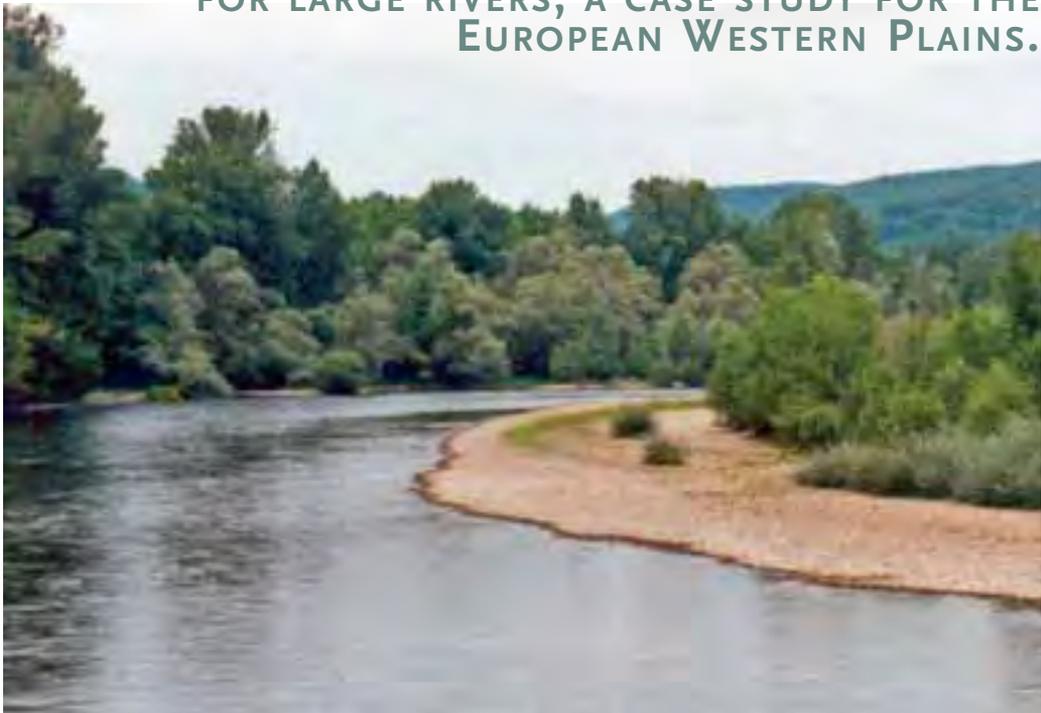


# V.1

## INCLUDING RIPARIAN VEGETATION IN THE DEFINITION OF MORPHOLOGICAL REFERENCE CONDITIONS FOR LARGE RIVERS; A CASE STUDY FOR THE EUROPEAN WESTERN PLAINS.



Kris Van Looy, Jean-Gabriel Wasson & Patrick Meire  
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Kris Van Looy<sup>1</sup>, Jean-Gabriel Wasson<sup>2</sup> & Patrick Meire<sup>3</sup>,

<sup>1</sup> Institute for Nature Conservation, Kliniekstraat 25, 1070 Brussels, phone: +32 2 558 18 59, fax +32 2 558 18 05 <http://www.instnat.be>

<sup>2</sup> CEMAGREF, UR Biologie des Ecosystèmes Aquatiques, Laboratoire d'Hydrécologie Quantitative - BP 220 – 69336 Lyon cedex 09 – FRANCE, phone: +33 4 72 20 87 99, fax: +33 4 78 47 78 75  
<http://www.lyon.cemagref.fr/bea/lhq/index.shtml> University of Antwerp, Department of Biology,

<sup>3</sup> Ecosystem Management Research Group, Universiteitsplein 1, BE-2610 Antwerpen (Wilrijk), phone: +32 3 820 22 64, Fax: +32 3 820 22 71, <http://www.ua.ac.be/ecobe>

## Abstract

Methods for defining and retrieving reference conditions for large rivers were explored with emphasis on hydromorphological and biological quality indicators.

Boundary conditions for riparian zone functioning were investigated for hydromorphological and riparian forests characteristics. Critical ranges for riparian forest area, for stages of riparian forest development and for sustainable populations of *Populus nigra* and *Salix purpurea* were determined in the search for useful measures from reference conditions.

After identification of reference conditions, a proposal for assessment and monitoring of the proposed indices is discussed for its applicability.

## Introduction

Human impacts alter the natural hydromorphological conditions in rivers. As hydro-morphology determines for a large part the ecological conditions, these pressures have severely altered the ecological status of rivers. The European Water Framework Directive (WFD, EC, 2000) demands a quantitative assessment of the ecological status and obliges the member States to achieve a “good ecological status” (or good ecological potential) of all waterbodies by 2015. The ecological status refers to “the quality of the structure and functioning of aquatic ecosystems” (WFD, art. 2). A good ecological status (or potential), is a “slight deviation” from type-specific reference conditions (or maximum potential). These reference conditions have to be derived for all types of water bodies and represent the values of the biological quality elements at “high status”, i.e. where “there are no, or only very minor, anthropogenic alterations of the physico-chemical and hydromorphological characteristics” (WFD, annex V, table 1.2). Reference conditions may be based either on historical or geographical comparisons or on modelling, or may be derived using a combination of these methods including historical data. Especially for larger rivers, defining reference conditions however, proves to be problematic. Historical data on structure and functioning of the freshwater ecosystem prior to degradation are often missing, and there are few, if any, modelling methods directly applicable to large rivers. This problem can be overcome through the identification of appropriate current reference sites as the guide. In selecting analogue

sites, the typology of the rivers must be carefully evaluated. Inherent differences among locations in geology, climate, position in the catchment, fluvial geomorphology, hydrology and biogeography must be considered (Pedroli et al. 2002, Palmer et al 2005).

Our research was tailored towards the definition of morphological reference conditions in western European large rivers. Among the hydromorphological parameters required by the WFD for the classification of ecological status, alongside of hydrological regime and river continuity, the “structure of the riparian zone” and the “river depth and width variation” are explicitly mentioned. The width-depth ratio is a good abiotic indicator of morphological alterations (Raudkivi, 1998), but the relationships between the magnitude of the changes in river geometry and the related biological impacts are poorly documented. On the other hand, riparian vegetation and especially riparian forests are yet documented as good integrative indicators for the hydromorphological conditions of large rivers, as was acknowledged in several international research programmes (Lefèvre et al. 2001, Hughes 2003). Riparian vegetation structure and dynamics not only respond to direct morphological alteration such as river channelization, but also to hydrological changes, especially the flood regime, and to the connectivity to alluvial aquifers (Décamps et al. 1988, Bornette & Amoros 1996, Girel & Manneville 1998, Grevilliot et al. 1999, Van Looy et al. 2003, Naiman et al. 2005), both parameters also required for the evaluation of hydromorphological conditions.

Starting point for this collaboration was the difficulty encountered in the definition of reference conditions for the heavily modified river Meuse. Human activities in the Meuse catchment’s area causing alