvement" is now associated with re-establishing formerly lost, more natural riparian habitats and processes.

There is a gap in restoration ecology between theory and practice. Although definable in restoration theory, full restoration to some pristine state is rarely a feasible practical option (if at all) due to irreversible alterations of geological, climatic and other processes. Indeed, the question arises which time slot in natural history should serve as the reference for a pristine state: the time after the last ice age, the beginning of the 19$^{th}$ century, present floodplain remnants or what? It is very difficult to define a particular time slot which would be commonly accepted as "pristine". In addition, Petts (1996) maintaining that, philosophically, the very notion of a return to a "natural" or "virgin" state through human action is bizarre. However, most authors use the term "restoration", and I have also followed this practice, although I am well aware that this is leaving the path of pure definition.

## Objectives, content and outline of this work

Swiss society is aware of the major ecological degradation caused by river regulation. Thus river conservation and restoration are now being addressed through legislative changes (Auenverordnung, GSchG) and action on the ground, such as river widenings. However, an extensive literature search and informal interviews with several river managers in Switzerland revealed little information on the positive or negative impacts of river widenings on the ecological performance of the "restored" river stretches. Many of these managers mentioned the lack of an easy-to-apply assessment method as a major reason for the lack of information on the ecological performance of river widenings. The interviews also showed that river widening projects do not follow a strategic restoration or river management plan for the whole catchment, but are mainly based on local, ad-hoc decisions.

Thus the objectives of this work are: (i) to provide a method for obtaining a rapid and robust assessment of river widenings from a nature conservation point of view, (ii) to increase scientific knowledge on the ecological performance of river widenings, which can then be fed into designing of future restoration projects, and (iii) to provide a framework for establishing a strategic planning tool for whole catchments to assist management authorities in setting priorities for planning river widenings.

This study reports on the results of research conducted along several Swiss rivers. It is divided into three main parts: the first paper is devoted to the description of the "stencil technique", a new method to assess restoration performance at the habitat level, the second paper focuses on the potential and limitations of river widenings to re-establish riparian vegetation and habitats, and the third paper addresses the need for a strategic planning tool for river restoration that integrates ecological as well as socio-economic needs. The last chapter presents a synthesis and some final remarks.

## Literature cited

Adams, W. M. and Perrow, M. R. 1999: Scientific and institutional constraints on the restoration of European floodplains. Pages 89-97 in *Marriott, S. B. and Alexander, J. (eds.)* Floodplains: Interdisciplinary Approaches, The Geological Society of London, London.

Bednarek, A. T. 2001. Undamming rivers: A review of the ecological impacts of dam removal. *Environmental Management* 27**:** 803-814.

Bonn, S. and Poschlod, P. 1998. Ausbreitungsbiologie der Pflanzen Mitteleuropas Grundlagen und kulturhistorische Aspekte. Quelle & Meyer, Wiesbaden, X, 404 S. pp.

BUWAL. 2002. Umwelt-Bericht Bd 1. Politik und Perspektiven des BUWAL. Bundesamt für Umwelt, Wald und Landschaft.

Grosjean, G. 1962. Die Ableitung der Kander in den Thunersee vor 250 Jahren. *Jahrbuch vom Thuner- und Brienzersee***:** 18-40.

Habersack, H.-M. and Nachtnebel, H.-P. 1995. Short-term effects of local river restoration on morphology, flow field, substrate and biota. *Regulated Rivers: Research & Management* 10**:** 291-301.

Habersack, H.-M., Koch, K. and Nachtnebel, H.-P. 2000. Flussaufweitungen in Österreich - Entwicklung, Stand und Ausblick. *Österreichische Wasser- und Abfallwirtschaft* 52**:** 143-153.

Hart, D. D. and Poff, N. L. 2002. A special section on dam removal and river restoration. *BioScience* 52**:** 653-655.

HLS. 2002. Historisches Lexikon der Schweiz. Stiftung Historisches Lexikon der Schweiz (HLS), Basel.

Huber, F., Kuhn, N., Müller-Wenk, R. and Peter, A. 2002. Gewässerraumnutzung und Umweltschaden. seecon gmbh, 81.

Hunzinger, L. M. 1998. Flussaufweitungen - Morphologie, Geschiebehaushalt und Grundsätze zur Bemessung. Vol. 159, VAW Mitteilungen, Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie der ETH Zürich, Zürich.

Martinet, F. and Dubost, M. 1992. Die letzten naturnahen Alpenflüsse. Vol. 11, Kleine Schriften, Internationale Alpenschutzkommission CIPRA, Vaduz.

Neilsen, M. 2002. Lowland stream restoration in Denmark: Background and examples. *Journal of the chartered institution of water and environmental management* 16**:** 189-193.

Perrow, M. R. and Wightman, A. S. 1993. River Restoration Project Phase 1. Feasability Study. Oxford Brookes University.

Petts, G. E. 1996: Sustaining the ecological integrity of large floodplain rivers. Pages 535-551 in *Walling, D. E. and Bates, P. D. (eds.)* Floodplain Processes, Wiley, Chichester.

Petutschnig, W. 1997. Vegetationsentwicklung auf Pionierstandorten einer Flussaufweitung an der Oberen Drau (Kärnten). *Carinthia II* 187**:** 409-421.

Pfister, C. 1999. Wetternachhersage. 500 Jahre Klimavariationen und Naturkatastrophen (1496-1995). Paul Haupt, Bern, Stuttgart, Wien, 304 pp.

Roulier, C. 2002: Schriftliche Mitteilung mit vollständiger Artenliste vom 6.6.2002. *(eds.)* zit. in Huber et al.

Schilling, M., Hunziker, R. and Hunzinger, L. 1996. Die Auswirkungen von Korrektionsmassnahmen auf den Geschiebehaushalt. Intrapraevent, 209-220.

Schnitter, N. 1992: Römischer Wasserbau in der Schweiz. Pages 152-159 in *Scheidegger, F. (eds.)* Aus der Geschichte der Bautechnik Bd.2, Birkhäuser, Basel.

Simons, J. H. E. J., Bakker, J. P., Schropp, M. H. I., Jans, L. H., Kok, F. R. and Grift, R. E. 2001. Man-made secondary channels along the River Rhine (the Netherlands); results of post-project monitoring. *Regulated Rivers-Research & Management* 17**:** 473-491.

Speich, D. 2002. Linth Kanal: die korrigierte Landschaft - 200 Jahre Geschichte. Baeschlin, Glarus, 87 pp.

Tockner, K., Schiemer, F. and Ward, J. V. 1998. Conservation by restoration: The management concept for a river-floodplain system on the Danube River in Austria. *Aquatic conservation - marine and freshwater ecosystems* 8**:** 71-86.

Vischer, D. 1986. Schweizerische Flusskorrektionen im 18. und 19. Jahrhundert. Vol. 84, VAW Mitteilungen, Zürich.

Vischer, D. 2003. Die Geschichte des Hochwasserschutzes in der Schwiz. Von den Anfängen bis ins 19. Jahrhundert. Berichte des BWG, Serie Wasser, Bundesamt für Wasser und Geologie (BWG), 208.

Auenverordnung. Verordnung vom 28. Oktober 1992 über den Schutz der Auengebiete von nationaler Bedeutung

Gewässerschutzgesetz (GSchG 1991). Bundesgesetz über den Schutz der Gewässer.

# Paper I

## A habitat-based method for rapid assessment of river restoration

*Submitted as:*

Sigrun Rohde, Felix Kienast and Matthias Bürgi: A habitat-based method for rapid assessment of river restoration. *Environmental Management*.

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## Abstract

Many rivers in industrialized countries have been modified by canalization. Restoration of the ecological integrity is now an important management goal in many places. One restoration approach is to create „river-widenings“ that permit braiding within a limited area. This study presents a new and efficient framework for rapid assessment of river widening projects and offers a novel method to compare restored sites with near-natural stretches (stencil technique). The new framework compliments existing assessment methods by evaluating spatial patterns of habitat and using landscape metrics as indicators. Three case studies from river restoration in Switzerland are presented for demonstration purposes.

The restoration projects are compared to pre-restoration conditions and near-natural conditions, which are assumed to bound the worst- and best-case condition of a river system. To account for the limited spatial extent of the restored sites the stencil technique was developed. Landscape metrics were calculated for each entire study area as well as smaller sections (clips) of the near natural reference. Clips were created by using a stencil of the same shape and size as the restored area to clip data for the near-natural reference (random window sampling technique). Subsequently the calculated metrics for the restored sites were compared to the range of values calculated for the near-natural data subset.

We conclude that the proposed method of using the stencil technique and landscape metrics for restoration assessment is valid and easy to apply. We found that river widenings do offer potential for re-establishment of riparian habitats. However, mainly pioneer successional stages were promoted, and the habitat mosaic of the restored section was more complex than near- natural reference sites.

**Keywords:** stencil technique, indicators, landscape metrics, GIS, random window sampling, riparian habitat, river restoration, Switzerland

## Introduction

River floodplains are widely acknowledged as being biodiversity hotspots (Malanson 1995, Naiman et al. 1993). However, in Europe only small areas are left in a relatively undisturbed condition. Most rivers have been subjected to a variety of human impacts, primarily regulation. These engineering works led to uniform landscapes characterized by canalized rivers lined with flood levees. As a result the floodplains lost their natural dynamics and patterns with a consequent decline in habitat and species diversity (Nilsson and Svedmark 2002, Pedroli et al. 2002, Petts and Calow 1996). Due to a new approach in river management an increasing number of restoration projects have been initiated in the last years. One measure is to create river widenings that permit braiding within a limited area. These measures seek to mimic natural patterns and processes and thus return the fluvial ecosystem to a close approximation of its condition prior to canalization. Despite the increasing number of river restoration projects, post- project evaluation has generally been neglected (Kondolf and Micheli 1995). The supposed reasons are limited financial resources and the lack of evaluation schemes which are efficient and easy to apply. Where post- project evaluation has been undertaken, it has concentrated on in-stream characteristics like channel geomorphology and channel wildlife (Brunke 2002, Downs 2001, Gilvear et al. 2002, Henry et al. 2002, Thomson et al. 2001), and largely diregarded the adjacent riparian landscape. Thus the purpose of our study was to establish a framework for rapid assessment of restoration projects which considers the whole floodplain, including the semi-terrestrial habitats (riparian zone).

The specific aims of the study are as follows: To develop a powerful and efficient method to assess the improvements achieved by the restoration measures against regulated and near- natural conditions; to identify easily-surveyed indicators which appropriately reflect landscape function and processes and to determine whether river widenings are suitable means to re-establish fluvial ecosystems.

Three case studies of river restoration projects are presented for demonstration purposes.

## Case study sites

In the case studies we analyzed three river restoration projects (river widenings) in Switzerland (see Figure 1). All river widenings are of about 5 ha in size. The first site is located at the Emme River in the community of Aefligen in the north western part of Switzerland, the second and third site are both located in the southern part of Switzerland at the Moesa River near the villages of Grono and Lostallo. Both rivers are heavily impaired by human activity, mainly through canalization. Restoration at the Emme River started around 1991. Embankments were removed on both sides and the channel was widened from 30m to 85m over a length of about 500m (see Figure 2).

After the widening process groins were installed every 35-50m for bank protection. At Grono (Moesa site I) the works for restoration started in winter/spring 1999. On both sides, forests were cleared over a length of up to 600m and the river bed was widened by up to 50m. To allow for undisturbed, hydrogeomorphic processes no bank protections were installed, except at the downstream end of the widening. The river widening at Lostallo (Moesa site II) was undertaken in 1997.

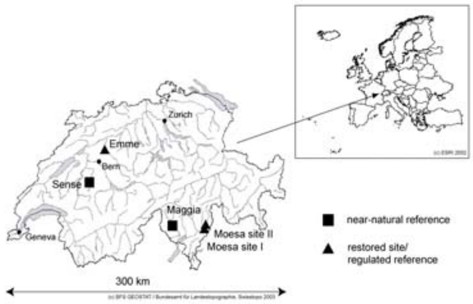


Figure 1. Study sites.

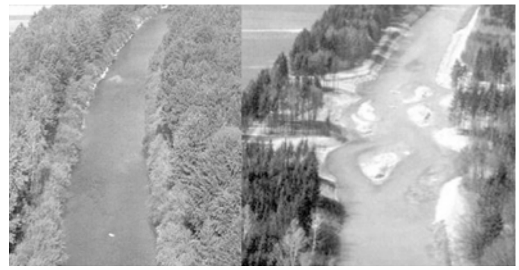

Figure 2. The Emme river at Aefligen before (left) and after restoration took place (right). (Documenta Natura)

As part of the restoration project the right-hand embankment was relocated to allow channel widening from 20m up to 85m. The relocated dam was protected by groins. Excavation material was used to build banks (1 m high) in the channel.

The Sense river near Plaffeien and the Maggia near Someo (see Figure 1) were selected for natural reference as there is little or no human impact on their hydrogeomorphic processes. Both sites belong to the most natural floodplains to be found in Switzerland (Gallandat et al. 1993). The restored sites and corresponding near-natural references can be seen at a glance in Figure 3. Information on the ecological conditions at each site is given in Table 1.

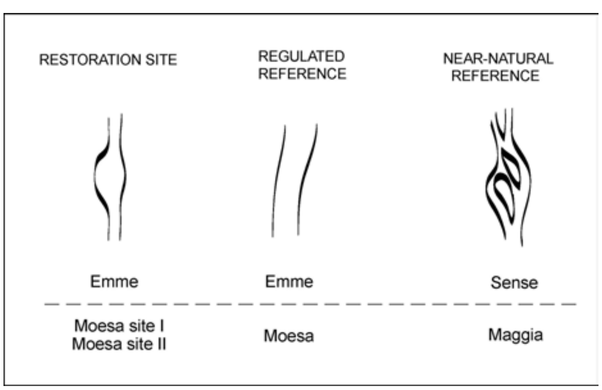


Figure 3. Restoration site and corresponding regulated/ near-natural reference.

Table 1. Characteristics of the restored (rs) and near-natural study sites (nr).

| Criteria | Description | Unit | Emme (rs) | Sense (nr) | Moesa (rs) | Maggia (nr) |
|---|---|---|---|---|---|---|
| **Geography** | | | | | | |
| biogeo | Biogeographic region | - | Plateau | Plateau | Southern part of Swiss Alps | Southern part of Swiss Alps |
| | | | temperate climate | temperate climate | insubrian climate | insubrian climate |
| **Hydrology** | | | | | | |
| Qmin_10 | Lowest discharge during a 10 year period | m3/s | 3.56 [1] | 1.47 [2] | 1.35 [1] | 0.85 [2] |
| Qmax_10 | Maximum discharge during a 10 year period | m3/s | 470 [1] | 495 [2] | 430 [1] | 650 [1] |
| HQ2 | Discharge of biennial flood | m3/s | 259 [1] | 163 [2] | 306 [1] | 299 [1] |
| Qm_10 | Mean yearly discharge during a 10 year period | m3/s | 18.8 [1] | 9.2 [2] | 20.8 [1] | 4.31 [2] |
| Qm_veg_10 | Average mean discharge during vegetation period for a 10 year period. Calculation: for the months May to October add the mean monthly discharges of the 10 years. Then divide the sum by 60 to get Qm_veg. | m3/s | 17.6 [4] | 9.36 [2] | 30.6 [4] | 6.84 [2] |
| Qmax_veg_10 | Average maximum discharge during vegetation period for a 10 year period. Calculation: for the months May to October add the maximum monthly discharges of the 10 years. Then divide the sum by 60 to get Qmax_veg. | m3/s | 141 [3] | 89.48 [2] | 150 [3] | 119.90 [2] |
| **Geomorphology** | | | | | | |
| J | slope | % | 0.62 | 1.80 | 0.80 | 0.99 |
| dm | Mean diameter of bedload | mm | 78.00 | not available | 55.00 | not available |

[1] Data from D. Streit (Federal Office for Water and Geology) (1991-2000)
[2] Data from the Riparian Zones Information Center, Yverdon (1986-1995)
[3] Own calculations based on data from D. Streit (Federal Office for Water and Geology) (1992-2001)
[4] Own calculations based on data from D. Streit (Federal Office for Water and Geology) (1991-2000)

## Methods and data base

### Selection of case study sites

As restoration seeks the return of an ecosystem to a close approximation of its condition prior to disturbance information about the pristine status is needed for comparison as part of the evaluation process. How can we obtain this information? Historical data is often rather poor and if historic sources are available, they need to be crosschecked, which is too time consuming to be implemented into a rapid assessment scheme. Instead we can use data from present natural or near- natural sites as references for the evaluation of restoration measures (Milner 1996). To be suitable as a reference the abiotic conditions of the near- natural reach must be similar to those to be found at the restoration site. Table 1 presents a set of criteria which are useful for the selection of reference sites. They include biogeographical as well as geomorphological and hydrological properties. We also investigated the regulated status before restoration took place. This allows us to evaluate the improvements achieved by the restoration process. Hence, two reference situations were chosen as we presumed that the near-natural and the regulated reaches would define the boundaries for „best“ and „worst“ condition, respectively, and that the restored sites would plot between these extremes (Downs 2001).

### Habitat maps

Habitat information was obtained by analyzing stereo pairs of photographs (1:5000 CIR) for the restored sites and for the near-natural reaches. To correct for distortion found in a normal aerial photograph we converted all images to orthophotos, using Erdas Imagine 5.1 (Leica Geosystems). The pre-restoration, regulated situation was reconstructed using information provided by the local authorities. Ground information about vegetation height and vegetation cover was added to represent the variety of structural features and different successional stages present within the floodplains.

Table 2 shows detailed information about the habitat classes that were distinguished. Digital vector maps of habitat cover were produced in ArcView 3.3 GIS (ESRI 1992) with a minimum mapping unit of 50m$^2$. Spatial resolution and scale, number of classes and accuracy of data processing markedly influence the subsequent metrics calculation (Blaschke and Petch 1999, Frohn 1998, Riitters et al. 1995). Thus a clear and standardized method for the mapping process must be applied to minimize biases arising from the mapping. For the calculation of the landscape metrics the vector maps were transformed into raster maps (resolution =1m$^2$). Depending on the resolution patches can be split or merged by the algorithm in converting from vector format to raster format, hence it was necessary to carefully check the resulting raster maps for accuracy and artifacts.

Table 2. Codes for 3-digit-habitat classification (X:Y:Z)

| | |
|---|---|
| **Habitat type (X)** | |
| 1 | Water |
| 2 | Bare gravel bar |
| 3 | Gravel bar with pioneer vegetation |
| 4 | Riparian bushes and woodland |
| 5 | Non-riparian bushes |
| 6 | Forests |
| 7 | Anthropogenic habitats |
| 8 | Reeds |
| **Vegetation cover (Y)** | |
| 1 | 10-20% |
| 2 | 20-40% |
| 3 | 40-60% |
| 4 | 60-80% |
| 5 | 80-100% |
| 6 | 5-10% |
| **Vegetation height (Z)** | |
| 1 | 0-1m |
| 2 | 1-3m |
| 3 | 3-5m |
| 4 | >5m |

## Landscape metrics

To compare pre-/post restoration habitat characteristics with the near-natural stage, landscape metrics were calculated. Landscape metrics quantify landscape composition and configuration (spatial arrangement). The heterogeneity of landscape matrices and the structure of specific boundaries in landscapes determine the movement of organisms, materials and energy (Pickett and Cadenasso 1995). Hence, landscape metrics can be interpreted as surrogates for the (inner) organization of a system which reflect landscape function and processes (Forman and Godron 1986, Miller et al. 1997). During the last 20 years numerous metrics have been proposed, many of them strongly correlated (Gustafson 1998, McGarigal and Marks 1995, Turner et al. 2001). Thus one needs to select a manageable set of independent metrics. According to several studies only a few major aspects were identified to describe landscape composition and landscape configuration (Herzog et al. 2001, Li and Reynolds 1994, Riitters et al. 1995). Landscape composition is quantified by (i) the number and (ii) proportion of land-cover types, whilst landscape configuration can be summarized as (i) the spatial arrangement of patches, (ii) number and size of patches, (iii) occurrence of edges and (iv) patch compaction (Herzog et al. 2001, Lausch and Herzog 2002, Li and Reynolds 1994, Riitters et al. 1995). Reviewing the aforementioned studies shows that a small set of metrics suffice to capture the principal properties of the landscape under consideration. Regarding the selection of metrics one has to bear in mind that each study has a unique setting and therefore the core metrics may differ. Thus our selection is based on the studies referred to before and theoretical considerations focusing on key features of riparian landscape pattern and their restoration. To cover the range of qualitatively different landscape properties we selected at least one metric for each above-named aspect (see Table 3). A test of the relationship among the selected indices showed that they are relatively independent, having a Pearson correlation coefficient $\leq 0.46$.

The raster version of PatchAnalyst (Rempel et al. 1999) was used for landscape metric calculation. For each site the selected landscape metrics were computed at the landscape level and – for selected key habitat types - at the habitat type (class) level.

We were also interested to know how far the present river widening deviates from the pre-restoration status before and from a near-natural status. For comparison we used the City Block Distance, also called „Manhattan“ metric.

Table 3. Landscape metrics and definitions related to selected landscape function and processes.

| Metric | Definition[1] | Examples of postulated, associated landscape function/processes |
|---|---|---|
| **Landscape composition** | | |
| PR | Patch Richness: measures the number of patch types present | Habitat diversity is a pre-requirement for species diversity. |
| %Area | Percentage of landscape occupied by each patch type | Habitat availability has strong influence on species populations. |
| **Landscape configuration** | | |
| MSI | Mean Shape Index: measures shape complexity of a patch compared to a standard shape (square for raster format) | The number of organisms can be a function of patch shape (Hamazaki 1996). |
| medPS | Median Patch Size (ha) | Patch size is a key feature representing suitable habitat. |
| MNN | Mean Nearest Neighbor: measures the distance from a patch to the nearest neighboring patch of the same type, based on edge-to-edge distance (m) | Dispersal and thus species colonization and the conservation of metapopulations are determined by the distance between suitable habitats. |
| MPI | Mean Proximity Index: measures the degree of isolation and fragmentation. MPI uses the nearest neighbor statistics and considers additionally the size of neighboring patches. | do. |
| IJI | Interspersion and Juxtaposition Index: measure of patch adjacency. IJI = 100 if all patch types are equally adjacent to all other patch types | The suitability as habitat for species with multiple habitat requirements depends on interspersion and juxtaposition of different habitat types. |
| ED | Edge Density: standardizes total edge length to a per unit area basis (m/ha) | - Water cycle regulation is a function of the shoreline (= ecotone length).<br>- The area of water-substrate interface (i.e. wetland-upland length of contact) is positively correlated with the efficiency of nitrogen retention (Pinay et al. 2002).<br>- Some species are more related to the amount of wetland edge than to the total amount of wetland (Browder et al. 1989). |

[1]For details see (McGarigal and Marks 1995)

This metric compares two cases i and j and is the sum of the distances on each variable, defined as follows (see also http://www.clustan.com/general_distances.html):

$$d_{ij} = \frac{\sum_k w_{ijk} \left| x_{ik} - x_{jk} \right|}{\sum_k w_{ijk}}$$

where: $x_{ik}$ is the value of variable k in case i, and $w_{ijk}$ is a weight of 1 or 0 depending upon whether or not the comparison is valid for the kth variable (if differential variable weights are specified it is the weight of the kth variable). The Manhattan metric aggregates the individual metrics into a single figure which allows the restoration measure to be rated on a scale of naturalness running from heavily altered (canalized) to near-natural.

## Data subset clips

### General considerations

An evaluation of restoration projects should be conducted in two steps. Firstly, the restored area should be compared with the regulated reference to detect any changes in landscape pattern due to the restoration process. Secondly, and of major importance, the restored area and a near-natural reference should be compared to see if the restored area matches the patterns inherent to a natural system. If significant differences can be found one should consider the different spatial extent of the areas under investigation, because the spatial extent of the map (window size) being analyzed has been shown to influence the values of landscape metrics considerably (Hunsaker et al. 1994, Qi and Wu 1996, Turner et al. 1989), especially those relating to patch complexity (Saura and Martinez-Millan 2001). Therefore caution is necessary when comparing areas of different extent. The influence of spatial extent can be reduced either by calculating the metric on the basis of a standard unit area (Freeman et al. 2003) (which can not be done for every metric) or by comparing the restored sites with a subset of near-natural areas of same size and shape as the restored sites. The latter approach is the one we used in this study. This approach is similar to the random window sampling technique used in studies of habitat selection in wildlife ecology (Mladenoff et al. 1995, Potvin et al. 2001, Ripple et al. 1991) but instead of using a square window, a mask of the same shape and size as the restored area was created to produce a data subset of comparable area from the near-natural reference sites. For the near-natural data subsets mean/median and range were calculated for each selected metric and compared with the values obtained from the restored/regulated sites. Statistical analysis was conducted with SPSS 11.0 for Windows.

## Subset generation

By means of the GIS a size and shape matched stencil („window“) of the restored area was produced. This stencil was used to cut out the subset of the habitat map of the natural reference using the clip function in ArcMap 8.1 (ESRI 1999) (see Figure 4). The stencil was positioned on the habitat maps with stencil centroids at randomly selected grid points of a $50m^2$ grid. Only grid points which allowed for a complete overlap between the stencil and the natural reference habitat map were used. The orientation of the stencil followed the mean stream direction. If a landscape patch was truncated by the edge of the stencil the portion of the patch within the stencil was included to provide for a constant sample unit. Sampling with overlapping was allowed (Potvin et al. 2001). The number of clips needed within a subset depends on the variability of the metric values within the subset. The clipping process proceeded until the obtained additional variability approached zero ($\Delta V = V_{n+1} - V \approx 0$). As the data were not normally distributed standard deviation and variance could not be used to describe the variability. Instead we calculated the variability as half the interquartile range (IQR) as percentage of the median (M): $V = \frac{0.5 * IQR}{M}$ (Lamprecht 1992). Based on $\Delta$ V the variability analysis showed that a sample size of 12 random windows provided a stabilization of the variability (except for MPI at the site of Lostallo (Moesa)). Consequently we used a set of 15 clips for the following investigations.

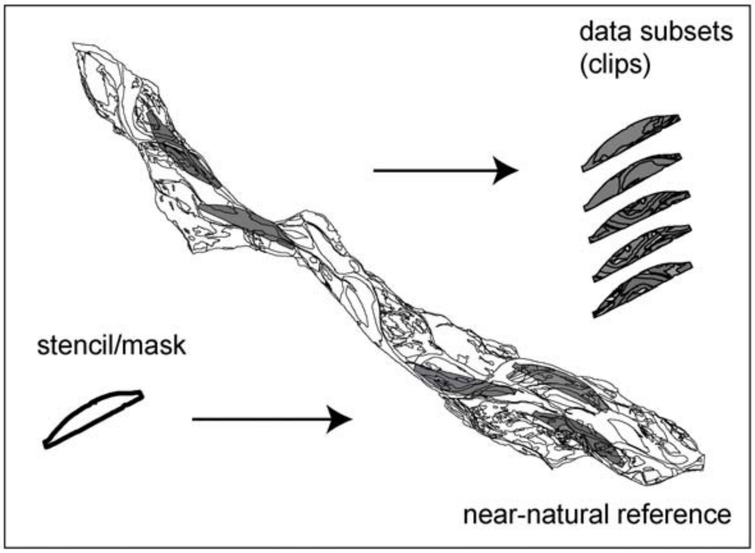


Figure 4. Stencil technique: Generation of data subsets (clips).

# Results

## Comparing the entire study areas

Regarding the landscape composition we find considerable match of habitat types between the restoration sites and their corresponding near-natural reference sites (see Table 4). Solely site I at the Moesa has only four habitat types in common with the near-natural reference. The restoration measures at the Emme River and Moesa site II lead to considerable improvements and more natural conditions in respect of the patch richness and number of riparian habitats. Looking at the habitat types which consistently appear at the restoration sites we can see that river widenings mainly promote young seral stages such as gravel bars with pioneer vegetation and riparian coppice (see Table 4). Late seral stages (riparian woodlands) are missing unless they are remnants which were formerly disconnected from the stream. This might be due to the young age and limited extent of the restoration site, as will be discussed later. The patch richness metric is a diversity measure based on the presence of a habitat type regardless the proportion of

Table 4. Landscape composition of the restoration sites (rs), corresponding regulated (rr) and near-natural (nr) references. For habitat codes refer to Table 2.

| **Habitat type** | **code** | **Emme (rs)** | **Emme (rr)** | **Sense (nr)** | **Moesa site I (rs)** | **Moesa site I (rr)** | **Moesa site II (rs)** | **Moesa site II (rr)** | **Maggia (nr)** |
|---|---|---|---|---|---|---|---|---|---|
| | | ***%Area*** | ***%Area*** | ***%Area*** | ***%Area*** | ***%Area*** | ***%Area*** | ***%Area*** | ***%Area*** |
| *water* | *100* | 37.09 | 27.39 | 19.24 | 84.91 | 35.40 | 46.66 | 32.64 | 10.43 |
| *bare gravel bars* | *200* | 13.51 | - | 23.13 | 14.15 | - | 19.01 | - | 31.89 |
| *gravel bars with pioneer vegetation* | *311* | 0.35 | - | 1.69 | 0.74 | - | - | - | 1.31 |
| | *321* | 2.72 | - | 4.05 | 0.2 | - | 0.24 | - | 4.69 |
| | *331* | 0.22 | - | 0.87 | - | - | - | - | 0.51 |
| | *341* | 2.15 | - | 0.31 | - | - | 0.35 | - | 0.73 |
| | *351* | 1.98 | - | 0.06 | - | - | 1.12 | - | 0.32 |
| | *361* | 1.58 | - | 4.19 | - | - | 3.93 | - | 1.56 |
| *riparian coppice* | *422* | 0.68 | - | 5.74 | - | - | 5.51 | - | 12.62 |
| | *432* | 0.11 | - | 3.55 | - | - | 3.65 | - | 3.91 |
| | *442* | 0.19 | - | 3.7 | - | - | 1.17 | - | 2.15 |
| | *452* | 7.67 | 22.83 | 2.22 | - | - | 4.95 | - | 1.98 |
| *riparian woodlands* | *423* | - | - | - | - | - | - | - | 2.47 |
| | *433* | - | - | 0.18 | - | - | - | - | 1.79 |
| | *443* | - | - | 0.44 | - | - | - | - | 0.87 |
| | *453* | 10.68 | - | 8.22 | - | - | 1.6 | - | 8.23 |
| | *424* | - | - | - | - | - | - | - | 0.02 |
| | *434* | - | - | 0.08 | - | - | - | - | - |
| | *454* | 18.51 | - | 20.16 | - | - | - | - | 14.27 |
| *non-riparian coppice* | *500* | 1.34 | - | - | - | - | 6.89 | 9.63 | - |
| *non-riparian woodlands* | *600* | 0.64 | 42.38 | - | - | 64.40 | 2.47 | 57.73 | - |
| *anthropogenic* | *700* | 0.58 | 7.4 | 2.15 | - | - | 2.46 | - | 0.25 |
| **patch richness** | | ***17*** | ***4*** | ***18*** | ***4*** | ***2*** | ***14*** | ***3*** | ***19*** |
| **number of riparian habitats** | | ***14*** | ***2*** | ***17*** | ***4*** | ***1*** | ***11*** | ***1*** | ***18*** |
| Total area (ha) | | 4.86 | 4.86 | 55.48 | 5.18 | 5.18 | 4.7 | 4.7 | 150.59 |

landscape occupied by the individual habitat type. As there are many species which have considerable minimum habitat area requirements it is also important to consider the area occupied by the individual habitat types. To avoid artifacts in differences of the occupied area due to varying water levels we regard water and bare gravel bars as a single, combined habitat type named „amphibious“. Table 4 shows that approx. 40% of the area in near-natural stretches belongs to this amphibious habitat. In contrast the restoration sites have a much higher percentage of either water or bare gravel bars (Emme 50%, Moesa site I 99%, Moesa site II 65%). Thus the river widenings provide a significant lower percentage of habitats for species which avoid amphibious ground than do the near-natural sites. At the restoration site of Aefligen (Emme) no differences in habitat occupation can be found for gravel bars with pioneer vegetation and riparian woodlands. In contrast both restoration sites at the Moesa differ (in some respects significantly) from their near-natural reference site at the Maggia River (see Table 4). Thus habitat composition at the restoration site of the Emme is more natural than at the sites at the Moesa.

In contrast to the landscape composition we find distinct differences in the landscape configuration between the restored sites and the near-natural references. The pattern of the widenings consists of smaller and more elongated patches, resulting in markedly higher edge densities (see Table 5).

Table 5. Landscape configuration of the restoration sites (rs), corresponding regulated (rr) and near natural (nr) reference.

| Metric | Emme (rs) | Emme (rr) | Sense (nr) | Moesa site I (rs) | Moesa site I (rr) | Moesa site II (rs) | Moesa site II (rr) | Maggia (nr) |
|---|---|---|---|---|---|---|---|---|
| **MSI** | 2.41 | 4.73 | 2.07 | 2.50 | 2.68 | 2.41 | 3.94 | 2.33 |
| **medPS** | 0.02 | 0.63 | 0.05 | 0.06 | 1.84 | 0.04 | 1.53 | 0.09 |
| **MNN** | 37.20 | 41.3 | 59.60 | 39.80 | 8.3 | 40.10 | - | 78.20 |
| **MPI** | 328.30 | 3.75 | 372.99 | 396.06 | 6089.37 | 176.79 | - | 1334.58 |
| **IJI** | 68.57 | 61.31 | 66.02 | 29.35 | 0.00 | 68.90 | 63.08 | 71.37 |
| **ED** | 1459.84 | 1081.30 | 1221.28 | 812.82 | 623.36 | 1470.91 | 699.47 | 759.16 |
| **Total area (ha)** | 4.86 | 4.86 | 55.48 | 5.18 | 5.18 | 4.7 | 4.7 | 150.59 |

For the restored sites at the Emme and Moesa site II, for example, the median patch size is less than half the size of the median patch size in the corresponding near-natural reference site. Our data shows that MSI generally increases with decreasing naturalness, which means that the more natural a site is the more compact and less elongate the patches are (see Table 5). Hence, a decrease in MSI indicates gain of interior habitat and less edge effects. Generally speaking, the restoration measures lead to a more natural habitat configuration, but the resulting pattern is more patchy than the pattern of the near-natural reaches.

As we suspected that there might be differences between the calculation at the landscape level and at the level of habitat types we calculated the metrics for selected habitat types, for example, gravel bars with pioneer vegetation, which are of special interest from a conservation point of view. As can be seen from Table 6 this calculation revealed the same results as obtained for calculation at the landscape level, namely smaller median patch size, higher edge density and mean shape index and less interspersed seral stages.

Landscape composition and configuration can be simultaneously assessed by means of the „Manhattan“ metric ($d_{ij}$) which is defined as the sum of the differences in the individual metrics. The calculated $d_{ij}$-values for the three widening projects are visualized in Figure 5. Overall the restoration projects at the Emme River and site II of the Moesa rate closer to near-natural conditions than does Moesa site I, where the restoration measures lead only to comparatively minor improvements.

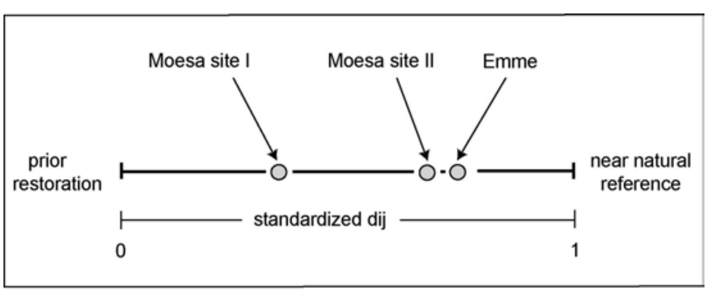


Figure 5. Rating of the restoration projects by means of the manhattan metric (standardized values: lowest dij-value = 0, highest dij-value = 1).

Table 6. Configuration metrics calculated for selected key habitats. Gravel bars with pioneer vegetation* at the restored site (rs) and at the near-natural reference (nr). For habitat codes refer to Table 2.

| landscape metric | Habitat type | Emme (rs) | Sense (nr) | Moesa I (rs) | Moesa II (rs) | Maggia (nr) |
|---|---|---|---|---|---|---|
| **MSI** | 311 | 2.26 | 1.82 | 2.13 | - | 2.66 |
| | 321 | 2.12 | 2.13 | 1.47 | 2.17 | 2.64 |
| | 331 | 2.89 | 1.70 | - | - | 1.85 |
| | 341 | 1.84 | 1.66 | - | 2.57 | 2.54 |
| | 351 | 3.18 | 1.79 | - | 3.16 | 2.25 |
| | 361 | 2.65 | 2.06 | - | 2.28 | 2.46 |
| **MedPS** | 311 | 0.0086 | 0.039 | 0.019 | - | 0.079 |
| | 321 | 0.066 | 0.078 | 0.01 | 0.011 | 0.13 |
| | 331 | 0.011 | 0.074 | - | - | 0.061 |
| | 341 | 0.044 | 0.051 | - | 0.017 | 0.071 |
| | 351 | 0.025 | 0.017 | - | 0.053 | 0.12 |
| | 361 | 0.012 | 0.041 | - | 0.061 | 0.088 |
| **MNN** | 311 | 137.77 | 97.12 | 218.52 | - | 130.76 |
| | 321 | 101.98 | 89.41 | 0.00 | 0.00 | 44.49 |
| | 331 | 0.00 | 353.95 | - | - | 180.6 |
| | 341 | 75.26 | 127.08 | - | 0.00 | 418.87 |
| | 351 | 18.51 | 2259.88 | - | 0.00 | 110.27 |
| | 361 | 25.46 | 74.15 | - | 66.49 | 97.09 |
| **MPI** | 311 | 0.00 | 0.37 | 0.00 | - | 56.95 |
| | 321 | 0.06 | 4.04 | 0.00 | 0.00 | 20.88 |
| | 331 | 0.00 | 7.50 | - | - | 0.13 |
| | 341 | 0.10 | 0.50 | - | 0.00 | 1.42 |
| | 351 | 236.46 | 0.00 | - | 0.00 | 0.27 |
| | 361 | 0.61 | 9.59 | - | 0.36 | 6.95 |
| **IJI** | 311 | 47.73 | 65.34 | 62.44 | - | 72.34 |
| | 321 | 33.79 | 77.49 | 61.82 | 29.15 | 78.37 |
| | 331 | 36.90 | 55.15 | - | - | 70.86 |
| | 341 | 56.92 | 50.60 | - | 27.02 | 70.71 |
| | 351 | 60.58 | 23.73 | - | 54.51 | 78.01 |
| | 361 | 64.74 | 72.14 | - | 73.06 | 83.65 |
| **ED** | 311 | 34.18 | 46.40 | 47.85 | - | 34.23 |
| | 321 | 87.30 | 87.50 | 11.58 | 19.59 | 69.29 |
| | 331 | 24.71 | 22.28 | - | - | 13.47 |
| | 341 | 81.13 | 9.66 | - | 28.11 | 18.51 |
| | 351 | 130.95 | 3.39 | - | 61.75 | 8.94 |
| | 361 | 143.72 | 92.55 | - | 144.37 | 44.11 |

* There are no gravel bars at the regulated reference sites

## Comparing data subsets (clips)

When we looked at the natural reference as a whole we found noticeable differences in the landscape configuration between restored and near-natural reaches. Are the differences as significant when we use the data subsets (clips) for comparison instead? The box plots of Figure 6 show the range of the metric values for each data subset and the value calculated for the restoration sites. For Emme and Moesa site II we can see that the calculated metrics lie within the range of the corresponding data subset in most instances. This is especially true for site II of the Moesa which matches all metrics except for edge density, that still being greater than for the near-natural data subset. For Moesa site I we find the same overall pattern as before when the comparison was done with the near-natural reference site as a whole. Only three out of seven metrics are within the near-natural range, reflecting the major differences between the restoration site and the near-natural stretch.

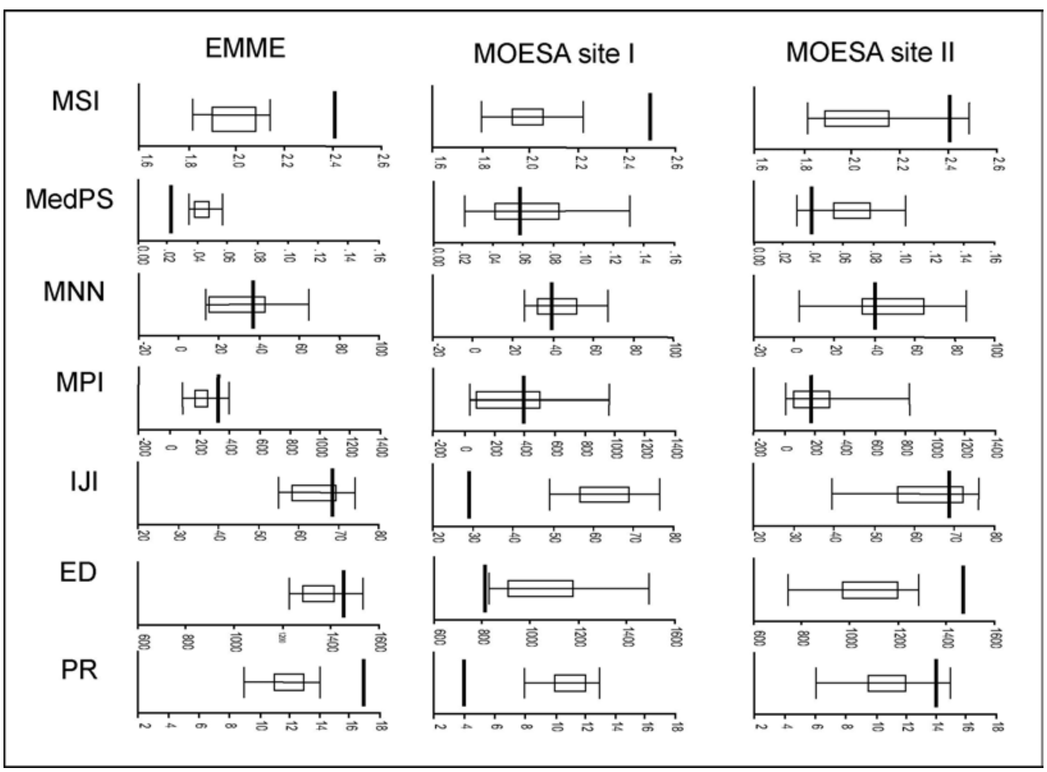


Figure 6. Metric values calculated for the restored sites (black bar) compared to range of metrics (boxplot) in the near-natural data subsets (clips).

Looking at the individual metrics in more detail we find that MNN and MPI, which reflect neighboring aspects, are within the near-natural range for all three restoration sites. For MNN the values even lie within the interquartile range. In contrast, the restored sites differ markedly from the near-natural sites if we compare the values of these metrics with the reference as a whole. This applies particularly to site I at the Moesa. In general one can say that the differences to be found between restored sites and near-natural stretches are less profound when comparison is done with the data subsets instead of the natural reference as a whole.

## Discussion

The presented methodological framework is an attempt to provide a rapid assessment of restoration measures based on readily available habitat data. The results of the method based on landscape metrics calculation, stencil subset sampling and comparison of the restored site versus a regulated/ near-natural reference are promising. However, the method has several limitations that have to be considered before drawing final conclusions.

### (1) A method based on habitat mapping

Many indicators used for river (restoration) assessment focus on in-stream components (Gergel et al. 2002, Innis et al. 2000). Benthos, temperature, water chemistry, velocity etc. are important characteristics to be considered. However, in-stream environment covers only 10-20% of the studied near-natural references. Thus in-stream indicators neglect most of the floodplain. The (semi-) terrestrial zone of a floodplain is generally characterized by a high habitat diversity and consequently high species richness, which should be considered when assessing restoration efforts. Additionally, processes in the riparian zone influence in-stream processes (Jones et al. 1999, Weller et al. 1998) (and vice versa). Therefore information on (semi-)terrestrial habitat should be included to complement existing assessment schemes.

Floodplains are characterized by the presence of a wide range of successional stages due to fluvial dynamics in natural river ecosystems. Therefore different horizontal and vertical structures of plant cover occur, which provide different animal habitat. This structural and functional diversity determines the richness of species diversity within riparian communities. Mapping merely based upon broad classes (forest, nonforest f.ex) and solely floristic characteristics does not account for this diversity. Therefore it is important to map also structural and successional features such as vegetation height and vegetation cover. The latter can easily be mapped using air photographs (orthophotos). Vegetation height might need field verification, depending on the area's topography.
In our rapid assessment we used habitat mapping that employs the widely acknowledged relationship between site characteristics and species abundance (Amoros 2001). One could argue that measuring species abundance would yield more accurate results. We acknowledge this but one has also to consider the following points:

- Firstly, a habitat reflects the potential for a typical biocoenosis to establish at a specific site. With our method we are able to judge this potential, i.e. whether or not the observed habitat pattern is similar to the near-natural conditions. This is of primary interest in the evaluation of restoration projects as restoration measures can mainly influence habitat conditions rather than species migration and colonization. The latter depends on time for colonization and on distance to seedling pools as well as on habitat availability. Colonization by a given species can therefore be decelerated in time despite favorable habitat conditions.
- Secondly, there is often a large year-to-year variability in the abundance of individual species due to factors that lie beyond the usual scale of a river restoration project. Therefore it is unlikely that assessment of individual species can inform the managers about the likely sustainability of the scheme, which is a vital consideration for restoration designers (Downs 2001). The alternative is to exploit the proven link between species and their physical habitats and to assess

the restoration project against its provision of a suitable habitat template (Downs 2001). Additionally, habitat maps are readily generated and cost-efficient, an important aspect considering the budget of many restoration projects.

## (2) A very formalized assessment based on landscape metrics

Our primary purpose was to generate a rapid assessment method that compares habitat properties after restoration with both the state prior to restoration and the near-natural state. To do so we employed landscape metrics calculation which is readily done once habitat maps are acquired.

Landscape metrics calculation is driven by the generally accepted paradigm that landscape pattern can be linked to landscape function and processes (Forman and Godron 1986, Honnay et al. 2003, Lausch and Thulke 2001). For an evaluation process the individual metrics should be independent from each other to avoid the weighting of single aspects. Thus the Pearsson correlation coefficient should be ideally less than 0.5. But finally, selection of the metrics should depend not only on correlation coefficients but on the questions to be answered as it is clear that each index adds additional information about the pattern of a specific site.

Potentials and limitations of the use of landscape metrics have been discussed by several authors (see Gustafson 1998, McGarigal and Marks 1995, Turner et al. 2001). Thus only a few remarks will be made here. Mean shape index (MSI) and mean patch fractal dimension (MPFD) are both measures of shape complexity. A simple test on sensitivity showed that MSI is more sensitive to changes in patch shape than is MPFD. Similar observations have been made by (Herzog et al. 2001, Moser et al. 2002). Thus MSI was selected for the evaluation of patch shape. MNN and MPI measure patch isolation and fragmentation. Both indices are based on the distance between patches, but in some cases spatial resistance in between suitable habitat patches may be as crucial an influence as distance on species dispersal. Thus interpretation of MNN and MPI is limited. One has also to bear in mind that at the landscape level MNN and MPI consider only patches having neighbors. Isolated habitat types are ignored. Therefore MNN and MPI are best interpreted in conjunction with the number of patches being present.

Landscape composition is a non-spatially-explicit characteristic. Following the ideas of the patch-shifting-concept and the statements of Gepp (1985) concerning the fluvial habitat mosaic the location of a single habitat patch may change with time but the total area occupied by a certain habitat type remains the same (within a limited range). Thus %land is a suitable indicator to be used in monitoring programs and evaluation processes.

## (3) Comparing entire study areas or subset clips

A methodological problem that occurs in many landscape studies is the comparison of study objects of different size (Frohn 1998, Saura and Martinez-Millan 2001). As we are well aware that the size of a study region influences certain landscape metrics we propose a new method (the stencil technique) that yields samples with constant size and shape. This is an important prerequisite for the comparison of different areas to reduce bias due to window size. As the clips are artificial subsets of natural patterns some remarks are needed for data interpretation. The patch size of the subset is likely to be underestimated as the stencil truncates the larger patches. These fragments of patches that are cut by the stencil border are likely to be smaller than the defined minimum mapping unit used in the habitat maps of the restored area. Therefore we used median values instead of mean values for the interpretation as the median is less sensitive to those artificial outliers than is the mean. The data subsets allow the characterization of the natural range of variability of habitat properties (composition & configuration) found at near-natural sites. This insight into the natural range of variability helps to assess whether the structural pattern found at a restoration site is within the natural range of variability of natural systems or if they differ from natural conditions (Poiani et al. 2000).

## (4) A method based on comparison of restored and near-natural sites

Near-natural stretches define the endpoint to aim for in a restoration process. Thus reference sites are needed to assess the degree of naturalness which has been achieved by a selected restoration project (Downs 2001, Innis et al. 2000, Milner 1996).

However, a major limitation of this study is that the assessment of the post restoration stage is not based on near-natural sites in situ but on the comparison of sites that are most similar to the site under investigation (analogy conclusion). If the reference sites do not belong to the same system as the restoration sites the most important differences between the areas need to be known and to be taken into account during the evaluation process. Thus natural references are best interpreted as „generalized models“.

In the process of restoration time plays a major role in the establishment of near-natural features. Succession needs some time to develop late seral stages like shrub and woodlands. Therefore evaluation should allow for this „time lag“ and should not take place until a few years after the restoration measures have been finished. Restoration at the Emme River was finished around 10 years ago but still lacks late seral stages initialized by the restoration process. The riparian woodlands which can be found at the Emme restoration site are remnants of the situation before the restoration measures took place. But even provided enough time for establishment it is still doubtful that all seral stages naturally present in a floodplain will occur in the river widenings due to their limited spatial extent. This is confirmed by the metric analysis at the habitat level which revealed a median patch size in the near-natural sites up to six times larger than that to be found at the present restoration sites. The sum of the mean patch sizes of each habitat class (excluding water) for the near-natural site at the Sense river is 7.5 ha. This area is one and a half times larger than the total extent of the river widening at the corresponding river widening at the Emme (5 ha). Thus the extent of the widenings does not allow the establishment of the whole range of floodplain habitats. One has also to consider that the river widenings solely open the channel but not allowing the former floodplain to be flooded. Therefore new habitats establish in the channel were stream velocity and scour is high. This hampers the development of woodlands which develop at sites with low disturbance level.

We were able to consider spatial variation in the near-natural clips, but acknowledge that we could not take temporal variation into account. It remains to be answered, if the temporal variation of the near-natural metric values produces considerably different ranges than the ranges for spatial variability obtained in this study.

## Conclusions

Given the limitations of the approach discussed above we conclude that:

a) Reference sites, both regulated and near-natural are pre-requisites for successful assessment. The proposed stencil technique is applicable to any restoration project and allows an efficient and rapid assessment of the degree of naturalness being achieved as it readily offers insights into similarities and differences between regulated, restored and near-natural sites. The clip of data subsets proofed to be a suitable method to assess to what extent a natural habitat pattern has been achieved by the restoration measures considering the limited spatial extent of those measures. Thus a manager can check if the restoration project has obtained a near-natural state, taken into account that the spatial dimension of the project is limited by socioeconomic constraints.

b) Considering the riparian zone complements in-stream indicators and thus maximizes the quality of the assessment on the performance of the restored site. This approach allows to assess the ecological integrity of a certain site, which is defined as the full range of elements and processes expected in a regions natural habitat (Karr and Dudley 1981).

c) Landscape metrics are valuable indicators for the evaluation of restoration projects as they are surrogates for landscape function and offer valuable insights into similarities and differences between landscape pattern in different landscapes. The proposed core set of landscape metrics (MSI, medPS, MNN, MPI, IJI, ED, %Area, PR) suffice to capture the principal properties of a natural pattern and they are intuitive and easily interpretable which makes them easy to communicate to a wide range of stakeholders. The Manhattan metric ($d_{ij}$) allows a quick and clear rating of restoration measures, thus supporting the evaluation process and communication.

d) River widenings provide the potential for the re-establishment of riparian habitat, mainly young seral stages, showing a more complex habitat mosaic than near-natural sites. Thus it is possible to re-establish some aspects of fluvial ecosystems, but river widenings can not replace (near) natural ecosystems.

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## Literature cited

Amoros, C. 2001. The concept of Habitat Diversity Between and Within Ecosystems Applied to River Side-Arm Restoration. *Environmental Management* 28**:** 805-817.

Blaschke, T. and Petch, J. 1999: Landscape structure and scale: comparative studies on some landscape indices in Germany and the UK. Pages 75-84 in *Maudsley, M. and Marshall, J. (eds.)* Heterogeneity in Landscape Ecology: Pattern and Scale, IALE UK, Bristol.

Browder, J. A., May, L. N., Rosenthal, A., Gosselink, J. G. and Baumann, R. H. 1989. Modeling future-trends in wetland loss and brown shrimp production in Louisiana using thematic mapper imagery. *Remote sensing of environment* 28**:** 45-52.

Brunke, M. 2002. Floodplains of a regulated southern alpine river (Brenno, Switzerland): ecological assessment and conservation options. *Aquatic conservation - marine and freshwater ecosystems* 12**:** 583-599.

Downs, P. 2001: Geomorphological evaluation of river restoration schemes: principles, method, monitoring, assessment, evaluation. Progress? Pages 243-249. in *Nijland, H. J. and Cals, M. J. R. (eds.)* River Restoration in Europe: practical approaches, Institute for Inland Water Management and Waste Water Treatment / RIZA, Lelystad.

Forman, R. T. T. and Godron, M. 1986. Landscape ecology. Wiley, New York a.o., XIX, 619 pp.

Freeman, R. E., Stanley, E. H. and Turner, M. G. 2003. Analysis and conservation implications of landscape change in the Wisconsin river Floodplain, USA. *Ecological Applications* 13**:** 416-431.

Frohn, R. 1998. Remote Sensing for Landscape Ecology. New metric indicators for monitoring, modeling and assessment of ecosystems. Lewis Publishers, Boca Raton, 99 pp.

Gallandat, J.-D., Gobat, J.-M. and Roulier, C. 1993. Kartierung der Auen von nationaler Bedeutung. Vol. 199, Schriftenreihe Umwelt, Bundesamt für Umwelt, Wald und Landschaft (BUWAL).

Gepp, J. 1985. Auengewässer als Oekozellen. Fluss-Altarme, Altwässer und sonstige Auen-Stillgewässer Oesterreichs; Bestand, Oekologie und Schutz. Grüne Reihe, Bundesministerium für Gesundheit und Umweltschutz, Wien, 322 pp.

Gergel, S. E., Turner, M. G., Miller, J. R., Melack, J. M. and Stanley, E. H. 2002. Landscape indicators of human impacts to riverine systems. *Aquatic science* 64**:** 118-128.

Gilvear, D., Heal, K. and Stephen, A. 2002. Hydrology and the ecological quality of Scottish river ecosystems. *Science of the total environment* 294**:** 131-159.

Gustafson, E. J. 1998. Quantifying landscape spatial pattern: what is the state of the art? *Ecosystems* 1**:** 143-156.

Hamazaki, T. 1996. Effects of patch shape on the number of organisms. *Landscape Ecology* 11**:** 299-306.

Henry, C., Amoros, C. and N, R. 2002. Restoration ecology of riverine wetlands: A 5-year post-operation survey on the Rhone River, France. *Ecolgical engeneering* 18**:** 543-554.

Herzog, F., Lausch, A., Müller, E., Thulke, H.-H., Steinhard, U. and Lehmann, S. 2001. Landscape Metrics for Assessment of Landscape Destruction and Rehabilitation. *Environmental Management* 27**:** 91-107.

Honnay, O., Piessens, K., Van Landuyt, W., Hermy, M. and Gulinck, H. 2003. Satellite based land use and landscape complexity indices as predictors for regional plant species diversity. *Landscape and urban planning* 63**:** 241-250.

Hunsaker, C. T., O'Neill, R. V., Jackson, B. L., Timmins, S. P., Levine, D. A. and Norton, D. A. 1994. Sampling to characterize landscape pattern. *Landscape Ecology* 9**:** 207-226.

Innis, S. A., Naiman, R. J. and Elliott, S. R. 2000. Indicators and assessment methods for measuring the ecological integrity of semi-aquatic terrestrial environments. *Hydrobiologia* 422/423**:** 111-131.

Jones, E. B. D., Helfman, G. S., Harper, O. J. and Bolstad, P. V. 1999. Effects of riparian forest removal on fish assemblages in southern Appalachian streams. *Conservation Biology* 16**:** 1454-1465.

Karr, J. R. and Dudley, D. R. 1981. Ecological perspectives on water quality goals. *Environmental Management* 5**:** 55-68.

Kondolf, M. G. and Micheli, E. R. 1995. Evaluating Stream Restoration Projects. *Environmental Management* 19**:** 1-15.

Lamprecht, J. 1992. Biologische Forschung: Von der Planung bis zur Publikation. Vol. 73, Pareys Studientexte, Verlag Paul Parey, Berlin and Hamburg, 157 pp.

Lausch, A. and Thulke, H.-H. 2001: The analysis of spatio-temporal dynamics of landscape structures. Pages 113-136 in *Krönert, R., Steinhard, U. and Volk, M. (eds.)* Landscape balance and landscape assessment, Springer-Verlag, Berlin, Heidelberg, New York.

Lausch, A. and Herzog, F. 2002. Applicability of landscape metrics for the monitoring of landscape change: issues of scale, resolution and interpretability. *Ecological Indicators* 2**:** 3-15.

Li, H. and Reynolds, J. F. 1994. A simulation experiment to quantify spatial heterogeneity in categorical maps. *Ecology* 75**:** 2446-2455.

Malanson, G. P. 1995. Riparian Landscapes. Cambridge University Press, Cambridge, 296 pp.

McGarigal, K. and Marks, B. 1995. FRAGSTATS: spatial pattern analysis program for quantifying landscape structure., U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 122.

Miller JN, Brooks RP and MJ, C. 1997. Effects of landscape patterns on biotic communities. *Landscape Ecology* 3**:** 137-153.

Milner, A. M. 1996: System Recovery. Pages 67-76 in *Petts, G. and Calow, P. (eds.)* River Restoration, Blackwell Science Ltd., Oxford.

Mladenoff, D. J., Sickley, T. A., Haight, R. G. and Wydeven, A. P. 1995. A regional landscape analysis and prediction of favorable gray wolf habitat in the Northern Great Lakes Region. *Conservation Biology* 9**:** 279-294.

Moser, D., Zechmeister, H. G., Plutzar, C., Sauberer, N., Wrbka, T. and Grabherr, G. 2002. Landscape patch shape complexity as an effective measure for plant species richness in rural landscapes. *Landscape Ecology* 17**:** 657-669.

Naiman, R. J., Décamps, H. and Pollock, M. 1993. The role of riparian corridors in maintaining regional biodiversity. *Ecological Applications* 3**:** 209-212.

Nilsson, C. and Svedmark, M. 2002. Basic Principles and Ecological Consequences of Changing Water Regimes: Riparian Plant Communities. *Environmental Management* 30**:** 468-480.

Pedroli, B., de Blust, G., van Looy, K. and van Rooij, S. 2002. Setting targets in strategies for river restoration. *Landscape Ecology* 17 (Suppl.1)**:** 5-18.

Petts, G. and Calow, P. 1996. River Restoration. Blackwell Science Ltd, Oxford, 231 pp.

Pickett, S. T. A. and Cadenasso, M. L. 1995. Landscape Ecology - spatial heterogeneity in ecological systems. *Science* 269**:** 331-334.

Pinay, G., Clément, J. C. and Naiman, R. J. 2002. Basic Principles and Ecological Consequences of Changing Water Regimes on Nitrogen Cycling in Fluvial Systems. *Environmental Management* 30**:** 481-491.

Poiani, K. A., Richter, B. D., Anderson, M. G. and Richter, H. E. 2000. Biodiversity Conservation at Multiple Scales: Functional Sites, Landscapes, and Networks. *BioSciense* 50**:** 133-146.

Potvin, F., Lowell, K., Fortin, M.-J. and Bélanger, L. 2001. How to test habitat selection at the home range scale: A resampling random windows technique. *Ecoscience* 8**:** 399-406.

Qi, Y. and Wu, J. 1996. Effects of changing spatial resolution on the results of landscape patterns analysis using spatial autocorrelation indices. *Landscape Ecology* 11**:** 39-49.

Rempel, R. S., Carr, A. and Elkie, P. 1999. Patch analyst and patch analyst (grid) function reference. Centre for Northern Forest Ecosystem Research, Ontario Ministry of Natural Resources, Lakehead University.

Riitters, K. H., O'Neill, R. V., Hunsaker, C. T., Wickham, D. H., Yankee, D. H., Timmins, S. P., Jones, K. B. and Jackson, B. L. 1995. A factor analysis of landscape pattern and structure metrics. *Landscape Ecology* 10**:** 23-29.

Ripple, W. J., Johnson, D. H. and Meslow, C. E. 1991. Old-growth and mature forests near spotted owl nests in western Oregon. *The Journal of Wildlife Management* 55**:** 316-318.

Saura, S. and Martinez-Millan, J. 2001. Sensitivity of Landscape Pattern Metrics to Map Spatial Extent. *Photogrammetric engineering & remote sensing* 67**:** 1027-1036.

Thomson, J., Taylor, M., Fryirs, K. and Brierley, G. 2001. A geomorphological framework for river characterization and habitat assessment. *Aquatic conservation - marine and freshwater ecosystems* 11**:** 373-389.

Turner, M. G., Gardner, R. H. and O'Neill, R. V. 2001. Landscape ecology in theory and practice. Pattern and process. Springer, New York, 401 pp.

Turner, M. G., O'Neill, R. V., Gardner, R. H. and Milne, B. T. 1989. Effects of changing spatial scale on the analysis of landscape pattern. *Landscape Ecology* 3**:** 153-162.

Weller, D. E., Jordan, T. E. and Correll, D. L. 1998. Heuristic models for material discharge from landscapes with riparian buffers. *Ecological Applications* 8**:** 1156-1169.

# Paper II

## River widening: a promising restoration approach to re-establish riparian habitats and plant species?

*Submitted as:*

Rohde[1], Schütz[1], Kienast[1] & Englmaier[2]: River widening: a promising restoration approach to re-establish riparian habitats and plant species. *River Research and Applications.*

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## Abstract

"River widenings" are commonly used technical means in river restoration to allow channel movement within a spatially limited area. Restoration seeks to restore fluvial processes and to re-establish a more natural riparian community. This study investigates the performance of five river widenings in Switzerland, focusing on the re-establishment of riparian (semi-) terrestrial habitats and species, and highlights some factors that seem to influence the performance.

The restoration projects are compared to pre-restoration conditions and near-natural conditions, which are assumed to represent the worst- and best-case conditions along a gradient of naturalness. Fuzzy ordination of vegetation relevées and landscape metrics calculation based on habitat maps revealed marked differences regarding the degree of naturalness achieved by each individual restoration project. However, we generally found that river widenings increased the in-stream habitat heterogeneity and enhanced the establishment of pioneer habitats and riparian plants. Analyses of species pools based on a hierarchic list of indicator species and correspondence analysis showed that the ability of river widenings to host typical riparian species and to increase local plant diversity strongly depends on the distance to near-natural stretches. Species dispersal and establishment might be hampered by decisions taken outside the scope of the restoration project. Therefore we conclude that further action on the catchment scale is needed to maximise the effort of local management.

**Keywords:** river widening, restoration, riparian habitat, riparian plant species, landscape metrics, Manhattan metric, reference system, assessment, Switzerland

## Introduction

Several studies have emphasized the importance of riparian ecosystems as centres of biodiversity since they link terrestrial and aquatic systems (Malanson, 1995; Naiman et al., 1993; Ward, 1998; Ward et al., 2002). However, intensive anthropogenic use and alteration of riverine landscapes have led to severe degradation of river-floodplain systems, especially in highly industrialised countries. River-bed erosion and loss of riparian habitat and species are among the most prominent consequences of these engineering works (Erskine, 1992; Pedroli et al., 2002; Petts and Calow, 1996). In recent years the restoration of these wetlands has become an important issue, enhanced by the European Union's Habitat and Water Framework Directives. In the Netherlands, for example, the number of stream restoration projects increased from 70 to 206 between 1991-1998 (Verdonschot and Nijboer, 2002).

One major conceptual framework in restoration ecology is the restoration threshold concept formulated by Hobbs and Norton (1996). A number of different states may exist for a system, but once a threshold is crossed the system needs some active management to remove the stressors and to allow the system to recover. Whisenant (1999) proposed two types of restoration thresholds: one caused by biotic stressors and the other caused by abiotic limitations. However, the re-establishment of the abiotic habitat conditions is a pre-requisite for the return of riparian species (Bakker et al., 2002, de Jonge and de Jong, 2002).

In Switzerland a new approach in river management has led to the initiation of river widenings to alleviate the effects of canalization, which is the major abiotic limitation. River widenings are small-scale restoration measures where flood levees are shifted, thus allowing channel movement within a limited area. Despite the increasing number of these restoration projects little scientific work has been done to assess what positive or negative impacts these restoration measures may have on riparian habitats and species. At the same time, there is a great need for such evaluations because several restoration projects will be initiated within the next few years. About 30,000 km of Swiss rivers and streams are in need of restoration (Peter 2003, personal communication). As Kondolf (1995) stressed: “Post-project evaluation is essential if the field of river restoration is to advance”.

The aim of the study reported here, which is part of the transdisciplinary Rhone-Thur project (www.rhone-thur.eawag.ch, 2003), was to investigate the potential of river widenings to re-establish fluvial ecosystems. The specific objectives were: (i) to demonstrate the degree of naturalness that can be achieved with river widening, (ii) to see which (semi-) terrestrial habitats and plant species benefit from such measures and (iii) to identify factors influencing the performance of the restoration process.

## Study sites

For this study five river widenings in four rivers in Switzerland were selected (Figure 1). River widenings are small-scale restoration measures where flood levees are shifted, thus allowing river movement within a limited area (Figure 2). As shown in Table 1, each river widening was compared with both a regulated reference and a near-natural reference to assess the ecological performance of the restoration projects. Detailed information about the restoration projects and the ecological conditions at each study site is given in Tables 2 and 3.

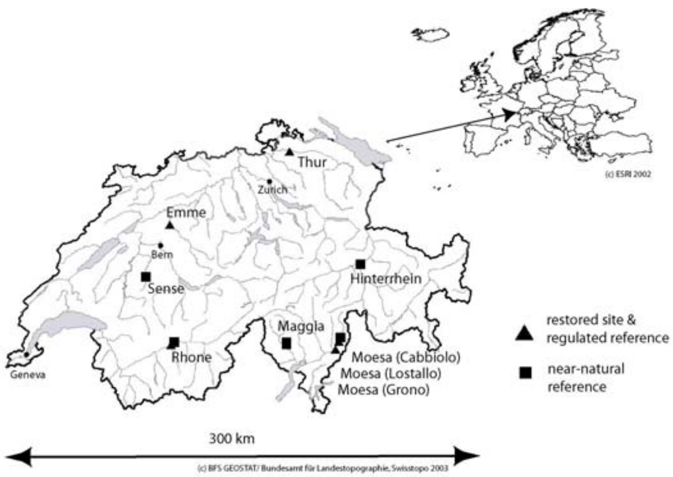


Figure 1. Study sites

The established reference system comprises a gradient of naturalness ranging from pre-restoration conditions (regulated reference) to near-natural conditions (near-natural reference). Pre-restoration conditions are assumed to represent the worst-case scenario and near-natural conditions the best (Downs 2001). The series of photographs shown in Figure 3 a-c examplifies such a study triplet: the Thur river prior to restoration (regulated reference), river widening of the Thur and the corresponding near-natural reference at the Hinterrhein. Figure 3d shows the Thur river prior to canalization for comparison. For two of the restored sites it was not possible to find any remaining near–natural stretches along the same river. Therefore we had to choose reference sites from two rivers that have similar biogeographical as well as geomorphological and hydrological properties.

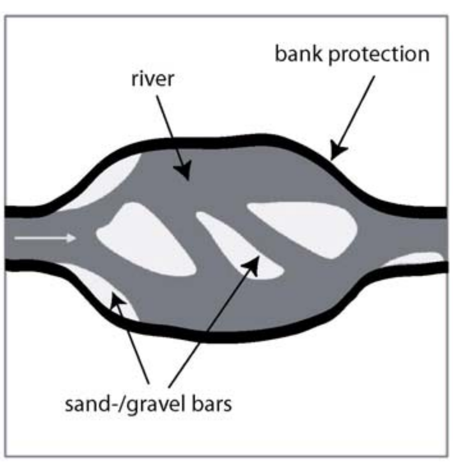


Figure 2. River widening - a small-scale river restoration which allows channel movement within a limited area.

Table 1: River widenings and corresponding regulated and near-natural reference sites for the investigation at the habitat and at the species level

| | | | |
|---|---|---|---|
| |  |  |  |
| **Investigation level** | **regulated reference** | **river widening** | **near-natural reference** |
| **Habitat level** | Thur<br>Rhone<br>Moesa<br>Emme | Thur<br>Rhone<br>Moesa<br>Emme | Hinterrhein<br>Hinterrhein<br>Maggia<br>Sense |
| **Species level** | Thur<br>Rhone<br>Moesa<br>Emme | Thur<br>Rhone<br>Moesa<br>Emme | Hinterrhein<br>Rhone<br>Moesa<br>Sense |

Table 2. Technical information on the investigated restoration projects

| River | Emme | Thur | Moesa | Moesa | Rhône |
|---|---|---|---|---|---|
| **Community** | Aefligen | Gütighausen | Grono | Lostallo | Chippis |
| **Year of construction** | 1991/1992 (1. phase) 1998/1999 (2. phase) | 1991-1992 | 1998/1999 | 1996/1997 | 1993-1994 |
| **Length** | 500m | 750m | 600m | 600m | 275m |
| **Widening** | 35-55m | up to 30m | up to 50m | 20m- 85m (right side) | 100m (right side) |
| **Bank protection** | groins on both sides (every 35m - 50m) | groins on both sides (every 20m), anchored tree fascines | none, except at the down-stream end of the widening (riprap) | groins | riprap |

Figure 3a-d. (left to tright)
a. Canalized Thur (Gütighausen) in 1967 (AWEL, ZH)
b. Widening of the Thur (Gütighausen) in 2000 (AWEL, ZH)
c. Current state of the near-natural stretch of the Hinterrhein (Rhäzüns) (J. Hartmann)
d. Thur (Niederbüren) around 1920 before river training took place (Amt f. Umweltschutz, SG)

Table 3. Characteristics of the study sites

| Criteria | Description | Unit | Rhone | Rhone | Hinterrhein | Thur | Maggia | Moesa | Moesa | Sense | Emme |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Geography** | | | | | | | | | | | |
| **River type** | Management | - | near-natural | River widening | near-natural | River widening | near-natural | near-natural | River widening | near-natural | River widening |
| **Locality** | | - | Pfynwald | Chippis | Rhäzüns | Gütighausen | Someo | Cabbiolo | Grono/Lostallo | Plaffeien | Aefligen |
| **Area** | | ha | 103 | 2.96 | 71.5 | 4.53 | 150.6 | 9.12 | 5.18 / 4.7 | 55.48 | 4.86 |
| **Biogeo** | Biogeographic region | - | Southern part of Swiss Alps | Southern part of Swiss Alps | Swiss Plateau | Swiss Plateau | Southern part of Swiss Alps | Southern part of Swiss Alps | Southern part of Swiss Alps | Swiss Plateau | Swiss Plateau |
| **Hydrology** | | | | | | | | | | | |
| **Qm_10** | Mean yearly discharge during a 10 year period | m3/s | 106 [1] | 106 [1] | 39 [1] | 48 [1] | 4.31 [2] | 20.8 [1] | 20.8 [1] | 9.2 [2] | 18.8 [1] |
| **Qmin_10** | Lowest mean daily discharge during a 10 year period | m3/s | 21.4 [1] | 21.4 [1] | 5.88 [1] | 3.35 [1] | 0.85 [2] | 1.35 [1] | 1.35 [1] | 1.47 [2] | 3.56 [1] |
| **Qmax_10** | Maximum mean daily discharge during a 10 year period | m3/s | 830 [1] | 830 [1] | 670 [1] | 1130 [1] | 650 [1] | 430 [1] | 430 [1] | 495 [2] | 470 [1] |
| **HQ2** | Discharge of biennial flood | m3/s | 462 [1] | 462 [1] | 369 [1] | 561 [1] | 299 [1] | 306 [1] | 306 [1] | 163 [2] | 259 [1] |
| **Qm_veg_10** | Average mean discharge during vegetation period (Apr.- Oct.) for a 10 year period. | m3/s | 162 [4] | 162 [4] | 54 [4] | 47 [4] | 6.84 [2] | 30.6 [4] | 30.6 [4] | 9.36 [2] | 17.6 [4] |
| **Qmax_veg_10** | Average maximum discharge during vegetation period for a 10 year period. | m3/s | 332 [4] | 332 [4] | 384 [4] | 316 [4] | 120 [2] | 150 [3] | 150 [3] | 89.48 [2] | 141 [3] |
| **Geomorphology** | | | | | | | | | | | |
| **J** | slope | % | 0.4 | 0.4 | 0.56 | 0.15 | 0.99 | 0.8 | 0.8 | 1.8 | 0.62 |
| **dm** | Mean diameter of bedload | mm | 50-100 | 50-100 | 60 | 40 | not available | 55 | 55 | not available | 78 |

[1] Swiss Federal Office for Water and Geology (1991-2000)

[2] Riparian Zones Information Center, Yverdon (1986-1995)

[3] Own calculations based on data from the Swiss Federal Office for Water and Geology (1992-2001)

[4] Own calculations based on data from the Swiss Federal Office for Water and Geology (1991-2000)

# Methods

## Data sampling

Digital habitat maps were obtained by analyzing orthophotos and ground-based surveys with a differential GPS (Leica GS50, DRS reference signal). These maps were used for landscape metrics calculations and as a basis for the stratified random placement of sample points for vegetation mapping.

The vegetation survey was carried out in 2002 from May to September. At each sample point a 5m x 5m quadrate was set up to survey alluvial pioneer vegetation at the river-widenings and at the near-natural stretches. All vascular plants present were recorded and their abundance estimated, following Braun-Blanquet (1964) and the nomenclature of Lauber and Wagner (1996). Additionally, for the restored sites all plants growing outside the plots were recorded to compile a complete species list for each restoration project.

We also investigated the plant composition of the dominant habitat types at the regulated reference sites and the surroundings of the river widening. The investigated habitat types were river-banks and embankments upstream of the river widening, nearby forest, forest edges and arable grassland.

## Data analysis

### Analysis of habitat maps

River restoration can be defined as returning the river system to its condition prior to degradation (Lewis 1990). We hypothesized that the degree of naturalness achieved by an individual restoration project varies according to the different biological organization levels, namely habitat and species level.

To assess the degree of naturalness achieved at the habitat level we analysed digital habitat maps. We applied landscape metrics calculation to quantify landscape configuration and composition since the presence of a diverse array of riparian landscape elements (= habitat types) is a pre-requisite for species colonization. Table 4 shows the selected landscape metrics, generated using the ArcView extension PatchAnalyst 2.0 (Rempel et al., 1999). For an overall assessment the "Manhattan metric", also known as City Block Distance, was used as indicator. The Manhattan metric aggregates the individual metrics into a single figure and allows, after standardization (range 0-1), the degree of naturalness achieved at the habitat level (Rohde et al., 2003) to be assessed.

Table 4. Landscape composition and configuration derived from landscape metrics calculation (McGarigal and Marks 1995). (PR: Patch Richness, MSI: Mean Shape Index, medPS: Median Patch Size, MNN: Mean Nearest Neighbor, MPI: Mean Proximity Index, IJI: Interspersion & Juxtaposition Index, ED: Edge Density)

| **Site** | **River type** | **Metric** | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | **PR** | **MSI** | **medPS** | **MNN** | **MPI** | **IJI** | **ED** |
| Emme | regulated | 4.00 | 4.73 | 0.63 | 41.30 | 3.75 | 61.31 | 1081.30 |
| Emme | restored | 17.00 | 2.41 | 0.02 | 37.20 | 328.30 | 68.57 | 1459.84 |
| Sense | near-natural | 18.00 | 2.07 | 0.05 | 59.60 | 372.99 | 66.02 | 1221.28 |
| Moesa (G) | regulated | 2.00 | 2.68 | 1.84 | 8.30 | 6089.37 | 0.00 | 623.36 |
| Moesa (G) | restored | 4.00 | 2.50 | 0.06 | 39.80 | 396.06 | 29.35 | 812.82 |
| Maggia | near-natural | 19.00 | 2.33 | 0.09 | 78.20 | 1334.58 | 71.37 | 759.16 |
| Moesa (L) | regulated | 3.00 | 3.94 | 1.53 | 0.00 | 0.00 | 63.08 | 699.47 |
| Moesa (L) | restored | 14.00 | 2.41 | 0.04 | 40.10 | 176.79 | 68.90 | 1470.91 |
| Maggia | near-natural | 19.00 | 2.33 | 0.09 | 78.20 | 1334.58 | 71.37 | 759.16 |
| Thur | regulated | 3.00 | 3.22 | 0.99 | 29.10 | 5.85 | 25.99 | 782.47 |
| Thur | restored | 6.00 | 2.63 | 0.12 | 85.40 | 1.76 | 47.51 | 795.15 |
| Hinterrhein | near-natural | 20.00 | 2.03 | 0.05 | 68.20 | 193.24 | 56.01 | 634.91 |
| Rhône | regulated | 2.00 | 1.58 | 1.49 | 0.00 | 0.00 | 0.00 | 411.14 |
| Rhône | restored | 6.00 | 2.18 | 0.07 | 9.40 | 71.39 | 66.14 | 1025.26 |
| Hinterrhein | near-natural | 20.00 | 2.03 | 0.05 | 68.20 | 193.24 | 56.01 | 634.91 |

### Preliminary treatment of vegetation relevées

We assumed that between-river differences in the species pools could influence the comparison of the species composition between the restored site and the near-natural reference. In cases where the restored site and the reference site were not located at the same river, we checked for species which did not occur in both species pools to control for this hypothesized regional effect. To our surprise we found only one such species, and it was consequently removed from the data set before starting the statistical analysis. The individual species pools were obtained using the data base of the Swiss Web Flora (http://www.wsl.ch/land/webflora, 2003; Welten and Sutter, 1982; Wohlgemuth 1998). This data base contains information on the species distribution within 593 mapping areas (ecoregions) of Switzerland. All species found in mapping areas crossed by the river (upstream of the restored site) were added to the species pool.

### Analysis of vegetation relevées

We conducted fuzzy-ordination (Roberts, 1986) using Mulva 5 (Wildi and Orlòci, 1990) to see if the vegetation composition of the restored sites is similar to the dominant habitat types found in the surroundings of the river widening (regulated reference) or similar to the near-natural reference. The ordination determines both the similarity of the restored sites to the near-natural reference (first ordination axis) and their similarity to the regulated reference (second ordination axis) and is based on the similarity index:

$$S_{x,y} = \frac{\sum x_i y_i}{\sum x_i^2 + \sum y_i^2 - \sum x_i y_i}, \qquad (i= 1, \ldots, n)$$

where $x_i$ and $y_i$ are the scores of species i in samples x and y and n is the number of species. The values of the first ordination axis (Axis 1) are used to assess the degree of naturalness achieved at the species level. We calculated the differences between the mean of the Axis 1-values of the restored site and the mean of the Axis 1-values of the corresponding near-natural reference to measure the degree of naturalness achieved by each restoration project.

We did a correspondence analysis (Hill, 1973; ter Braak and Smilauer, 2002) to identify those species which differentiate most between the restored site and the corresponding near-natural reference. Before the analysis we transformed the values of cover-abundance (Braun-Blanquet, 1964) following van der Maarel (1979) with $y= x^{0.5}$. To identify those species which benefit most from the restoration measures, we examined a total of 43 relevées gained from the restored sites and calculated the frequency of all recorded species.

A major goal of restoration is to maintain and enhance natural species diversity. Besides this general goal of enhancing species diversity, establishing a site specific species composition is of special interest. Therefore we compiled a list of riparian species (= indicator species) and performed a Mann-Whytney U test (SPSS 11.0) to identify potential significant differences between restored sites and corresponding near-natural references, both in terms of overall species richness and with respect to the presence of riparian species. The list of riparian species is based on Kuhn (1987) in which all plant communities (in the sense of European phytosociology) that can be found in the floodplains of Switzerland are listed. Kuhn (1987) also indicated those communities which are mainly restricted to floodplains and thus depend on fluvial habitats. For all these listed plant communities, "character" species were identified based on the electronic data base of Pantke (2003) and the findings of Moor (1958). In some cases Ellenberg (1996) and Oberdorfer (1992, 1993) were used as additional references.

The identified species were grouped into three classes as follows:

Class1: Floodplain-dependent species sensu stricto: Species whose survival mainly depends on fluvial habitats.

Class 2: Floodplain-dependent species sensu lato: Species which have their natural primary habitat in floodplains, but which can today also be found in certain secondary habitats (e. g. gravel-pits) outside the floodplains.

Class 3: Additional species which typically occur in floodplains (besides species normally found in intensively managed grassland), but which do not depend on riparian habitats. These are species which have an abundance of more than 20% in the data base of Pantke (2003).

Drawing on findings from other restoration projects, we assumed that the man-made system would be more accessible to alien species than are natural systems (D'Antonio and Meyerson, 2002). Therefore we compared the presence of alien vascular plants (neophytes) at the restored sites and the near-natural references. The list of neophytes was adopted from the Swiss Red List of threatened plants (Landolt, 1991).

### Analysis of recorded species versus restoration potential

Concerning the performance of the restoration measures we were interested to see how many riparian species can be found at the restored sites in relation to the species which could potentially be found due to the species pool (see above). To account for the time needed for species colonization, we divided the species pool into a local species pool which only considers species occurring in the mapping area of the restored site and a regional species pool which contains the species of all mapping areas located upstream the river widening (see Figure 4).

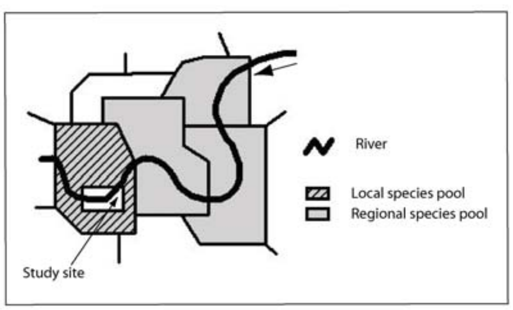


Figure 4. Nested species pools (schematic). The sum of grey mapping areas (Swiss WebFlora) forms the regional species pool. The hatched mapping area forms the local species pool.

# Results

## Degree of naturalness at the species and the habitat level

The mean degree of naturalness achieved by the river widenings is 0.46 for the habitat level and 0.56 for the species level. However, there are considerable differences between the projects (Figure 5). At the habitat level for example the river widening of the Thur river yields a degree of naturalness of 0.03. This indicates that the restoration project resulted in only slight improvement in shifting the habitat composition and configuration towards the near-natural. In contrast, the restoration project of the Emme river led to major improvements with a degree of naturalness of 0.7. This project had the best performance at the habitat level.

Major differences were also found between the individual restoration projects in the degree of naturalness achieved at the species level (Figure 5). The restoration project of the Thur, for example, achieved a degree of naturalness of only 0.23, whereas the widening of the Moesa near Grono (Moesa (G)) showed best performance with a degree of naturalness of 0.73. As can be seen in Figure 6, the species composition of the river widening of the Thur is mainly influenced by its surroundings, namely the species of the neighbouring forest edges. For the other restored sites, no such distinct relationship could be found between the vegetation of the river widening and a single habitat type of the surrounding landscape.

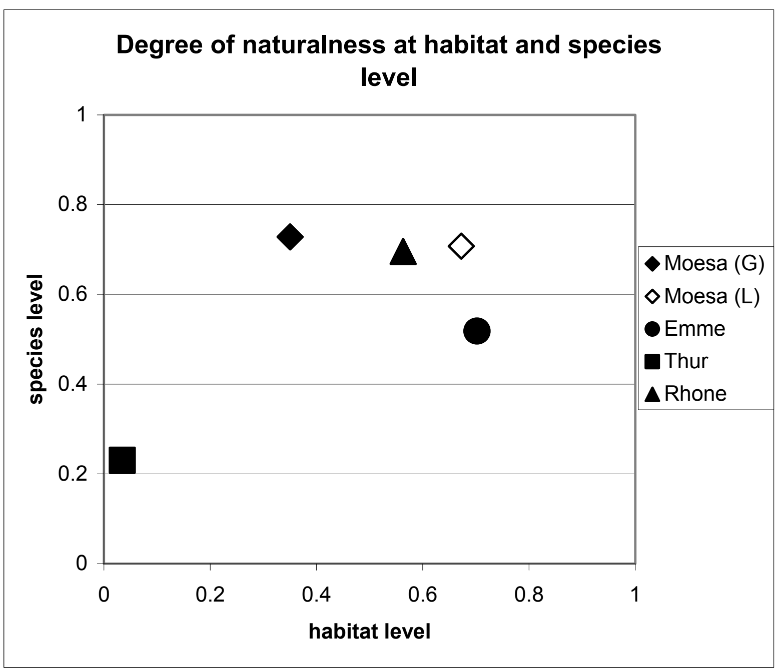


Figure 5. Degree of naturalness achieved at the habitat and species level (0 = condition prior to restoration, 1 = condition at near-natural reference). Values obtained from standardized Manhattan metric calculation and fuzzy ordination.

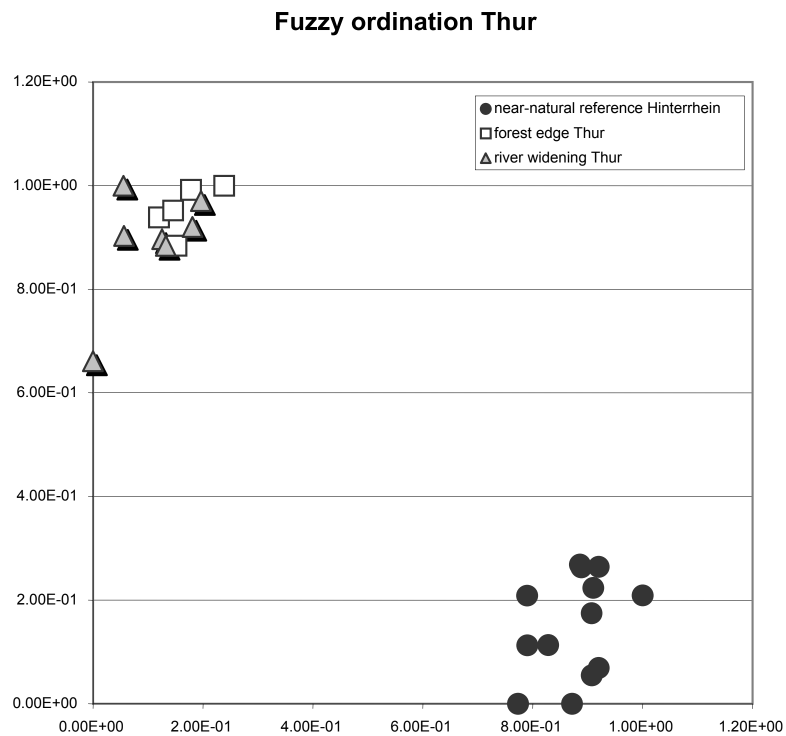


Figure 6. Similarity between the vegetation found at the Thur river widening and the regulated reference (forest edge) and near-natural reference (Hinterrhein).

A comparison of the performance at the habitat level and performance at the species level reveals marked differences between the individual projects. Figure 5 shows, for example, that the restoration at the Emme achieved only a moderate degree of naturalness at the species level but achieved a high degree of naturalness at the habitat level. Figure 5 also shows that the restoration project of the Moesa (G) achieved the highest degree of naturalness at the species level, but only the second-last at the habitat level. The river widenings of the Moesa near Lostallo (Moesa (L)), Rhone and Thur show no differences in the ranking at the species level compared to ranking at the habitat level. However, the restoration projects generally performed better at the species level than at the habitat level.

## Differentiating species

For the river widening of the Thur river Figure 7 clearly shows differences between the study sites at the Thur and the corresponding near-natural reference at the Hinterrhein. The five most positively differentiating species of the Thur are *Phalaris arundinacea, Rumex obtusifolius, Lolium perenne, Dactylis glomerata* and *Lolium multiflorum*, with CA-weights of species ranging from 12.59 (*Phal. arund.*) to 4.87 (*Lol. mult.*). Except for *Phalaris arundinacea*, all species are generally found in agricultural grasslands. At the near-natural site of the Hinterrhein *Calamagrostis pseudophragmites* (weight 18.33), *Myricaria germanica* (18.07), *Gypsophila repens* (12.46), *Picea abies* (11.82) and *Tussilago farfara* (11.1) were the first five most positively differentiating species. Figure 7 also indicates that the Thur and Hinterrhein sites have only a few species in common.

At the restored Emme site we found a slightly different situation. The river widening and the near-natural reference site of the Sense still form distinct groups but both host a reasonable number of species which can be found at both sites. These are mainly grassland and ruderal species, with the grassland species tending to be more abundant at the Emme river site. Again, *Phalaris arundinacea* (9.61) and *Lolium multiflorum* (5.23) belong to the most positively differentiating species of the restored site, together with *Salix alba* (11.18), *Populus nigra* (5.41) and *Solidago gigantea* (2.49). For the near-natural Sense river site ruderals are the most positively differentiating species (*Daucus carota*, *Picris hieracoides*, *Hieracium piloselloides*, *Leontodon autumnalis* and *Geranium robertianum*). For the Moesa and Rhône sites no distinct differences could be found for the restored sites and the corresponding near-natural reference sites (Figure 8).

## Species richness and presence of riparian and alien species

The analysis of species richness revealed substantial differences between the restored Emme site and the corresponding near-natural reference along the Sense river. The mean number of species found at the near-natural site was twice as high as the number

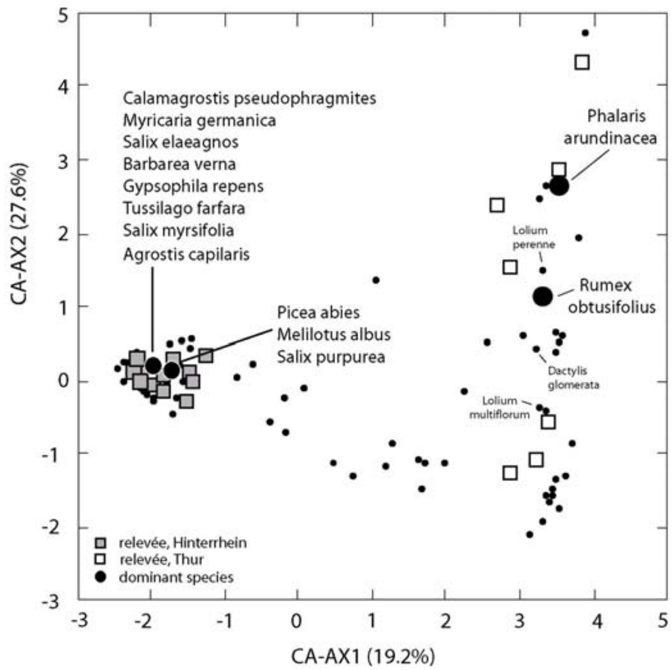


Figure 7. Bi-Plot of correspondence analysis of the river widening of the Thur and the corresponding near-natural reference along the Hinter-rhein.

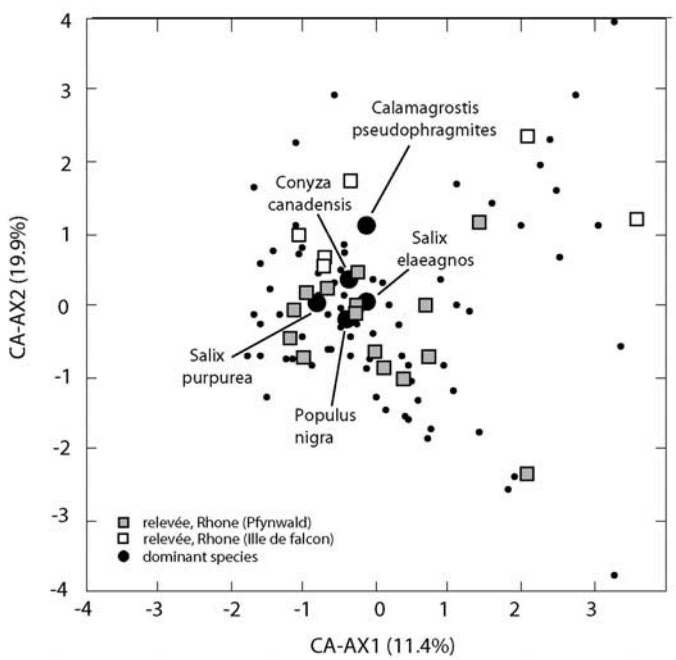


Figure 8. Bi-Plot of orrespondence analysis of the river widening at Ille de falcon (Rhône) and the corresponding near-natural reference at Pfynwald (Rhône).

found at the Emme widening (Table 5). A noticeable result was gained for the restored site of the Moesa (G) where the mean species richness was significantly higher than the mean species richness at the corresponding near-natural site along the Moesa near

Cabbiolo (Moesa (C)) (Table 5). No significant differences could be found between the restored and near-natural sites along the Rhone (IdF), Thur and Moesa (L) (Table 5).

We found a significantly lower mean number of riparian species of class 1+2 for the Thur and Emme river widenings than at their corresponding near-natural references. No significant differences were found for the restoration projects along the Rhône (IdF) and Moesa (L). Again, at the restored site of the Moesa (G) more species were found than at the corresponding near-natural reference (Moesa (C)). However, all near-natural references have a higher diversity of riparian species whose survival mainly depends on fluvial habitats (class 1 species) (Table 5). Three species (*Hippophae rhamnoides, Epilobium fleischeri and Salix daphnoides*) only occurred at the near-natural sites. The most abundant species of class 1 to be found at the river widenings were willow species, namely *Salix eleagnos* and *Salix alba*.

Our findings about the presence of alien species tend to confirm the postulated vulnerability of the river widenings to invasion by non-indigenous species. Except for the restored site on the Rhône river high numbers of alien species were found at all restored sites (Table 5).

Table 5. Species diversity, presence of riparian and alien species at the restored sites and near-natural references. Riparian species class 1: floodplain-dependent species in sensu stricto, class 2: floodplain-dependent species in sensu lato, class 3: additional typical species (see text). a, b: significant differences at p = 0.05.

| | **Emme** | **Sense** | **Moesa (G)** | **Moesa (C)** | **Moesa (L)** | **Moesa (C)** | **Thur** | **Hinterrhein** | **Rhône** | **Rhône** |
|---|---|---|---|---|---|---|---|---|---|---|
| **River type** | River widening | near-natural | River widening | near-natural | River widening | near-natural | River widening | near-natural | River widening | near-natural |
| **No. of relevées** | 7 | 15 | 6 | 10 | 8 | 10 | 7 | 13 | 6 | 15 |
| **No.species/ relevée** | 29 a | 55 b | 58 a | 44 b | 36 | 44 | 22 | 21 | 17 | 22 |
| **class 1** | 2 | 2 | 3 | 3 | 3 | 3 | 1 a | 4 b | 3 | 3 |
| **class 2** | 3 a | 6 b | 8 a | 6 b | 5 | 6 | 2 | 2 | 3 | 3 |
| **class 3** | 12 a | 26 b | 24 | 20 | 15 | 20 | 10 | 9 | 7 | 9 |
| **Total recorded species** | 131 | 178 | 205 | 132 | 237 | 132 | 141 | 82 | 140 | 97 |
| **Total recorded class 1 species** | 4 | 7 | 5 | 6 | 6 | 6 | 3 | 5 | 4 | 9 |
| **Total recorded alien species** | 10 | 4 | 15 | 5 | 11 | 5 | 11 | 4 | 4 | 3 |
| **% of total recorded species** | 8 | 2 | 7 | 4 | 5 | 4 | 8 | 5 | 3 | 3 |

## Benefiting habitats and species

River widening primarily increases the amount of in-stream habitat heterogeneity and lead to the formation of bare gravel bars and the establishment of different types of herbaceous pioneer vegetation and willow shrubs. Riparian woodlands are hardly found due to the time needed for their development and the limited spatial extent of the river widenings (Rohde et al., 2003).

At the species level we identified 9 species which had a frequency of more than 50% in the releveés of the restored sites. Amongst them are four grasses (*Agrostis stolonifera*, *Agropyron repens*, *Dactylis glomerata*, *Deschampsia cespitosa*), one alien herb (*Conyza canadensis*) and four tree species (*Populus nigra*, *Salix purpurea*, *S. alba*, *S. eleagnos*). The willow *Salix eleagnos* was the most abundant species with a frequency of 84%. All the willows belong to the riparian species classes 1 and 2. The other species belong to class 3, except *Dactylis glomerata*, which is usually found on intensively managed grassland.

## Recorded species versus restoration potential

Generally, great similarities between the regional and the local species pool were found for riparian species and the differences were not as great as expected. Only for the riparian species of class 1 at the Emme and Thur site was the local species pool about a third less than the regional species pool. Given the similarities in the individual regional and local species pools, we concentrate on the findings relating to the local species pool. We found the restored sites along the Moesa to be the most efficient projects in terms of sharing around 40% of the riparian species classes 1 and 2 with their local species pool (Figure 9). At the Emme, Thur and Rhône (IdF) sites merely 15% to 19% of the local species pool of riparian species (class1+2) could be found at the restored sites (Figure 9).

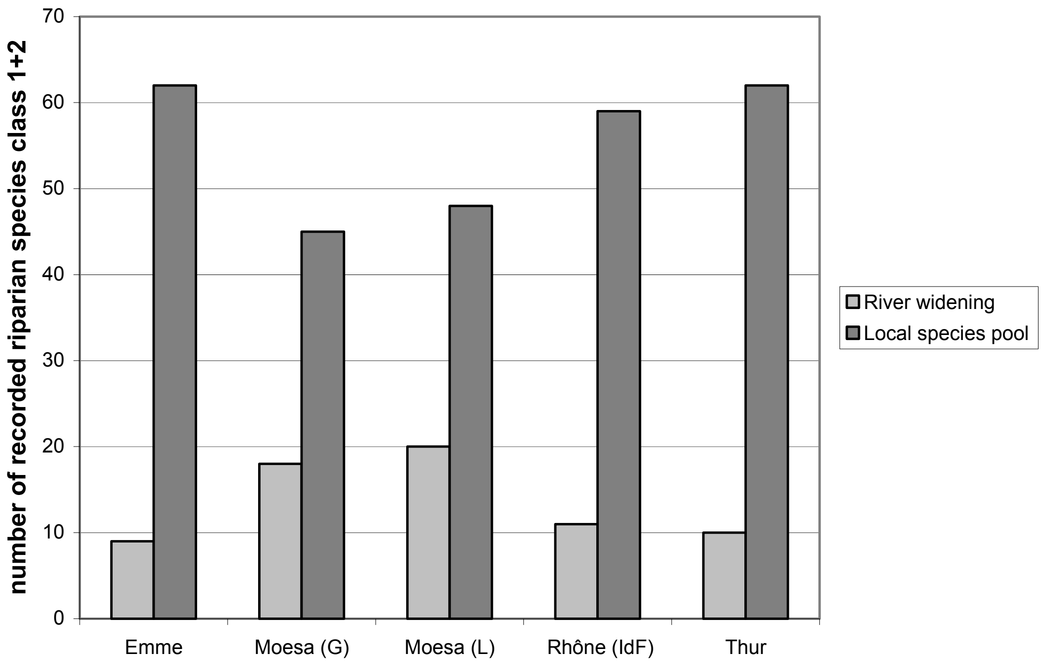


Figure 9. Recorded riparian species (class 1+2) at the river widenings in relation to the corresponding local species pool. Class 1: riparian species sensu stricto, class 2: riparian species sensu lato (see text).

# Discussion

Restoration seeks to return an ecosystem to its condition prior to degradation. Looking at the degree of naturalness brought about by the river widenings investigated, our data show: (1) different performances at the species and habitat level, and (2) differences between the individual restoration projects. The assessment of the restoration performance is based on an ecological value system. However, we are well aware that other value systems (recreation, aesthetics, etc.) need to be consulted for a global evaluation of restoration measures.

Depending on the organizational level (species or habitat), the results for the restoration projects along the Moesa (G) and the Emme river clearly show different degrees of naturalness. At the Emme river site, restoration performs well at the habitat level and provides the potential for the establishment of a desired biocoenosis. However, actual species colonization is hampered by a low ecological permeability of the regulated river system leading to a rather poor performance at the species level. On the other hand, results from the river widening of the Moesa (G) show that some single components of the restored ecosystem may perform better than others. At the habitat level Moesa (G) shows poor performance with low habitat diversity. But the established gravel bars provide suitable site attributes for the establishment of riparian plants and thus the restoration project performs well at the species level.

Besides finding differences in performance at the habitat and species levels we also found differences in the degree of naturalness achieved by the individual restoration projects. One could argue that this is due to two major driving forces that influence species colonization, namely (i) the age of the restored site and (ii) distance away from species pools. Concerning the age of the restored site we have no indication that this is the main restricting factor since the oldest restoration project (Thur, 10 years old) showed the worst and the five-year old river widening of the Moesa (L) showed the best overall performance. At the species level the age of a restored site does not a priori limit the development of pioneer vegetation as these vegetation types naturally exhibit a high turnover due to the fluvial disturbance regime. Thus the establishing alluvial vegetation is always at the young seral stage. However, we believe that time needs to be considered in association with the distance from the species pools and the ecological permeability of the environment. The more distant the species pools and the greater the impediments to species movement, the more time needed for species arrival and colonization.

Concerning the distance of the restored sites from potential species pools, we have indications that the location of the river widenings is of major importance (see Tabacchi et al., 1996). The restoration projects with the best performance at the species level were the river widenings along the Rhone and the Moesa which have near-natural stretches less than 10 km away upstream. These near-natural stretches provide a viable species pool with their propagules floating down the river to colonize the newly created habitats of the river widenings. In contrast, the species compositions of the isolated river widenings along the Emme and Thur river with no near-natural stretches upstream are mainly influenced by the intensively managed surroundings with only few riparian species of class 1+2 (see Tabacchi et al., 1996). Among the latter willows are the most abundant and most frequent species. The establishment of these species can be linked to the bank protection upstream, where willows are used to prevent bank erosion.

Regarding the species which finally became established at the river widenings, it seems that river-widenings are generally able to provide habitats for some riparian species but mainly promote grassland species. This is due to the competitiveness of these species and the dominance and proximity of agricultural land at all restored sites. Looking at the colonization by alien species we found the restored sites are more accessible to these species than the near-natural reaches. This poses a potential threat as alien species may outcompete native vegetation and thus interfere with the restoration goal (Chornesky and Randall, 2003; Pysek and Prach, 1995). At the river widening of Moesa (L), for example, Buddleija davidii reached a cover up to 25%. However, this site was the only one where an alien species became dominant.

The fact that the near-natural references generally show a higher richness in riparian species of class 1 than the river widenings is probably due to three factors: the time needed for the species to arrive, the high degree of specialisation of these species and the small extent of the sites under investigation. The near-natural references are larger in area than the small-scale river widenings and thus have: i) more habitat diversity and thus more habitat available for colonization by stenotopic species, ii) more habitat and thus less competition for colonisation and iii) a higher probability of species surviving (high) floods. The relationship between the vulnerability of riparian vegetation to catastrophic flooding and the abundance of riparian vegetation was shown by Hawkins et al. (1997).

This study has investigated the potential of river widenings to re-establish riparian habitat and vegetation. Since data collection took place only once, the study cannot provide more than a "snap shot" of the ongoing processes. Long time series on the vegetation development are necessary for a comprehensive assessment to allow time for species dispersal and the naturally high variability and turnover in species composition due to hydrodynamic and geomorphic processes. However, evaluation three years after restoration might yield initial indications of the restoration success (Urbanska, 1997). Replicating the vegetation sampling could also help to answer the question whether the hydrodynamic and geomorphic processes at the river widenings are sufficient to allow for a diverse vegetation pattern of several successional stages. We think that in the long term the willow saplings will establish extensive shrubs which will grow over the gravel bars and thus outcompete the pioneer herbs and grasses due to suppressed hydrodynamics by dams and hydroelectric power plants.

## Conclusion

The following conclusions can be drawn from this investigation of five restoration projects, bearing in mind that there are some uncertainties due to the short observation time:

a) River widenings provide the potential to restore some elements of riparian ecosystems: They promote in-stream habitat heterogeneity and the establishment of bare gravel bars as well as herbaceous pioneer vegetation and shrubs (*Salix sp., Myricaria germanica*, etc.). However, the river widenings show generally better performance at the species level than at the habitat level. Besides willows, grasses are the most abundant species to be found in river widenings, namely: *Agrostis stolonifera*, *Agropyron repens*, *Dactylis glomerata* and *Deschampsia cespitosa*. However, riparian herbs, for example, *Epilobium fleischeri* are also found.

b) Restoration projects perform differently depending on the level of biological organization: We emphasize the need for a hierarchical approach when assessing restoration efforts (see also Noss, 1990; Pedroli et al., 2002). We suggest habitat level and species level as appropriate organizational levels when assessing restoration efforts from a conservation point of view. However, further aspects need to be considered in a more global evaluation (including e.g. aesthetics and recreational value).

c) The establishment of riparian vegetation following a restoration project depends on the distance to near-natural reaches as the presence of a viable seed bank is an important pre-requisite for the rehabilitation of (semi-) natural vegetation (Nienhuis et al., 2002). Thus the closer a river widening is to a near-natural river stretch, the better its performance. Generally, one should consider the regional setting and the landscape context when planning river widenings or any other restoration measure (Hughes et al., 2001).

d) River widenings are small-scale restoration measures which locally remove the stresses of canalization. However, the success of such river restorations does not depend solely on local action but also on decisions taken at the catchment scale which are outside the scope of the restoration measure. The re-establishment of riparian habitats and communities is often impaired by constraints located outside the actual restoration projects, for example, bedload excavation or hampered species dispersal due to dams (Andersson et al., 2000). Therefore catchment scale processes need to be considered and additional regional management solutions are required to maximise the effects of local management.

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# Literature cited


Bakker, J. P., Esselink, P., Dijkema, K. S., van Diun, W. E. and de Jonge, V. N. 2002. Restoration of salt marshes in the Netherlands. *Hydrobiologia* 478**:** 29-51.

Braun-Blanquet, J. 1932. Plant sociology. The study of plant communities. McGraw-Hill, New York, London.

Chornesky, E. A. and Randall, J. M. 2003. The threat of invasive alien species to biological diversity: Setting a future course. *Annals of the Missouri Botanical Garden* 90**:** 67-76.

D'Antonio, C. and Meyerson, L. A. 2002. Exotic Plant species as Problems and Solutions in Ecological Restoration: A Synthesis. *Restoration Ecology* 10**:** 703-713.

de Jonge, V. N. and de Jong, D. J. 2002. Ecological restoration in coastal areas in the Netherlands: concepts, dilemmas and some examples. *Hydrobiologia* 478**:** 7-28.

Downs, P. 2001: Geomorphological evaluation of river restoration schemes: principles, method, monitoring, assessment, evaluation. Progress? Pages 243-249. in *Nijland, H. J. and Cals, M. J. R. (eds.)* River Restoration in Europe: practical approaches, Institute for Inland Water Management and Waste Water Treatment / RIZA, Lelystad.

Erskine, W. D. 1992. Channel response to large-scale river training works- Hunter River, Australia. *Regulated Rivers* 7**:** 261-278.

Landolt, E. 1991. Gefährdung der Farn- und Blütenpflanzen in der Schweiz. Bundesamt für Umwelt, Wald und Landschaft, Bern.

Lewis, R. R. 1990: Wetland restoration/creation/enhancement terminology: Suggestions for standardizing. Pages 417-422 in *Kusler, A. and Kentula, M. E. (eds.)* Wetland creation and restoration: the status of the science, Island Press, Washington, DC.

Malanson, G. P. 1995. Riparian Landscapes. Cambridge University Press, Cambridge, 296 pp.

Naiman, R. J., Décamps, H. and Pollock, M. 1993. The role of riparian corridors in maintaining regional biodiversity. *Ecological Applications* 3**:** 209-212.

Nienhuis, P. H., Bakker, J. P., P., G. A., Gulati, R. D. and de Jonge, V. N. 2002. The state of the art of aquatic and semi-aquatic ecological restoration projects in the Netherlands. *Hydrobiologia* 478**:** 219-233.

Pedroli, B., de Blust, G., van Looy, K. and van Rooij, S. 2002. Setting targets in strategies for river restoration. *Landscape Ecology* 17 (Suppl.1)**:** 5-18.

Peter, A. 2003. Personal communication.

Petts, G. and Calow, P. 1996. River Restoration. Blackwell Science Ltd, Oxford, 231 pp.

Pysek, P. and Prach, K. 1995. Invasion dynamics of Impatients glandulifera - A century of spreading reconstructed. *Biological Conservation* 74**:** 41-48.

Rempel, R. S., Carr, A. and Elkie, P. 1999. Patch analyst and patch analyst (grid) function reference. Centre for Northern Forest Ecosystem Research, Ontario Ministry of Natural Resources, Lakehead University.

Roberts, D. W. 1986. Ordination on the basis of fuzzy set theory. *Vegetatio* 66**:** 123-131.

Rohde, S., Kienast, F. and Bürgi, M. 2003. A habitat-based method for rapid assessment of river restoration. *Environmental Management. In review.*

ter Braak, C. J. F. and Smilauer, P. 2002. CANOCO Reference manual and CanoDraw for Windows user's guide. Software for Canonical Community Ordination (version 4.5). Biometris, Wageningen and Ceské Budejovice.

Urbanska, K. M. 1997: Plant population ecology and restoration ecology. in *Urbanska, K. M., Webb, N. R. and Edwards, P. J. (eds.)* Restoration Ecology and Suistainable development, Cambridge University Press.

Verdonschot, P. F. M. and Nijboer, R. C. 2002. Towards a decision support system for stream restoration in the Netherlands: an overview of restoration projects and future needs. *Hydrobiologia* 478**:** 131-148.

Ward, J. V. 1998. Riverine landscapes: biodiversity patterns, disturbance regimes, and aquatic conservation. *Biological Conservation* 83**:** 269-278.

Ward, J. V., Tockner, K., Arscott, D. B. and Claret, C. 2002. Riverine landscape diversity. *Freshwater Biology* 47**:** 517-539.

Wildi, O. and Orlòci, L. 1990. Numerical exploration of community patterns. SPB Acad. Publ., The Hague, 124 pp.

# Paper III

# Room for rivers: an integrative search strategy for floodplain restoration

*Submitted as:*

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## Abstract

River restoration aims to re-establish the ecological integrity of a river ecosystem and is one of the answers to river deterioration. However, restoration measures are nowadays mainly a reactive, site-by-site activity rather than based on strategic planning. This study presents an integrated search strategy to identify river reaches where the restoration of floodplains and their biocoenosis is less likely to be undermined by poor environmental conditions and where the greatest benefits (judged according to ecological and socio-economic criteria) are to be expected.

The search strategy helps management authorities in setting priorities and allocating resources. It also helps to identify management deficiencies and data gaps. The search strategy presented focuses on catchment-wide issues and is based particularly on spatially explicit information. A hierarchical filter process combines the possibilities of GIS with multiple criteria decision analysis (MCDA) to generate restoration suitability maps. The filter process is based on a list of criteria and indicators that capture the ecological key processes (hydrology, bed load, connectivity, biodiversity, water quality), as well as crucial socio-economic aspects (e.g. public attitude, flood protection) that need to be taken into account when planning for floodplain restoration. Such a systematic and standardized procedure selecting river reaches to be considered for floodplain restoration provides objectivity and transparency and thus helps to ensure public accountability. It also helps to set priorities and thus avoid inefficiency. The strategy is illustrated through a case study from the Rhone-Thur Project in Switzerland, which gives information on indicator suitability functions and weightings. We used ModelBuilder 1.0a (an ArcView extension) to integrate different data layers into a single Ecological Restoration Suitability Index (ERSI) layer. The resulting map shows that the majority of Swiss rivers have high ecological restoration suitability. However, the results also show that only about half of these river reaches are located in areas where the local people are in favour of environmental policies (public attitude measured on the basis of public votes).

**Keywords**: river restoration, search strategy, priority setting, restoration suitability index, ecological and socio-economic criteria and indicators, multi criteria decision making (MCDM)-GIS Analysis.

## Introduction

River floodplains are widely acknowledged as biodiversity hotspots (Malanson 1995, Naiman et al. 1993, Ward et al. 2002). The ecological integrity of a river system is dependent upon the connectivity between the main channel and its floodplain (Petts and Calow 1996). However, river training works have led to major ecological degradation, including river-bed erosion and declining habitat and species diversity (Erskine 1992, Nilsson and Svedmark 2002, Pedroli et al. 2002, Petts and Calow 1996). Since the negative impacts of river channelization have become apparent more and more, river degradation is now being addressed through legislative change, for example, the Habitats Directive and the Water Framework Directive of the European Union; and research and action on the ground (see for example restoration projects in Denmark (Neilsen 2002), The Netherlands (Neilsen 2002, Nienhuis et al. 2002) and Switzerland (Rohde et al. 2003)).

At present, however, restoration sites are often selected opportunistically and on an ad hoc basis rather than according to a strategic planning process (Clarke et al. 2003, Hobbs and Norton 1996). In many cases restoration projects are not based on superior planning but react on local decisions, e.g. flood defence work or road development (Holmes 1998, VAW 1993). Thus due attention is not always given to the underlying ecological processes that form rivers and their floodplains. Consequently, many projects have not been self-sustaining and have required continued management input, for example, mimicking geomorphic processes with excavating works. Clarke et al. (2003) argue that river restoration will only be sustainable if it is undertaken within a process-driven and strategic framework with inputs from a wide range of specialists.

When developing such a strategic framework in present-day, multi-land-use catchments, it should be noted that restoration possibilities are restricted and that all sectors of society need to be included in planning and decision-making. Due to limited financial and spatial resources a debate starts about the efficiency of restoration measures and the questions arise: Where are promising river stretches which are less likely to be undermined by poor environmental conditions? Where shall we spend our money and space to fulfill the various social demands and ecological requirements concerning rivers and their floodplains? Answering these questions is not easy. They are key questions that arise also in related planning processes, e.g. the location of landfills (Kontos et al. 2003), the evaluation of route alignments (Sadek et al. 1999) or the design of reserve networks (Villa et al. 2002).

## Aims and scope

The presented integrative search strategy is a framework for pro-active planning that moves away from the traditional view of restoration as a reactive, site-by-site activity towards a framework where restoration occurs at a landscape and catchment scale and becomes an important, strategic component of landscape and regional planning (Naveh 1994, Webb 1997). It focuses on the restoration of riparian floodplains by widening rivers or re-allocating flood levees to allow river braiding or meandering and thus the re-establishment of a wide array of in-stream and riparian habitats (riffles, pools, gravel bars, softwoods etc.).

The GIS-based, integrative search strategy presented here is designed for use by government agencies and management authorities at the national and catchment level to assist them in identifying those river reaches where floodplain restoration is less likely to be undermined by poor environmental conditions and where the greatest benefits (judged according to ecological and socio-economic criteria) are to be expected. Using objective ecological and socio-economic criteria enables river reaches to be selected for floodplain restoration in a transparent and reproducible way. It is also thought to (i) provide a checklist of ecological and socio-economic criteria and indicators that need to be considered in the planning process of floodplain restoration and (ii) to allow the impact of these indicators on the restoration potential to be explored.

It may be worth clarifying that the search strategy focuses on catchment-wide issues and provides information on a broad scale (pre-screening). It is based on spatially explicit information for the whole catchment. Thus the level of detail is only sufficient to signal the restoration suitability of a particular river reach. Once a promising river reach is identified, more detailed investigations are necessary to choose a suitable location for restoration (site selection). Furthermore, different restoration alternatives should be compared for the chosen restoration site (alternative selection). It is, however, beyond the scope of this study to address the “site selection” and “alternative selection” project phases, for a discussion of these phases and stakeholder involvement in the decision process, refer to Hostmann et al. (2004).

# The integrative search strategy

## A hierarchical filter process

Figure 1 shows the general outline of the proposed search strategy and its implementation in the planning process. Our search strategy focuses on floodplain restoration and thus the improvement of the eco-morphological condition of a river by means of river widening or flood levee re-allocation. Therefore, the starting point is an analysis of the eco-morphological deficits (artificial bank and/or river-bed stabilization) of the river system. River reaches in good eco-morphological condition are excluded in this search strategy, and only those with a morphological deficit are included.

Restoration suitability is determined by constraints and factors which might restrict or favour restoration efforts. The task of assessing restoration suitability is completed in a hierarchical filter process (Filters 1-3) where the corresponding filters consist of several criteria. Filter 1 determines river reaches which are not suitable for river restoration based on limiting constraints. All river reaches not excluded by this filter are generally suitable for river restoration. The second filter (Filter 2) evaluates the restoration suitability according to specific ecological criteria (e.g. hydrology and biodiversity). The overall restoration suitability of a stretch of river from an ecological point of view is assessed using the Ecological Restoration Suitability Index (ERSI). The third filter (Filter 3) takes into account socio-economic factors that can play an important role in selecting a suitable river reach. Restoration experience has shown that socio-economic aspects need to be considered in order to implement planning successfully. The result of this search strategy is the identification of river reaches suitable for restoration according to both ecological and socio-economic criteria. The three filters of the search strategy are shown in Figure 1 and will be discussed in more detail in the following sections.

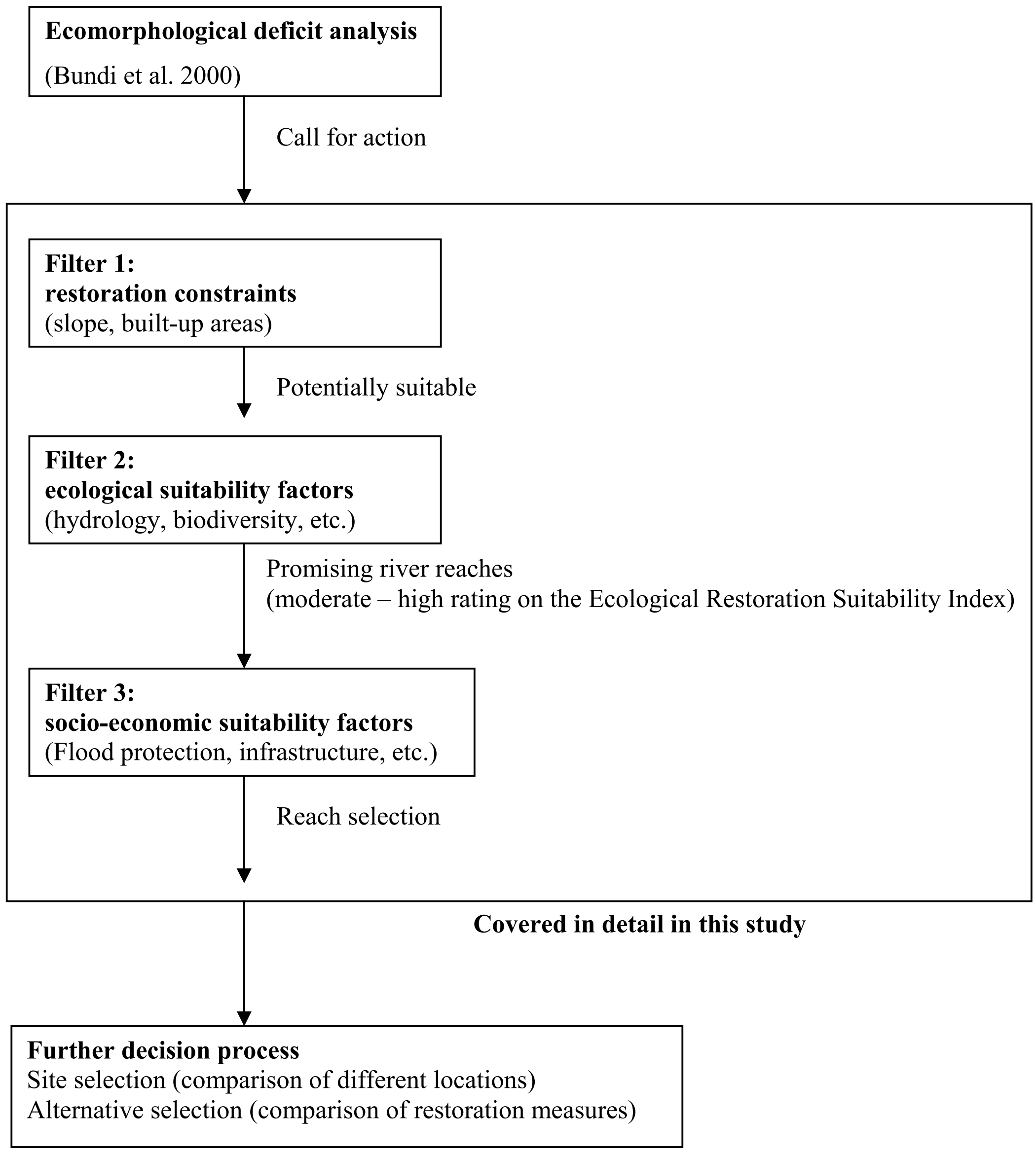


Figure 1. Search strategy to identify river reaches highly suitable for floodplain restoration

## Filter 1: pre-selection based on limiting constraints

The first filter defines the minimum pre-requisites to be met for floodplain restoration. It determines river reaches to be excluded from further consideration based on the attributes of selected constraints. These constraints constitute the general framework which cannot be changed. We considered the following two factors as constraints:

(i) slope > 6%
(ii) location within built-up areas.

The threshold slope of 6% was obtained from a spatial analysis of the distribution of floodplains in Switzerland. This analysis showed that extended floodplains can only be found in areas with a slope < 6% because steeper slopes naturally result in straight river courses. As opportunities for floodplain restoration within settlements are limited, urban streams are not considered. However, the needs of urban inhabitants, e.g. recreation, are taken into account in the assessment/selection procedure (Filter 3).

## Filter 2: evaluation of ecological suitability

### Introduction

The second filter involves determining the ecological restoration suitability of a river stretch. It is based on the idea that the environmental catchment conditions drive the success of floodplain restoration and thus the restoration potential (Malmquist 2002, Poff 1997). In planning restoration the processes which form the landscape and the wider context in which the project is placed needs to be considered. Hence, the second filter evaluates ecological restoration suitability on the basis of non-deterministic, but driving factors.

Based on a broad literature review (Brookes and Shields 1996, Calow and Petts 1994, Marriott and Alexander 1999, Naiman and Bilby 1998, Nilsson and Svedmark 2002, Osborne et al. 1993, Pedroli et al. 2002, Petts and Calow 1996), we identified the following five factors to be the key elements in affecting the restoration potential of a river (suitability factors) : i) hydrology, ii) bed load, iii) water quality, iv) connectivity and v) biodiversity. Table 1 summarizes the chosen ecological suitability factors and corresponding indicators.

Table 1. Ecological suitability factors (criteria) and corresponding indicators (incl. range) (Filter 2)

| Criteria | Indicator | Indicator range |
|---|---|---|
| Hydrology | Water abstraction [%] | < 20<br><20 + increased winter flow<br>20-40<br>40-60<br>60-80<br>> 80 |
| | Hydropeaking | peak flow : base flow < 3(4):1<br>peak flow : base flow > 3(4):1 |
| | Dam | No<br>Yes |
| Bed load | River bed erosion | Transport capacity:bedload discharge < 4:3<br>Transport capacity:bedload discharge > 4:3 |
| Water quality | Chemistry | Very good<br>Good<br>Moderate<br>Bad<br>Very bad |
| | Arable land [%] | 0-2.33***<br>2.33-6.69<br>6.69-12.3<br>12.3-21.59<br>21.59-35.88 |
| Connectivity | Distance from present floodplains [km] | 0-10<br>10-25<br>25-50<br>50-100<br>> 100 |
| | Distance from gravel pits [km] | < 10<br>> 10 |
| | Presence of artificial migration barriers [per km]** | 0<br>1-3<br>> 3 |
| Biodiversity | Percentage [%] of regional riparian species pool (flora) | 0-10***<br>10-34<br>34-50<br>50-70<br>70-100 |
| | Percentage [%] of regional riparian species pool (fauna) | 0-7***<br>7-19<br>19-32<br>33-49<br>49-74 |

**) vertical height of the barriers: trout zones = 70 cm, all other fish zones = 25 cm
***) Classes according to present situation in Switzerland (relative, not absolute assessment)

The five factors are incorporated in the Ecological Restoration Suitability Index (ERSI) for assessing the ecological restoration suitability of a river reach. This index is a unitless variable with values between 0 (moderate suitable) and 1 (highly suitable). However, sub-indices values for each indicator are reported with the overall score and all values are used to describe the restoration suitability of an individual reach. This allows users to make their own assessment about the relative importance of each indicator. Furthermore, ecological deficiencies in the river system whose removal will have a great positive effect on the overall restoration suitability can be identified.

### Hydrology

It is recognized that (near-) natural river flows are the key to restoring floodplains as the establishment and persistence of riparian habitats rely on a complex, dynamic hydrological regime with intra- and inter-annual flood variations in timing, duration, magnitude and shape of the hydrograph (Hughes and Rood 2003). Thus flow characteristics are important parameters for the assessment of floodplain restoration suitability.

However, anthropogenic flood regulation and hydropower production have altered the hydro-regime of many rivers by changing flow volume, cutting peak flows and changing seasonalities. The influence of a changed flow regime on the state of a river is well documented (Bowen et al. 2003, Bunn and Arthington 2002, Cereghino et al. 2002, Lagarrigue et al. 2002). Direct measurements of the hydrological condition of each river reach typically require the analysis of extended data sets and are thus not appropriate for pre-selecting river reaches for restoration management on a broad scale.

Therefore, the following indicators are used as surrogates to evaluate flow characteristics for restoration purposes:

(i) Water abstraction
(ii) Hydropeaking
(iii) Dams.

The latter do not only prevent free water flow but also hinder the migration of some aquatic species and change the seasonal flow regime. An extensive literature review by Limnex (2003) on hydropeaking showed that a ratio of about 3(4):1 between the peak flow and base flow phases was a critcal value. With smaller ratios no major impacts on the river biocoenosis are to be expected. However, Limnex (2003) emphasizes that this value should only be taken as a rough guide.

### Bed load

The sediment regime plays a major role in determining the biotic composition, structure and function of floodplains. Floodplains show a steady state shifting mosaic of habitats varying in successional age (Bornette et al. 1994, van der Nat et al. 2003). Transient islands and sand/gravel bars are characteristic features of floodplains. These typical elements are formed by erosion, transport and deposition processes due to water and sediment fluxes, which are the dominant channel-forming mechanisms (Clarke et al. 2003). However, in many rivers, artificial bank stabilization and sediment retention basins have led to a lack of bed-load material. This is associated with a decline in alluvial deposits and habitats. A balanced sediment regime is an important driving force in the process of floodplain restoration, whilst a lack of sediment hampers river rehabilitation and thus restoration suitability. To assess restoration suitability from a geomorphologic point of view the following indicator is proposed:

(i) River-bed erosion.

In general a lack of sediment is assumed if the ratio between the transport capacity of a river and the bed-load discharge exceeds 4:3 for a period longer than 10 years (Bezzola 2003, personal communication). However, the sediment regime can hardly be analysed on the catchment scale as it requires an extended data set and is very time consuming. Therefore we propose using the extent of river-bed erosion as an indicator for the status of the sediment regime. River bed incision is strongly correlated with deficient bed-load transport and is thus a surrogate for the above mentioned ratio between transport capacity and bed-load discharge. River-bed erosion can be assessed according to the written or oral descriptions of local authorities, photogrammetric channel data or comparisons of photographs taken of constructions within the river bed (e.g. bridges) where changes in river-bed level can be roughly estimated from. The presence of river-bottom sills also indicates a lack of sediment as they are commonly used by river engineers to prevent/stop river-bed erosion. Having said that, it is possible that river-bed may be paved so that there is no river bed erosion but still a lack of sediment.

### Water quality

Investigations of benthic macro-invertebrates (Nedeau et al. 2003) and fish communities (Pretty et al. 2003) have shown that poor chemical water quality can reduce the positive effect of physical habitat restoration. Both chemical and physical parameters affect the success of a restoration project. High loads of fine sediment, for example, hamper high benthic diversity and abundance due to the absence of local flow refugia and spawning grounds. Research shows that arable land use is a major source of pollution with fine sediments (Allan et al. 1997, Basnyat et al. 1999, Walser and Bart 1999).

Therefore we included

(i) Chemical water quality
(ii) Percentage of arable land in the watershed
(iii) Presence of riparian woodland

as indicators for assessing restoration suitability.

Characteristics of the chemical water quality of a river reach were selected according to the Swiss Program for investigating and assessing of flowing waters (BUWAL 2003) and include: ortho-phosphates, nitrates, nitrites, ammonium, DOC and pH. The scheme contains temperature-dependent critical values to account for the natural differences between headwaters and lowland rivers.

Water quality is not only described chemically but also physically, for example, turbidity and temperature. Temperature is of major importance as it drives many chemical processes and the metabolism of living organisms. The natural temperature regime and turbidity can be heavily disturbed by anthropogenic effluents (e.g. power stations or sewage plants) and the logging of riparian woodland. In cases where temperature data is not available, the presence of hydropeaking, water abstraction and riparian woodland are proposed as surrogates.

### Connectivity

Rivers are longitudinally, laterally, vertically and temporally connected with their environment (Amoros and Bornette 2002, Ward 1998). Connectivity is a pre-requirement for the flux of energy, water, sediments and nutrients, as well as of species dispersal and migration. Thus restoration suitability increases with connectivity.

To assess the degree of spatial connectivity of a certain river reach, the following indicators are proposed:

(i) Artificial migration barriers
(ii) Distance from current floodplains
(iii) Distance from gravel pits.

Dams, weirs, etc. are artificial barriers which have considerable influence on aquatic life as they hamper or interrupt species movement along the river channel. Thus, such barriers impair restoration suitability.

Distance from species pools is a major factor besides the ecological permeability of an environment, behind species colonization at a new established site. Investigations (Rohde et al. 2003) showed that the vegetation composition of river widenings within a distance of 10km downstream of near-natural floodplains was similar to that found at the near-natural sites, while the vegetation composition of isolated river widenings was mainly influenced by the immediate surroundings. There have been many studies investigating hydrochory, but there is no general information on dispersal distances as these vary from species to species (Pedroli et al. 2002). However, the number of dispersed species generally decreases with distance from the species pool, as, for example, shown by Waals (1938) in Ellenberg (1996). Thus the greater the distance from a species pool, the lower the probability of species arrival and therefore the less suitable for restoration.

Gravel pits have been identified as providing secondary habitats for some riparian species (Catling and Brownell 2001, Pinder 1997, Santoul 2002, Sidle and Kirsch 1993). Therefore they may function as species pools. Thus the presence of gravel pits was also included as indicator for connectivity. A distance of 1km from gravel pits was found to be reasonable to have a positive impact on the restoration suitability as research on amphibians, for example, has shown that individuals are capable of covering distances up to 3-4 km (Miaud et al. 2000, Ray et al. 2002) and many riparian plant species are not only hydrochor, but also anemochor (Bonn and Poschlod 1998).

### Biodiversity

The number of riparian species present in a region surges the potential for colonization by riparian species and thus the probability of re-establishing near-natural biocoenosis. The more riparian species present in a river region, the more species could potentially benefit from restoration efforts.

For Switzerland Schneider et al. (2003), Peter (personal communication) and Rohde et al. (2003) provide lists of riparian species whose survival mainly depends on fluvial habitats. These lists include fish, birds, mammals, mussels, insects (C*arabidae, Saltatoria, Apidae, Heteroptera*) and (semi-) terrestrial flora. For roughly estimating how suitable a river stretch is to enhance those species the following indicator is suggested:

(i) The presence of riparian species (flora & fauna).

The presence of riparian species is measured as a percentage of the local species pool derived from distribution maps. This procedure reflects the current colonization potential and also takes into account biogeographical differences.

Species colonization clearly depends not only on the species pool, but also on the species abundance and ecological permeability of the region. The extent of species movement within the landscape is difficult to assess. Nevertheless, over the longer term we might expect that restoration sites placed in species-rich regions are more likely to be colonized by riparian species than sites with a low species pool.

## Filter 3: integration of socio-economic factors

### Introduction

Floodplain restoration projects affect not only the ecological state of a river, but also economic and social aspects (Ehrenfeld 2000). Hence, socioeconomic factors should be considered in identifying of suitable river reaches for floodplain restoration. Filter 3 describes important socio-economic factors which can influence the feasibility of a restoration project. We identified the following four factors to be of major importance: i) flood protection, ii) existing infrastructure, iii) recreational opportunities and iv) public attitudes (Table 2). In contrast to the ecological criteria, the socio-economic factors are not be aggregated into a suitability index. Each socio-economic factor is represented as an individual GIS map layer. Depending on the specific decision context, one or more socio-economic layers can be combined with the ecological suitability layer. For example, if a decision maker is interested in both ecological restoration and improving flood protection, these two GIS layers can be combined. The resulting layer indicates the river reaches with a high ecological suitability and a high potential for improving flood protection.

Table 2. Socioeconomic criteria and corresponding indicators including indicator range (Filter 3)

| **Criteria** | **Indicator** | **Indicator range** |
|---|---|---|
| Flood protection | Protection deficits | >0<br><0 |
| Existing infrastructure | Distance away of the infrastructure | < three times the width of the river<br>> three times the width of the river |
| Recreational opportunities | Distance to populated areas [km] | >10<br>≤10 |
| Public attitude | Public attitude towards env. policies | Technocratic<br>Ecological |

Beside the proposed factors, other socio-economic factors may also influence the feasibility of restoration projects. Issues such as “costs of the project” or “ownership of the land” (public or private land) are important topics. However, these factors depend very much on the local conditions and are not easily aggregated in a national search strategy. However, it is important to emphasize that these factors have to be evaluated in the later decision-making process, when different locations for restoration or different restoration alternatives are considered (Hostmann et al. 2004).

### Flood protection

Flood retention is one of the most important socio-economic aspects in floodplain restoration. Providing more room for rivers increases the retention volume and thus reduces the risk of damaging the surrounding area. Hence, combinating of ecological restoration and improved flood protection can increase the public acceptance of a project.
The following indicator provides information on the flood protection level within the river basin:

(i) Protection deficits

The protection deficit is the difference between the protection objective defined by the public authority and the existing protection level for a specific river reach. The need for restoration measures increases the larger the protection deficit. We propose varying protection objectives, which depend on the purpose of the area under consideration. Settlements and infrastructure, for example, need a greater protection than farming areas. The public authority in Switzerland, for example, requires the 100-year flood ($Q_{100}$) as a protection objective for settlements, whilst the protection objective for high-intensity farming areas is proposed as ranging from a 20-year flood ($Q_{20}$) up to a 50-year flood ($Q_{50}$) (BWG 2001).

### Existing infrastructure

Existing infrastructure may complicate or constrain restoration projects. There are different types of infrastructure, such as highways, railways, houses and groundwater recharge stations, which are strong constraints on restoration projects since they are not likely to be removed. In contrast, other types of infrastructure such as power supply lines and gas pipes are more likely to be relocated, but may still complicate restoration projects.

To assess the suitability of a restoration project based on existing infrastructure, the following indicator is proposed:

(i) Distance between the infrastructure and the river.

The necessary space for a river widening depends on the type of the river and the restoration measures. In general, it can be assumed that if the infrastructure is located closer than three (to four) times the width of the existing river bed, the rehabilitation measures will be constrained.

### Recreation opportunities

Natural or near-natural rivers make attractive recreation areas, providing opportunities for activities such as eco-tourism, sport fishing and other outdoor activities (Costanza et al. 1997). Hence, improving recreational opportunities can be an important objective in restoration projects and can increase the public acceptance of the project.

The potential for recreational activities depends on the distance between the river and the next closest densely populated area (village, town). Thus the restored sites should be close to populated areas to allow for local recreation. To assess the suitability of restoration projects for recreation, the following indicator is proposed:

(i) Distance between the river and the populated areas.

We suggest 10km as an adequate threshold, as a distance up to 10km between the recreational site and the populated area seems to be a reasonable distance to travel for recreation purposes (ARE and BFS 2001).

## Public attitudes

Most restoration projects are financed by the government (local, regional or federal government), and hence mainly paid for with public money. In Switzerland, for example, the public even has in some cases to vote in a referendum on the restoration project. That shows that the general attitude of the public towards restoration projects is a major factor affecting their implementation.
We assume that if a community has an ecological attitude this can increase the feasibility of restoration projects. Therefore, the following indicator is proposed:

(i) Public attitude towards environmental projects (ecological or technocratic).

There is hardly any data on public attitude towards river restoration projects available on a national scale. In the absence of such data, surrogate data featuring general public attitudes towards environmental policies could be used instead. This could be obtained from public polls (Herrmann and Leuthold 2001, 2003).

## Restoration priorities

Limited resources will not allow floodplain restoration at every reach identified as suitable by this search strategy. Therefore priorities need to be set. However, the prioritizing process should not only consider the suitability values but also include biogeographical aspects. The overall aim should be to restore a healthy network of floodplains representative of their natural diversity. Such a network should ensure that headwaters, middle reaches and lower courses from different biogeographic regions are represented equally so as to sustain the natural array of processes and species which characterise our floodplains.

## Spatial multiple criteria decision analysis

### Data requirements

To apply the search strategy, the following information is needed:

(i) Quantitative, spatially explicit data about the selected indicators, which will be implemented in a geographical information system (grid layers). These may be readily available from inventories or can be generated from existing information by using, for example, buffer, merge or cost-distance functions provided by the GIS software. Data scarcity does not limit the application, as we allowed some redundancy in the indicator selection.

(ii) Suitability functions and weightings of the selected indicators for GIS modelling and sensitivity analysis (Filter 2). These can be obtained from expert interviews (e. g. using the Delphi process).

### MCDA-GIS modelling and sensitivity analysis

For the hierarchical filter process a geographic information system is used to manage and analyse the spatial data. In filter 1 all those areas that are not considered suitable for floodplain restoration are excluded by a Boolean-type selection.

In filter 2 the Ecological Restoration Suitability Index (ERSI) is calculated by a numerical overlay of the selected indicators (Figure 2). The combination of these indicators in a single restoration suitability index is a multiple criteria decision analysis (MCDA) problem. Within a geographical information system (GIS), each indicator is represented in a thematic grid layer while each cell in the database is taken as an alternative to be evaluated in terms of its quality or appropriateness for a given end, e.g. floodplain restoration (Pereira and Duckstein 1993).

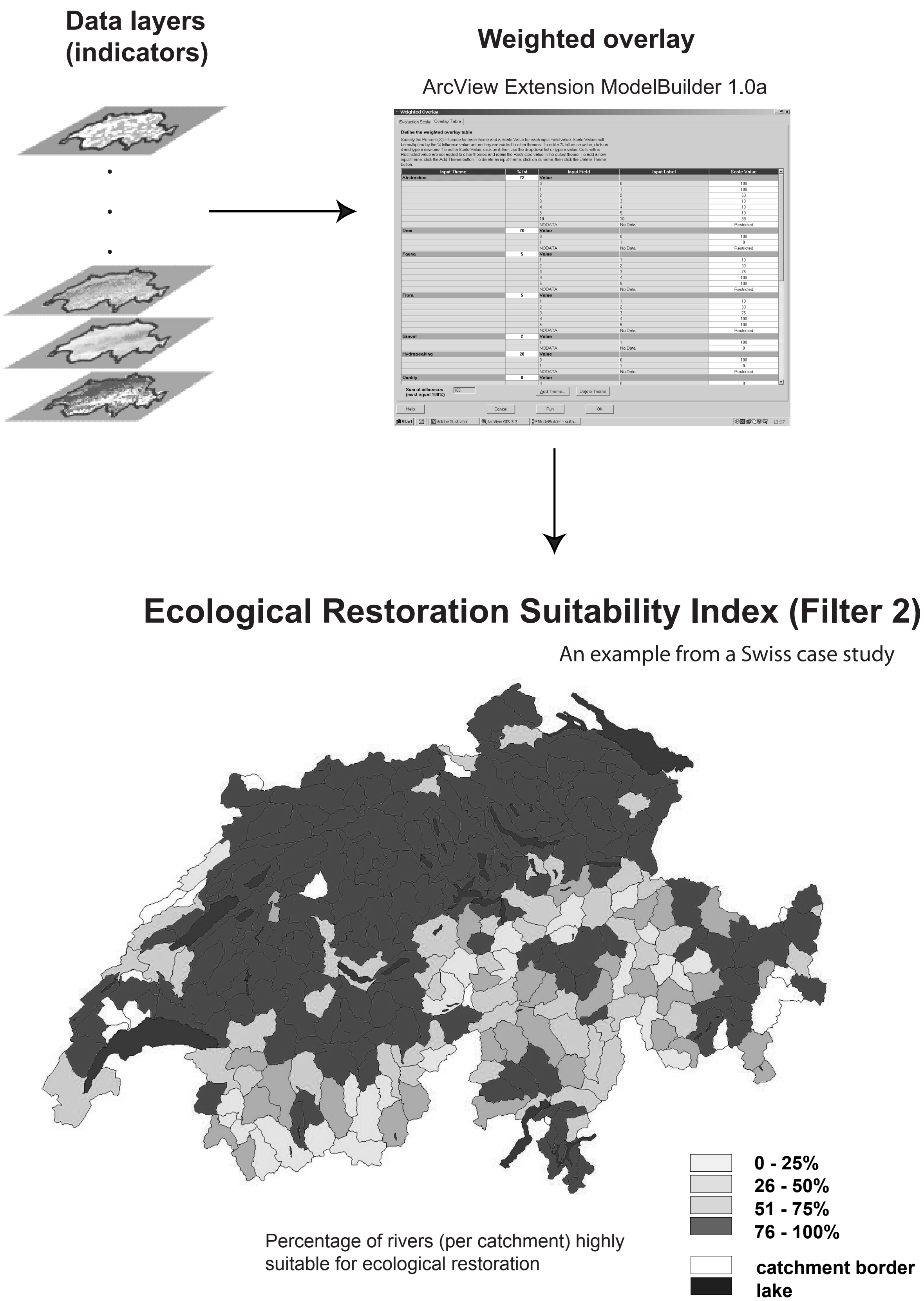


Figure 2. MCDM-GIS modelling

The combination of GIS and MCDA is a powerful approach to land suitability assessment (Joerin et al. 2001) and different applications have been described in the literature (e.g. Bojorquez-Tapia et al. 2001, Jankowski et al. 1997, Joerin et al. 2001, Pereira and Duckstein 1993, Store and Kangas 2001).

There are numerous MCDA methods to combine different indicators within an assessment/selection procedure (Malczewski 1999). This study adapts the multi-attribute value theory (MAVT) approach based on the weighted additive model. Additive decision rules are the best known and most widely used MCDM methods in GIS-based decision-making (Malczewski 1999). For example, Store & Kangas (2001) applied the multi-attribute utility theory (MAUT) for habitat suitability evaluation within forest management planning and species conservation. Other MCDM methods include outranking techniques such as PROMETHEE (Brans et al. 1986) and ELECTRE (Roy et al. 1986). However, outranking techniques require pair-wise comparisons among alternatives, which is impractical for applications where the number of alternatives/cells in a database is in the range of tens or hundreds of thousands (Pereira and Duckstein 1993).

The MAVT-approach (e.g. Belton and Stewart 2002, von Winterfeldt and Edwards 1986) involves three elements: (1) a single value (suitability) function for each indicator which is used to transform the indicator levels into an interval-value scale, (2) the weightings to determine the relative importance of each indicator and (3) the prediction of outcomes for the indicators. The overall value for the suitability status of a cell A is the weighted average of the single indicator values:

$$V(A) = \sum wi\ vi(ai) \qquad (1),$$

where V(A) is the overall value of the cell A, ai represents the outcome for indicator i resulting from cell A, vi(ai) is the single indicator suitability function and wi is a normalized weight for indicator i. The overall value of a cell V(A) represents the Ecological Restoration Suitability Index (ERSI) of this cell.

In the GIS the map layer of each indicator was integrated in a suitability model (Figure 2). The attribute levels of the indicators were standardized to a continuous scale of suitability from 0 (the least suitable) to 100 (the most suitable) (indicator suitability function). Each standardized factor is then multiplied by its corresponding weight (Table 3). Finally, the suitability model produces a suitability map showing the overall ERSI with cell values ranging from 0 to 100. To make the resulting map more user-friendly, the Ecological Restoration Suitability Index is reclassified into 3 equal classes:

- Class 1: highly suitable
- Class 2: fairly suitable
- Class 3: moderate suitable.

Filter 3 is a visual overlay of the ecological suitability map with the single maps of the socio-economic factors. The overlay is not done numerically as suitability values and weights depend more on local management and planning goals and restrictions than on general scientific knowledge.

A sensitivity analysis allows the relative influence of the weightings on the ERSI to be investigated. This tests how the results will change if the weightings of the criteria are changed. A sensitivity analysis is a useful tool in situations where the relationships between variables and their relative importance are uncertain as it helps with data interpretation.

Table 3. Indicator-suitability functions to calculate the Ecological Restoration Suitability Index (ERSI) and weighting schemes used for sensitivity analysis.

| **Indicator** | **Indicator range** | **Suitability** | **Weighting scheme used for sensitivity analysis** | | | |
|---|---|---|---|---|---|---|
| | | | Expert | Abiotic | Biotic | Equal |
| Water abstraction [%] | < 20 | 100 | 0.22 | 0.24 | 0.08 | 0.1 |
| | <20 + increased winter flow | 88 | | | | |
| | 20-40 | 63 | | | | |
| | 40-60 | 13 | | | | |
| | 60-80 | 13 | | | | |
| | > 80 | 13 | | | | |
| Hydropeaking | peak flow : base flow < 3(4) :1 | 100 | 0.2 | 0.18 | 0.08 | 0.1 |
| | peak flow : base flow > 3(4) :1 | 0 | | | | |
| Dam | No | 100 | 0.2 | 0.18 | 0.08 | 0.1 |
| | Yes | 0 | | | | |
| Chemistry | Very good | 100 | 0.08 | 0.1 | 0.03 | 0.1 |
| | Good | 100 | | | | |
| | Moderate | 60 | | | | |
| | Bad | 20 | | | | |
| | Very bad | 0 | | | | |
| Percentage arable arable land (%) | 0-2.33*** | 100 | 0.08 | 0.1 | 0.03 | 0.1 |
| | 2.33-6.69 | 75 | | | | |
| | 6.69-12.3 | 50 | | | | |
| | 12.3-21.59 | 25 | | | | |
| | 21.59-35.88 | 0 | | | | |
| Distance from present floodplains [km] | 0-10 | 100 | 0.1 | 0.05 | 0.2 | 0.1 |
| | 10-25 | 83 | | | | |
| | 25-50 | 60 | | | | |
| | 50-100 | 40 | | | | |
| | > 100 | 0 | | | | |
| Distance from gravel pits [km] | < 10 | 100 | 0.02 | 0.05 | 0.1 | 0.1 |
| | > 10 | 0 | | | | |
| Percentage [%] of regional riparian species pool (flora) | 0-10*** | 13 | 0.05 | 0.05 | 0.2 | 0.1 |
| | 10-34 | 33 | | | | |
| | 34-50 | 75 | | | | |
| | 50-70 | 100 | | | | |
| | 70-100 | 100 | | | | |
| Percentage [%] of regional riparian species pool (fauna) | 0-7*** | 13 | 0.05 | 0.05 | 0.2 | 0.1 |
| | 7-19 | 33 | | | | |
| | 19-32 | 75 | | | | |
| | 32-49 | 100 | | | | |
| | 49-74 | 100 | | | | |

**) vertical height of the barriers: trout zones = 70 cm, all other fish zones = 25 cm
***) Classes according to present situation in Switzerland (relative, not absolute assessment)

## Case Study

The integrative search strategy presented here was applied as part of the Rhone-Thur Project in Switzerland. The Swiss network of water courses covers about 61’000 km of streams and rivers. Preliminary studies suggest that 43% of the stream and river network is in need of restoration (Peter et al. 2003). As a result the Swiss Federal Ministries for environment and water formulated “sufficient room for water courses” as a major development objective (BUWAL/BWG 2003). The ministries ask to achieve these objectives by considering ecological as well as socio-economic criteria.

The search strategy was developed as planning tool and a preliminary case study was conducted using spatial data from various sources (BFS-GEOSTAT 1992/97, BFS-GEOSTAT/BUWAL 2001, BFS-GEOSTAT/BUWAL/BUWAL/ARE/BAKOM 2002, BWG/BUWAL 2003, CSCF 2003, Herrmann and Leuthold 2003, Wohlgemuth et al. 1999). Data was available to cover most of the ecological indicators (Filter 2). Only the indicators “bed load” and “presence of artificial migration barriers” could not be implemented due to incomplete data bases. A modified Delphi process survey of nine river ecology experts was used to assess the appropriateness of each ecological criterion and corresponding indicator; and to estimate the single indicator suitability functions on the basis of their best professional judgements (Table 3).

ArcView GIS 3.3. and ModelBuilder 1.0a were used to perform the spatial multiple criteria decision analysis. Each suitability indicator represented its own map layer and the data was grided into 100m x 100m grid cells. Figure 2 shows the input maps of the ecological suitability assessment (MCDM-GIS- analysis, see above) and the resulting ecological restoration suitability map on the catchment scale.

For some of the data GIS layers were readily available. Others had to be produced from existing information by using spatial function and analysis tools provided by the GIS software. For example, the distance to the nearest floodplain reserve (Filter 2) was calculated with the CostDistance function within the SpatialAnalyst extension of

ArcView3.3. We decided not to use the buffer function, as this would not take into account bends and meanders.

For some criteria (e.g. proportion of arable land (Filter 2)) the suitability of a river stretch was not assessed on the basis of thresholds that have an ecologically based rational. Instead, we ranked the existing data. The ranking (classification) of the data was done using the “natural breaks” function in ArcView, which finds groupings and patterns inherent in the data and minimizes the sum of the variance within each of the classes (Jenk’s optimization). This procedure identifies the most suitable areas according to present-day environmental conditions.

Figure 2 shows the percentage of the river reaches highly suitable for ecological restoration within the catchment areas. This result is based on the expert weighting scheme (Table 3). It is striking that for the majority of the catchment areas, the river reaches are highly suitable for restoration (class 1). In total, 80% of all river reaches in the study area are classified as highly suitable and 20% of the river reaches are fairly suitable (class 2) for restoration (Figure 3). None of the rivers are classified as moderate suitable (class 3). The majority of river reaches that are highly respectively fairly suitable for restoration can be found in the lowland region of Switzerland. This geographical differentiation has to do with the fact that alpine rivers are especially affected by water abstraction and hydropeaking due to hydropower production. These factors which limit restoration suitability are weighted relatively high by the experts (Table 3).

To determine how the weightings of the indicators influence the results, three additional weighting schemes were applied for the sensitivity analysis: (i) an abiotic scheme, which emphasizes the abiotic criteria, (ii) a biotic scheme, which emphasizes the biotic indicators and (iii) a third scheme where all indicators received equal weightings (Table 3). Major differences occur between the results of the expert weighting and of the biotic weighting scheme and the scheme with equal weightings (Figure 3).

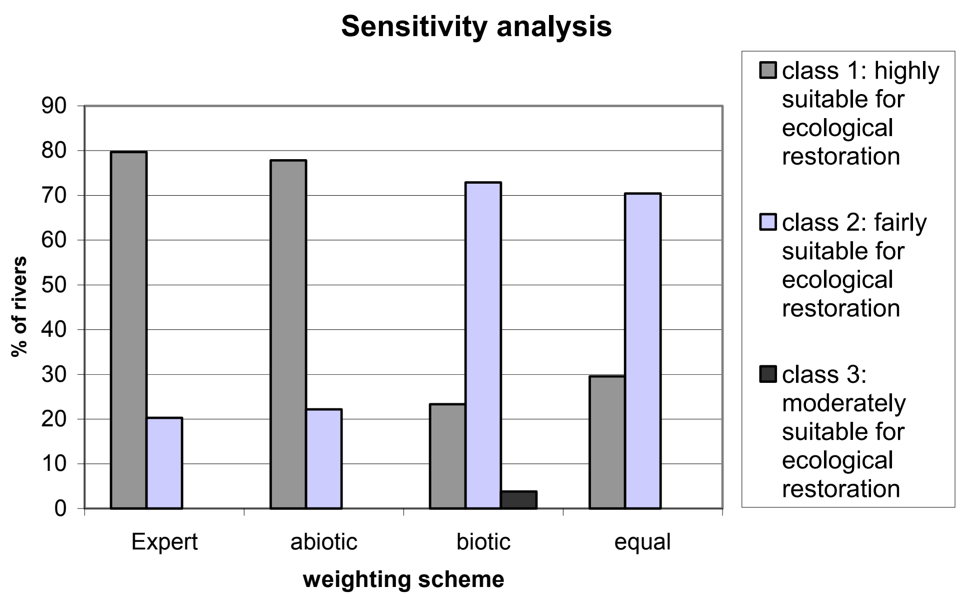


Figure 3. Sensitivity analysis for the Ecological Restoration Suitability Index (ERSI)

For these two models, the majority of the river reaches are "fairly suitable" (class 2) for restoration, whilst the expert weighting classifies the majority as "highly suitable" (class1).

However, only in the case of the biotic model are river reaches (cells) classified as "moderately suitable" (class 3) (Figure 3). The biotic model has the lowest percentage of highly suitable rivers since it emphasizes the biotic indicators, whilst most river reaches in Switzerland have a poor local species pool (flora and fauna) and are not very close to current near-natural floodplains.

In general, the results of the sensitivity analysis show that the data is rather robust in distinguishing between the classes "moderately suitable" and "fairly/highly suitability". On the other hand, there is a high sensitivity for the classification between class 1 and class 2.

The assessment of the ecological restoration suitability (Filter 2) is followed by the integration of the socio-economic factors (Filter 3). Figure 4 gives an example of the

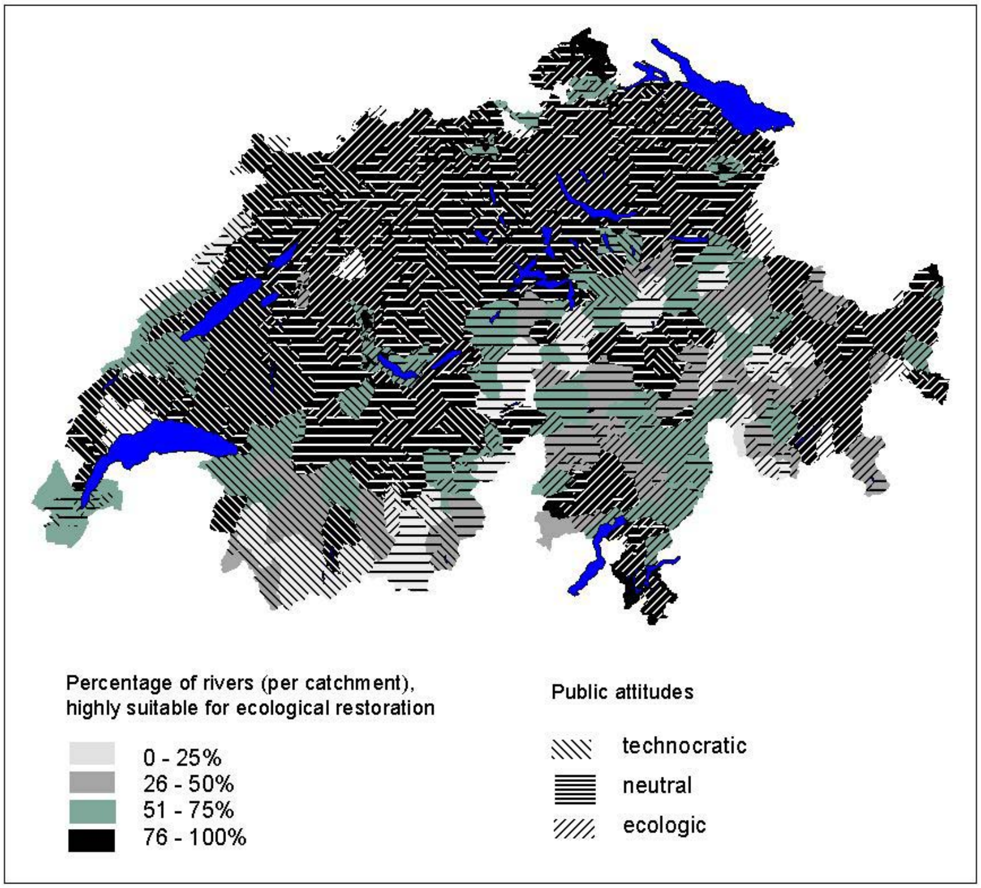


Figure 4. Ecological restoration suitability and public attitudes (Filter 3)

outcomes of applying filter 3 and shows the ecological suitability map and public attitudes towards environmental projects. In general, the majority of the Swiss public supports restoration projects. A national survey showed that 78% of the Swiss people want to provide rivers with more space (Pro Natura 2000). However, some regions are more progressive ecologically than others. Based on the analysis of 158 federal referendums held between 1981 and 1999, Hermann and Leuthold (2001) classified each community in Switzerland as taking either an ecological or technocratic stance towards environmental topics. Figure 4 shows those areas where public attitudes are ecological and where is very high restoration potential. These are areas where the restoration process is likely to be successful, in terms of the planning processes as well as ecological gain. Our results show that only about half of the river reaches highly

suitable for ecological restoration are located in areas where public attitudes are ecological. However, experience shows that public attitudes can change with information and stakeholder involvement. Thus our results do not imply that the areas with technocratic attitudes should be excluded from consideration, but that there might be more resources needed there to achieve public support.
The map in Figure 4 is a preliminary result, as the data of Herrmann and Leuthold (2003) represents general public attitudes towards environmental projects. There will be a nation-wide survey within the Rhone-Thur project focusing on public attitudes towards river restoration which will provide more detailed information (Junker et al., in prep.).

## Discussion

The main purpose of this study was to describe important ecological and socio-economic criteria for assessing restoration suitability and to develop a search strategy to identify river reaches where the greatest benefits from restoration can be expected. The case study illustrating its application. Although the selected criteria and parameter values represent mainly Swiss conditions, the proposed approach can easily be adapted to other study areas, e.g. by integrating “navigation” as a socioeconomic criterion within filter 3.

The strategy concentrates on assessing suitability and priority for restoration of floodplains and their biocoenosis. Other restoration measures, like removing dams and reducing water abstraction, are not specifically addressed. These are very important issues which are tackled by, for example, the Green Hydropower Project (Truffer et al. 2003). However, the model presented here implies a deficiency analysis which gives information on where improvements of abiotic conditions are needed and which measures would have the most far-ranging effects favouring the restoration efforts.

Restoration suitability is driven by numerous factors. However, practical applications require a manageable set of indicators and data. In this regard the search strategy is a compromise between accuracy and costs, which can guide and support decisions, but never "make" decisions.

In order to estimate the Ecological Restoration Suitability Index (ERSI) based on the weighted additive model, the decision maker's preference should satisfy a condition known as mutual preferential independence. This requires that every subset of attributes should be preferentially independent of its complement (Belton 1999). There are different ways to deal with a lack of mutual preferential independence. It may be possible to redefine or restructure the attributes in a way which achieves preferential independence (Belton 1999). Another way is to estimate the interactions of the attributes and use the multiplicative model (Keeney and Raiffa 1976, von Winterfeldt and Edwards 1986). In this study, we selected the ecological criteria so as to be as independent as possible. However, some redundancy was allowed to enable the application of the search strategy in situations where data is scarce and the sensitivity analysis was done to assess the effects of different weightings of the indicators.

Lack of data limits the completeness of information to be integrated into the suitability model of the search strategy. In cases of data scarcity one can use surrogate data instead of direct measurements. Data on public attitudes, for example, can be estimated from ballot results instead of personal interviews. Having said that, one has to be careful that the chosen surrogate implies the information needed. In general, data scarcity does not prevent the application of our search strategy, as we allowed some redundancy in the indicator selection.

The quality of the search strategy does not solely depend on the implemented factors and data availability. It also depends on accuracy, age and resolution of the input data. When interpreting the data one should be aware of the spatial resolution of the input data. We worked on a basis of a 100m x 100m grid (for technical reasons). Underlying ecological and socio-economic criteria, however, are often based on much coarser resolutions, for example, reach level for hydropeaking or municipal level for the indicator "public attitude". The model presented here produces a suitability map with crisp boundaries between the individual suitability classes. However, real-world boundaries are mainly continuous ones. Water quality, for example, will rarely change abruptly but rather will be fuzzy with increasing dilution. The crisp boundaries in the suitability model are an artefact resulting from abstraction of real-world data into the GIS-compatible map layers of the input data. Hence, the level of detail is only sufficient to signal river reaches of different restoration suitability on the catchment scale.

It is important to emphasise that this search strategy does not replace more detailed investigations, which provide the foundation for comparing different restoration sites within one river reach and different alternatives for the chosen restoration site. The strength of this search strategy lies in the pre-screening of spatial data on a national scale and its ability to focus restoration activity on the most promising areas.

## Conclusions

The integrative search-strategy presented and its implied GIS-model are valuable tools to assist policy makers and planners in making decisions about floodplain restoration. As is every model there are some constraints. For example, the simplification of reality due to limited data input and spatial resolution. Nevertheless, we think that the application of the suggested search strategy will enable an efficient planning process, as it:

a) eases priority setting and allocation of resources because it helps to identify river reaches where the present conditions favour restoration efforts and thus justify further specific and detailed investigations (pre-screening);

b) merges input from a wide range of specialists and provides a comprehensive set of objective, ecological as well as socio-economic indicators or surrogates for assessing restoration suitability. The Ecological Restoration Suitability Index

(ERSI) signals ecological deficiencies where further action, for example, residual flow management, is needed to foster restoration success;

c) can be flexibly adapted to local situations with, for example, restricted data availability. Its flexibility also means that different scenarios can be produced subject to (future) changes in the environment or planning targets and

d) provides a “check-list” of clearly defined criteria and indicators respectively surrogates for sustainable river management and ensures as much objectivity and standardization as possible. Such a replicable selection procedure could be seen by politicians and stakeholders as being less prescriptive and individually intrusive than a subjective assessment.

In a nutshell, the search strategy presented here enables a strategic, proactive and efficient planning process, which is based on both ecological and socio-economic criteria. Such a systematic planning procedure provides transparency and thus helps to ensure public accountability, and it also helps to set priorities and thus avoid inefficiency. It enables projects to be located where they are less likely to be undermined by adverse influences, and where the greatest gains (both ecological and socio-economic) are to be made. We acknowledge, however, that further development of the presented search strategy is desirable, and we invite others to become involved in the process of further refinement.

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# Literature cited

Allan, J. D., Erickson, D. L. and Fay, J. 1997. The influence of catchment land use on stream integrity across multiple spatial scales. *Freshwater Biology* 37**:** 149-161.

Amoros, C. and Bornette, G. 2002. Connectivity and biocomplexity in waterbodies of riverine floodplains. *Freshwater Biology* 47**:** 761-776.

ARE and BFS. 2001. Mobilität in der Schweiz. Ergebnisse des Mikrozenzus 2000 zum Verkehrsverhalten. Bundesamt für Raumentwicklung, Bundesamt für Statistik, Bern and Neuenburg.

Basnyat, P., Teeter, L. D., Flynn, K. M. and Lockaby, B. G. 1999. Relationships between landscape characteristics and nonpoint source pollution inputs to coastal estuaries. *Environmental Management* 23**:** 539-549.

Belton, V. 1999: Multi-criteria problem structuring and analysis in a value theory framework. Pages 12-1 - 12-32 in *Gal T., e. a. (eds.)* Multicriteria Decision Making, Kluwer Academic Press, Dordrecht, Netherlands.

Belton, V. and Stewart, T. J. 2002. Multiple Criteria Decision Analysis - An integrated approach. Kluwer Academic Publishers, Boston/Dordrecht/London.

BFS-GEOSTAT. 1992/97. Arealstatisik der Schweiz. Bundesamt für Statistik, Servicestelle GEOSTAT, Neuchâtel.

BFS-GEOSTAT/BUWAL. 2001. Aueninventar. Bundesamt für Statistik, Servicestelle GEOSTAT, Neuchâtel.

BFS-GEOSTAT/BUWAL/BUWAL/ARE/BAKOM. 2002. Siedlungsgebiete der Schweiz. Bundesamt für Statistik, Servicestelle GEOSTAT, Neuchâtel.

Bojorquez-Tapia, L. A., Diaz-Mondragon, S. and Ezcurra, E. 2001. GIS-based approach for participatory decision making and land suitability assessment. *International Journal of Geographical Information Science* 15**:** 129-151.

Bonn, S. and Poschlod, P. 1998. Ausbreitungsbiologie der Pflanzen Mitteleuropas Grundlagen und kulturhistorische Aspekte. Quelle & Meyer, Wiesbaden, X, 404 S. pp.

Bornette, G., Amoros, C., Castella, C. and Beffy, J. L. 1994. Succession and fluctuation in the aquatic vegetation of 2 former Rhone river channels. *Vegetatio* 110**:** 171-184.

Bowen, Z. H., Bovee, K. D. and Waddle, T. J. 2003. Effects of flow regulation on shallow-water habitat dynamics and floodplain. *Transactions of the American Fisheries Society* 132**:** 809-923.

Brans, J. P., Vincke, P. and Mareschal, B. 1986. How to select and how to rank projects: The PROMETHEE method. *European Journal of Operational Research* 24**:** 228-238.

Brookes, A. and Shields, F. D. 1996. River channel restoration: guiding principles for sustainable projects. John Wiley & Sons Ltd, Chichester.

Bundi, U., Peter, A., Frutiger, A., Hütte, M., Liechti, P. and Sieber, U. 2000. Scientific base and modular concept for comprehensive assessment of streams in Switzerland. *Hydrobiologia* 422/423**:** 477-487.

Bunn, S. E. and Arthington, A. H. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management* 30**:** 492-507.

BUWAL. 2003. Methoden zur Untersuchung und Beurteilung der Fliessgewässer in der Schweiz. Modul Chemie. Chemisch-ohysikalische Erhebungen. *Vollzug Umwelt (Entwurf)*.

BUWAL/BWG. 2003. Leitbild Fliessgewässer Schweiz. Für eine nachhaltige Gewässerpolitik., Bern, 12 pp.

BWG. 2001. Hochwasserschutz an Fliessgewässern, Wegleitung. Biel, 72 pp.

BWG/BUWAL. 2003. GEWISS - Gewässerinformationssystem Schweiz. Bern.

Calow, P. and Petts, G. 1994. The Rivers Handbook: hydrological and ecological principles. Vol. 1, Blackwell Science Ltd, Oxford, 523 pp.

Catling, P. M. and Brownell, V. R. 2001. Biodiversity of adult damselflies (Zygoptera) at eastern Ontario gravel pit ponds. *Canadian Field-Naturalist* 115**:** 402-405.

Cereghino, R., Cugny, P. and Lavandier, P. 2002. Influence of intermittent hydropeaking on the longitudinal zonation patterns of benthic invertebrates in a mountain stream. *International review of hydrobiology* 87**:** 47-60.

Clarke, S. J., Bruce-Burgess, L. and Wharton, G. 2003. Linking form and function: towards an eco-hydromorphic approach to sustainable river restoration. *Aquatic conservation - marine and freshwater ecosystems* 13**:** 439-450.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., Sutton, P. and van den Belt, M. 1997. The value of the world's ecosystem services and natural capital. *Nature* 387**:** 253-260.

CSCF. 2003. Base cartographique. Centre Suisse de Cartographie de la Faune, Neuchâtel.

Ehrenfeld, J. G. 2000. Defining the limits of restoration: the need for realistic goals. *Restoration Ecology* 8**:** 2-9.

Erskine, W. D. 1992. Channel response to large-scale river training works- Hunter River, Australia. *Regulated Rivers* 7**:** 261-278.

Herrmann, M. and Leuthold, H. 2001. Weltanschauung und ihre soziale Basis im Spiegel eidgenössischer Volksabstimmungen. *Swiss Political Science Review* 7**:** 39-63.

Herrmann, M. and Leuthold, H. 2003. Atlas der politischen Landschaften. Ein weltanschauliches Portrait der Schweiz. vdf-Verlag, Zürich, 136 pp.

Hobbs, R. J. and Norton, D. A. 1996. Towards a conceptual framework for restoration ecology. *Restoration Ecology* 4**:** 93-110.

Holmes, N. 1998: The river restoration project and its demonstration sites. Pages 133-148 in *DeWaal, L. C., Large, A. R. G. and Wade, P. M. (eds.)* Rehabilitaiton of Rivers: Principles and Implementation, John Wiley, Chichester.

Hostmann, M., Truffer, B., Reichert, P. and Borsuk, M. 2004. Stakeholder values in decision support for river rehabilitation. *Archiv für Hydrobiologie, Supplement Volume Large Rivers* under review.

Hughes, F. M. R. and Rood, S. B. 2003. Allocation of River Flows for Restoration of Floodplain Forest Ecosystems: A Review of Approaches and Their Applicability in Europe. *Environmental Management* 32**:** 12-33.

Jankowski, P., Nyerges, T. L., Smith, A., Moore, T. J. and Horvath, E. 1997. Spatial group choice: a SDSS tool for collaborative spatial decision-making. *International Journal of Geographical Information Science* 11**:** 577-602.

Joerin, F., Thériault, M. and Musy, A. 2001. Using GIS and outranking multicriteria analysis for land-use suitability assessment. *International Journal of Geographical Information Science* 15**:** 153-174.

Keeney, R. L. and Raiffa, H. 1976. Decisions with Multiple Objectives. Wiley, New York.

Kontos, T. D., Komilis, D. R. and Halvadakis, C. P. 2003. Siting MSW landfills on Lesvos island with a GIS-based methodology. *Waste management & research* 21**:** 262-277.

Lagarrigue, T., Cereghino, R., Lim, P., Reyes-Marchant, P., Chappaz, R., Lavandier, P. and Belaud, A. 2002. Diel and seasonal variations in brown trout (Salmo trutta) feeding patterns and relationship with invertebrate drift under natural and hydropeaking conditions in a mountain stream. *Aquatic living resources* 15**:** 129-137.

Limnex. 2003. Gewässerökologische Auswirkungen des Schwallbetriebes: Ergebnisse einer Literaturstudie. Vol. 75, Mitteilungen zur Fischerei, Bundesamt für Umwelt, Wald und Landschaft, Bern.

Malanson, G. P. 1995. Riparian Landscapes. Cambridge University Press, Cambridge, 296 pp.

Malczewski, J. 1999. GIS and multicriteria decision analysis. John Wiley & Sons, INC., New York.

Malmquist, B. 2002. Aquatic invertebrates in riverine landscapes. *Freshwater Biology* 47**:** 679-694.

Marriott, S. B. and Alexander, J. 1999. Floodplains: Interdisciplinary Approaches. Vol. 163, Geological Society special Publication, The Geological Society London, London, 330 pp.

Miaud, C., Sanuy, D. and Avrillier, J.-N. 2000. Terrestrial movements of thenatterjack toad Bufo calamita (Amphibia, anura) in a semid-arid, agricultural landscape. *Amphibia-Reptilia* 21**:** 357-369.

Naiman, R. J. and Bilby, R. E. 1998. River Ecology and Management. Lessons from the Pacific Coastal Ecoregion. Springer-Verlag, New York, 705 pp.

Naiman, R. J., Décamps, H. and Pollock, M. 1993. The role of riparian corridors in maintaining regional biodiversity. *Ecological Applications* 3**:** 209-212.

Naveh, Z. 1994. From biodiversity to ecodiversity: a landscape-ecology approach to conservation and restoration. *Restoration Ecology* 2**:** 180-189.

Nedeau, E. J., W., M. R. and Kaufmann, M. G. 2003. The effect of an industrial efluent on an urban stream benthic communigy: water quality vs. habitat quality. *Environmental Pollution* 123**:** 1-13.

Neilsen, M. 2002. Lowland stream restoration in Denmark: Background and examples. *Journal of the chartered institution of water and environmental management* 16**:** 189-193.

Nienhuis, P. H., Buijse, A. D., Leuven, R. S. E. W., Smits, A. J. M., de Nooij, R. J. W. and Samborska, E. M. 2002. Ecological rehabilitation of the lowland basin of the river Rhine (NW Europe). *Hydrobiologia* 478**:** 53-72.

Nilsson, C. and Svedmark, M. 2002. Basic Principles and Ecological Consequences of Changing Water Regimes: Riparian Plant Communities. *Environmental Management* 30**:** 468-480.

Osborne, L. L., Bayley, P. B., Higler, L. W. G., Statzner, B., Triska, F. and Iversen, T. 1993. Restoration of Lowland Streams - an introduction. *Freshwater Biology* 29**:** 187-194.

Pedroli, B., de Blust, G., van Looy, K. and van Rooij, S. 2002. Setting targets in strategies for river restoration. *Landscape Ecology* 17 (Suppl.1)**:** 5-18.

Pereira, J. M. C. and Duckstein, L. 1993. A multiple criteria decision-making approach to GIS-based land suitability evaluation. *International Journal of Geographic Information Systems* 7**:** 407-424.

Peter, A., Kienast, F. and Nutter, S. 2003. The Rhone-Thur River project: a comprehensive river rehabilitation project in Switzerland. *(subm.)*.

Petts, G. and Calow, P. 1996. River Restoration. Blackwell Science Ltd, Oxford, 231 pp.

Pinder, L. C. V. 1997. Research on the Great Ouse: Overview and implications for management. *Regulated Rivers-research and management* 13**:** 309-315.

Poff, N. L. 1997. Landscape filters and species traits:towards mechanistic understanding and prediction in stream ecology. *Journal of the North American Benthological Society* 16**:** 391-409.

Pretty, J. L., Harrison, S. S. C., Shepherd, D. J., Smith, C., Hildrew, A. G. and Hey, R. D. 2003. River rehabilitation and fish populaitons: assessing the benefit of instream structures. *Journal of Applied Ecology* 40**:** 251-265.

Pro Natura. 2000. Fliessgewässer. Studie von LINK Institut.

Ray, N., Lehmann, A. and Joly, P. 2002. Modeling spatial distribution of amphibian populations: a GIS approach based on habitat matrix permeability. *Biodiversity and Conservation* 11**:** 2143-2165.

Rohde, S., Schütz, M., Kienast, F. and Englmaier, P. 2003. River widenings: a promising approach to re-establish riparian habitats and species? *Regulated Rivers Research and Applications* under review.

Roy, B., Présent, M. and Silhol, D. 1986. A programming method for determining which Paris metro stations should be renovated. *European Journal of Operational Research* 24**:** 318-334.

Sadek, S., Bedran, M. and Kaysi, I. 1999. GIS platform for multicriteria evaluation of rout alignments. *Journa of transportation engineering-ASCE* 125**:** 144-151.

Santoul, F. 2002. The waterbirds of gravel pits in the Garonne river floodplain. Carrying capacity and management plan of Saint-Caprais and Lavernose-Lacasse gravel pits. *Bulletin de la Societe Zoologique de France* 127**:** 371-374.

Schneider, K., Walter, T. and Umbricht, M. 2003. AUA - Datenbank zur Fauna in Auen. Eidgenössischen Forschungsanstalt für Agrarökologie und Landbau (FAL).

Sidle, J. G. and Kirsch, E. M. 1993. Least tern and piping plover nesting at sand pits in Nebraska. *Colonial Waterbirds* 16**:** 139-148.

Store, R. and Kangas, J. 2001. Integrating spatial multi-criteria evaluation and expert knowledge for GIS-based habitat suitability modeling. *Landscape and urban planning* 55**:** 79-93.

Truffer, B., Bratrich, C., Markard, J., Peter, A., Wuest, A. and Wehrli, B. 2003. Green Hydropower: The contribution of aquatic science research to the promotion of sustainable electricity. *Aquatic Sciences* 65**:** 99-110.

van der Nat, D., Tockner, K., Edwards, P. J., Ward, J. V. and Gurnell, A. M. 2003. Habitat change in braided flood plains (Tagliamento, NE-Italy). *Freshwater Biology* 48**:** 1799-1812.

VAW, V. f. W., Hydrologie und Glaziologie der Eidgen. Techn. Hochschule Zürich. 1993. Strada. Flussmorphologisches Gutachten zur geplanten Innrevitalisierung im Zusammenhang mit der Umfahrungsstrasse Strada.

Villa, F., Tunesi, L. and Agardy, T. 2002. Zoning Marine Protected Areas through Spatial Multiple-Criteria Analysis: the Case of the Asinara Island National Marine Reserve of Italy. *Conservation Biology* 16**:** 515-526.

von Winterfeldt, D. and Edwards, W. 1986. Decision analysis and behavioral research. Cambridge University Press, Cambridge.

Walser, C. A. and Bart, H. L. 1999. Influence of agriculture on in-stream habitat and fish community structure in Piedmont watersheds of the Chattahoochee River System. *Ecology of freshwater fisch* 8**:** 237-246.

Ward, J. V. 1998. Riverine landscapes: biodiversity patterns, disturbance regimes, and aquatic conservation. *Biological Conservation* 83**:** 269-278.

Ward, J. V., Tockner, K., Arscott, D. B. and Claret, C. 2002. Riverine landscape diversity. *Freshwater Biology* 47**:** 517-539.

Webb, N. R. 1997: The development of criteria for ecological restoration. in *Urbanska, K. M., Webb, N. R. and Edwards, P. J. (eds.)* Restoration Ecology and Suistainable development, Cambridge University Press.

Wohlgemuth, T., Boschi, K. and Longatti, P. 1999. Swiss Web Flora. WSL.

# Synthesis and final remarks

## Restoration: an iterative and integrative process

Progress in the restoration of riparian landscapes can only be achieved through an iterative process that integrates input from a wide range of disciplines (ecology, hydrology, geomorphology, sociology and economics) and that is based on the interaction between theory and practice.

Each restoration project constitutes an experiment in the “landscape laboratory”. Lessons learned from the success and failure of these experiments will advance the science of river restoration. These experiments allow to understand the underlying ecological and socio-economic principles and processes that drive restoration and to refine theoretical concepts in restoration ecology and planning processes. The shared knowledge gained from research and application in the field also helps to develop methods to reverse or ameliorate river degradation and to improve existing restoration measures. Thus, a dialogue between research community and practitioners is necessary to ensure that the knowledge thus obtained is applicable and meets the requirements of restoration practice in the field.

## Assessment scheme and indicators

Monitoring and post-project evaluation are essential for adapting the knowledge gained from success and failure to future projects. When assessing a restoration project, two main questions arise: “Which attributes should we measure?” and “How do we measure the temporal development of these attributes?”.

River ecosystems are very complex, including physical and chemical processes over a wide range of spatial and temporal scales and numerous variables and interactions, which may obscure many cause-and-effect relationships. Therefore, a combined set of attributes, namely, structure, function and composition, to be applied at different hierarchical levels (landscape, species and processes), should be monitored over a long time period.

My analyses show that landscape metrics and selected species are valuable indicators for monitoring and evaluating the performance of a restoration project (paper 2). Investigations on the basis of functional groups (e.g. dispersal strategies, competition, etc.) would yield additional information.

However, assessment needs to be embedded in a value system that serves as reference. Such a reference system should consist of the status before restoration took place and a desired system status, for example, a known near-natural area (papers 1 and 2). The measurement itself can be done on the basis of similarity indices (paper 2). An alternative is to assess restoration performance relative to the range of natural variability. In this context the presented "stencil technique" has proofed to be a fruitful approach for comparing landscapes of different sizes on the basis of landscape metrics (paper 1). For highly dynamic ecosystems, such as riparian landscapes, "natural variability" (in time and in space) is an aspect that deserves greater attention.

## Potential and limitations of re-establishing riparian landscapes

The canalization of the rivers is a major cause of the loss of riparian habitats and their associated biodiversity. Removing the confining "corset" of dikes and groins is very important in restoring these habitats, as space ("room for rivers") is a pre-requisite for bringing back near-natural processes, habitats and species. This study shows that river widenings allow the re-establishment of some aspects of riparian landscapes, such as the early successional stages of a riparian habitat (e.g. gravel bars) or some riparian species (papers 1 and 2). However, re-establishing riparian landscapes does not solely depend on the space provided (local decisions), but also on catchment-related decisions, such as residual flow or sediment management and land use.

The stochastic nature of flood events and sediment transportation, which are the two major driving forces in the riparian ecosystem, means that the outcome of a particular restoration measure may differ when carried out at different locations or at different times. Thus the transferability of the results from this study is limited. However, the presented results may serve as a baseline indicating what potentially could take place when rivers are widened within a limited area.

Additionally, a discussion of the potential and limitations of restoration measures should not neglect the fact that there is no guarantee that restoration will not have adverse side-effects and the possibility that restoration may have an impact well beyond the restored reach of a river. Examples include an increased risk of flooding due to increased sedimentation up-stream of the river widening, increased risk of clogging at the contraction zone downstream of the widening or a risk of contamination due to spilling of pollutants from former waste dumps.

## Recommendations for future restoration projects

Sustainable restoration requires a reinstatement of unaffected fluvial processes, such as natural water and sediment fluxes. This is more difficult than "creating" river widenings with islands and bars or pool-riffle sequences. Restoring these key processes means less management will be required to maintain the desired channel structures and habitats. Otherwise regular measures (e.g. sediment excavation) will be needed to mimic natural processes.

The success and performance of a restoration project depend on decisions taken at the local level as well as on the catchment scale. Thus restoration should be undertaken considering a wide spatial context to account for the degree of longitudinal, lateral and vertical connectivity in a river system (catchment approach). By linking a range of different initiatives and schemes within a particular catchment (e.g. residual flow management, flood defense and agri-environment schemes) it may be possible to restore not just the reach, but the whole catchment.

River and floodplain restoration (usually this should be described more properly as rehabilitation – see General introduction) is the return of a degraded stream ecosystem to a close approximation of its remaining natural potential. It is therefore necessary to know which ecological deficiencies occur in a river system and to which degree these are reversible, if at all. Reversibility of human influences (e.g. by water abstraction, sediment excavation and land-use change) may prove impossible or may not be desirable economically or socially. Quantifying and recognizing both the ecological limitations on restoration and the socio-economic barriers to its implementation (= remaining natural and "socio-economic" restoration potential) helps to prevent disillusionment and to locate restoration measures where they are least likely to be undermined by unfavourable environmental conditions. Hence, such a procedure allows (i) a vision suitable for the river within its present and future environmental framework to be formulated, and (ii) those environmental conditions to be identified that need to be improved to meet ecological needs, e.g. residual flow management (paper 3).

(River) restoration should not take place detached from society, as any environmental planning affects people and what those people value. A planning procedure which includes all sectors of society in decision-making (stakeholder involvement) provides transparency and helps to ensure public support and accountability. Therefore, a strategic and pro-active planning concept is essential when "real-world" restoration is going to advance (paper 3).

## Further research

Restoration ecology and river restoration are fairly young disciplines. Thus many aspects still remain to be investigated. The following suggestions give an idea of what further research is needed to advance the science of restoration.

Although it is generally acknowledged (in terms of restoration) that "bigger is better", we do not know "how large a restored floodplain needs to be?". Research in geomorphology gained experience in calculating the minimum channel width to allow for alternating bars or braiding (e.g. Hunzinger 1998, Yalin and da Silva 2001) and in calculating the oscillation width of a river, which is approximately 5-6 times the channel width (BWG 2001). However, the channel width for braiding is too tight for the whole range of riparian habitat types (including woodlands) to be re-established. Morever, the natural oscillation width seems to be unrealistic in most cases. Therefore, research on the ecological minimum width for river widenings is needed. However, research should also include investigations of the ecological minimum length of river widenings. I propose for a start as the ecological minimum requirements for river widenings that the width should be three times the channel width based on the findings of Hunzinger (1998) and the length of three riffle-pool sequences. However, this suggestion is based on observations during fieldwork and needs to be verified in a detailed and broad study. Future research on the required minimum size of river widenings should focus on the formulation of minimum standards taking into consideration environmental parameters, such as flow, slope and grain size, instead of definite, absolute numbers.

Further research needs to be done to assess the outcome of restoration measures and the conditions under which they were conducted. This should be comprehensive and include habitats, species and food webs as well as chemical and physical processes. Additionally, more research is required on the postulated relationship between landscape composition/configuration and processes and biocoenosis. This is especially important when using landscape metrics as indicators for success and failure. A major question which still needs to be answered is “what change in the numerical value of a single metric is ecologically relevant?”.

## Overall conclusion

The restoration of riparian landscapes is possible to a limited degree, given enough space and the reinstatement of natural processes (hydro-/morphodynamics). Restoration will improve if it moves away from a species-focused to a process- and catchment-focused approach, because “Managing a river to maintain minimum water flow or sustain a single ‘important species’ is like teaching pet tricks to a wolf: The animal may perform, but it is not much of a wolf anymore” (www.crcwater.orgissues3/rivermanagment.html).

Otherwise restoration runs the risk of “being seen as a sort of gardening with wild species in natural mosaics”, as Allen & Hoekstra (1992) commented.

Concluding that river widenings have the potential to re-establish riparian landscapes and species does not imply that it is general feasible to re-create nature and does not deny the important need to conserve near-natural areas. Indeed, my results reveal the limitations of “human-made nature”. Furthermore, (near-) natural ecosystems provide a skeleton on which restoration activities are built, as they are sources for (i) research on natural fluvial processes and (ii) species re-colonization. However, “human-made nature” (e.g. river widenings) is a valuable measure to reduce the pressure upon near-natural areas caused by people seeking recreation. Increased opportunities for recreation are one of the socio-economic values generated by river widenings. Surveying and publication of the social benefits provided by river widenings and stakeholder involvement will increase public accountability and support for future river widening projects.

Going back to the origins of the term “landscape” we see that it is derived from the landscape phrase of “shaping land”. The recent change in public attitudes towards river management means that it should be possible to provide room for rivers and to shape rivers in such way that they are no longer “straight river channels” but rather future “riverscapes”.

## Literature cited

Allen, T. H. F. and Hoekstra, T. W. 1992. Toward a unified ecology. Columbia University Press, New York, 384 pp.

BWG. 2001. Hochwasserschutz an Fliessgewässern. Wegleitung. Bundesamt für Wasser und Geologie, Biel.

Hunzinger, L. M. 1998. Flussaufweitungen - Morphologie, Geschiebehaushalt und Grundsätze zur Bemessung. Vol. 159, VAW Mitteilungen, Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie der ETH Zürich, Zürich.

Yalin, M. S. and da Silva, A. M. F. 2001. Fluvial Processes. IAHR International Association of Hydraulic Engineering and Research, Kingston.

# Appendix

## Swiss Riparian Species

**Class1: Floodplain-dependent species *sensu stricto*:**
(Species whose survival mainly depends on fluvial habitats)

*Calamagrostis pseudophragmites*
*Carex acutiformis*
*Epilobium dodonaei*
*Epilobium fleischeri*
*Hippophaë rhamnoides*
*Lysimachia thyrsiflora*
*Myricaria germanica*
*Salix alba*
*Salix daphnoides*
*Salix myrsinifolia*
*Salix triandra*
*Salix viminalis*
*Salix elaeagnos*

**Class 2: Floodpalin dependent species *sensu lato*:**
(Species which have their natural primary habitat in floodplains, but which can today also be found in certain secondary habitats (e.g. gravel-pits) outside the floodplains)

*Aegopodium podagraria*
*Alopecurus aequalis*
*Alnus glutinosa*
*Alnus incana*
*Amelanchier ovalis*
*Anagallis minima*
*Artemisia vulgaris*
*Atriplex prostrata*
*Berberis vulgaris*
*Berteroa incana*
*Bidens cernua*
*Bidens connata*
*Bidens radiata*
*Bidens tripartita*
*Butomus umbellatus*
*Carduus personata*
*Carex pseudocyperus*
*Centaurea diffusa*
*Centaurium pulchellum*
*Chaerophyllum aureum*
*Chaerophyllum bulbosum*
*Chenopodium ficifolium*
*Chenopodium glaucum*
*Chenopodium polyspermum*
*Chenopodium rubrum*
*Chondrilla chondrilloides*
*Colutea arborescens*
*Cornus mas,sanguinea*
*Hippocrepis emerus*
*Corrigiola litoralis*
*Cotinus coggygria*
*Cotoneaster integerrimus*
*Cotoneaster tomentosus*
*Crepis setosa*
*Cruciata laevipes*
*Cyperus fuscus*
*Daucus carota*
*Echium vulgare*
*Epilobium roseum*
*Erigeron annuus*
*Erigeron annuus*
*Erigeron annuus subsp. str*
*Glyceria maxima*
*Hieracium piloselloides*
*Hieracium staticifolium*
*Isolepis setacea*

**Class 2: Floodpalin dependent species *sensu lato* (cont.)**
(Species which have their natural primary habitat in floodplains, but which can today also be found in certain secondary habitats (e.g. gravel-pits) outside the floodplains)

*Juncus bufonius*
*Juncus capitatus*
*Juncus tenageia*
*Lamium maculatum*
*Linaria vulgaris*
*Lythrum portula*
*Melilotus albus*
*Melilotus altissimus*
*Melilotus officinalis*
*Montia fontana subsp. chon*
*Myosotis cespitosa*
*Cotoneaster tomentosus*
*Crepis setosa*
*Cruciata laevipes*
*Cyperus fuscus*
*Daucus carota*
*Echium vulgare*
*Epilobium roseum*
*Erigeron annuus*
*Erigeron annuus*
*Erigeron annuus subsp. str*
*Glyceria maxima*
*Hieracium piloselloides*
*Hieracium staticifolium*
*Isolepis setacea*
*Juncus bufonius*
*Juncus capitatus*
*Juncus tenageia*
*Lamium maculatum*
*Linaria vulgaris*
*Lythrum portula*
*Melilotus albus*
*Melilotus altissimus*
*Melilotus officinalis*
*Montia fontana subsp. chon*
*Myosotis cespitosa*
*Oenothera biennis*
*Oenothera glazioviana*
*Oenothera parviflora*
*Petasites hybridus*
*Phalaris arundinacea*
*Phragmites australis*
*Picris hieracioides*
*Polygonum hydropiper*
*Polygonum lapathifolium s.*
*Polygonum lapathifolium su*
*Polygonum minus*
*Prunus mahaleb*
*Ranunculus sceleratus*
*Reseda luteola*
*Rhamnus alpina*
*Riccia glauca*
*Rorippa amphibia*
*Rosa micrantha*
*Rosa villosa*
*Rumex aquaticus*
*Salix fragilis*
*Salix purpurea*
*Salix x rubens*
*Sambucus ebulus*
*Schoenoplectus lacustris*
*Scrophularia canina*
*Sium latifolium*
*Sparganium emersum*
*Sparganium erectum*
*Sparganium erectum*
*Tanacetum vulgare*
*Tragopogon dubius*
*Typha angustifolia*
*Typha latifolia*
*Viburnum lantana*
*Barbarea vulgaris*
*Equisetum hyemale*
*Humulus lupulus*

**Class 3: Additional characteristic species**

(Species which typically occur in floodplains (except those normally found in intensively managed grasslands), but which do not depend on riparian habitats)

*Achillea millefolium*
*Agropyron repens*
*Agropyron repens*
*Agrostis gigantea*
*Agrostis rupestris*
*Agrostis stolonifera*
*Alchemilla vulgaris*
*Alliaria petiolata*
*Alopecurus geniculatus*
*Amaranthus blitum*
*Amaranthus caudatus*
*Amaranthus retroflexus*
*Angelica sylvestris*
*Anthriscus sylvestris*
*Anthyllis vulneraria*
*Arabis alpina*
*Arctium tomentosum*
*Arenaria serpyllifolia aggr.*
*Artemisia campestris*
*Astragalus alpinus*
*Atriplex patula*
*Bidens frondosa*
*Brachypodium pinnatum*
*Brachypodium sylvaticum*
*Brassica oleracea*
*Calamagrostis epigejos*
*Calamagrostis varia*
*Caltha palustris*
*Calystegia sepium*
*Campanula cochleariifolia*
*Capsella bursa-pastoris*
*Cardamine amara*
*Cardamine hirsuta*
*Cardamine pratensis*
*Cardamine resedifolia*
*Carduus acanthoides*
*Carduus defloratus*
*Carex acuta*
*Carex alba*
*Carex ornithopoda*
*Carex vesicaria*
*Carex vulpina*
*Cerastium arvense*
*Chaenorrhinum minus*
*Chaerophyllum hirsutum*
*Chelidonium majus*
*Chenopodium album*
*Chenopodium bonus-henricus*
*Cirsium arvense*
*Cirsium oleraceum*
*Cirsium vulgare*
*Clematis vitalba*
*Conyza canadensis*
*Cornus sanguinea*
*Corylus avellana*
*Crataegus laevigata*
*Crataegus monogyna*
*Crepis capillaris*
*Deschampsia cespitosa*
*Digitaria sanguinalis*
*Echinochloa crus-galli*
*Epilobium hirsutum*
*Equisetum arvense*
*Equisetum fluviatile*
*Equisetum ramosissimum*
*Erigeron acer*
*Erucastrum gallicum*
*Erucastrum nasturtiifolium*
*Erysimum cheiranthoides*
*Euonymus europaeus*
*Euphorbia cyparissias*
*Euphorbia peplus*
*Euphrasia salisburgensis*
*Eurhynchium striatum*
*Fallopia convolvulus*
*Festuca arundinacea*
*Festuca gigantea*
*Festuca rubra aggr.*
*Festuca rupicola*
*Filipendula ulmaria*
*Fragaria vesca*
*Frangula alnus*
*Fraxinus excelsior*
*Galeopsis tetrahit*
*Galium aparine*
*Galium palustre*
*Geranium pyrenaicum*
*Geranium robertianum*

**Class 3: Additional characteristic species (cont.)**

(Species which typically occur in floodplains (except those normally found in intensively managed grasslands), but which do not depend on riparian habitats)

*Geum rivale*
*Geum urbanum*
*Glechoma hederacea*
*Glyceria fluitans*
*Gypsophila repens*
*Helianthus annuus*
*Heracleum sphondylium*
*Hieracium intybaceum*
*Hylocomium splendens*
*Hypericum perforatum*
*Hypnum cupressiforme*
*Impatiens noli-tangere*
*Impatiens parviflora*
*Iris pseudacorus*
*Isatis tinctoria*
*Juniperus communis .*
*Lactuca serriola*
*Lamium album*
*Lamium purpureum*
*Leontodon hispidus .*
*Leontodon hispidus*
*Lepidium campestre*
*Leucanthemopsis alpina*
*Ligustrum vulgare*
*Plantago major*
*Linaria alpina*
*Lonicera xylosteum*
*Lotus corniculatus*
*Lycopersicon esculentum*
*Lysimachia nummularia*
*Lysimachia vulgaris*
*Lythrum salicaria*
*Malva neglecta*
*Matricaria recutita*
*Medicago lupulina*
*Melica nutans*
*Mentha aquatica*
*Mentha longifolia*
*Myosotis arvensis*
*Myosotis scorpioides*
*Myosoton aquaticum*
*Nasturtium officinale*
*Origanum vulgare*
*Oxalis fontana*
*Oxytropis campestris .*
*Papaver rhoeas*
*Pastinaca sativa .*
*Petasites paradoxus*
*Picea abies*
*Pinus sylvestris*
*Plagiomnium undulatum*
*Plantago major subsp. intermedia*
*Poa alpina*
*Poa angustifolia*
*Poa annua aggr.*
*Poa compressa*
*Poa glauca*
*Poa palustris*
*Polygonum amphibium*
*Polygonum aviculare*
*Polygonum mite*
*Polygonum persicaria*
*Populus nigra .*
*Portulaca oleracea .*
*Potentilla anserina*
*Prunus avium*
*Prunus padus .*
*Prunus spinosa*
*Quercus petraea*
*Quercus pubescens*
*Quercus robur*
*Racomitrium canescens*
*Ranunculus lingua*
*Raphanus raphanistrum*
*Reseda lutea*
*Rhamnus cathartica*
*Rhytidiadelphus triquetrus*
*Rorippa x*
*Rorippa islandica*
*Rorippa sylvestris*
*Rosa canina*
*Rubus caesius*
*Rumex acetosa*
*Rumex crispus*
*Rumex maritimus*
*Rumex scutatus*
*Sagina saginoides*
*Salix appendiculata*

**Class 3: Additional characteristic species (cont.)**

(Species which typically occur in floodplains (except those normally found in intensively managed grasslands), but which do not depend on riparian habitats)

*Sambucus nigra*
*Sanguisorba minor .*
*Saponaria ocymoides*
*Saponaria officinalis*
*Saxifraga aizoides*
*Saxifraga bryoides*
*Saxifraga oppositifolia*
*Scrophularia nodosa*
*Scrophularia umbrosa*
*Sempervivum arachnoideum*
*Senecio vulgaris*
*Setaria pumila*
*Setaria viridis*
*Silene dioica*
*Silene pratensis*
*Silene vulgaris .*
*Sinapis arvensis*
*Sisymbrium officinale*
*Solanum dulcamara*
*Solanum nigrum*
*Solidago gigantea*
*Sonchus asper*
*Sonchus oleraceus*
*Sorbus aria*
*Stachys sylvatica*
*Stellaria media*
*Stereocaulon alpinum*
*Symphytum officinale*
*Teucrium chamaedrys*
*Thuidium tamariscinum*
*Thymus praecox .*
*Thymus serpyllum aggr.*
*Tortella tortuosa*
*Trifolium pallescens*
*Trifolium saxatile*
*Tripleurospermum perforatum*
*Tussilago farfara*
*Urtica dioica*
*Valeriana montana*
*Valeriana officinalis*
*Verbascum densiflorum*
*Verbascum nigrum*
*Verbascum phlomoides*
*Verbascum thapsus .*
*Veronica anagallis-aquatica*
*Veronica beccabunga*
*Veronica bellidioides*
*Veronica chamaedrys*
*Veronica persica*
*Vicia cracca .*
*Viola tricolor*

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# Curriculum Vitae

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| | |
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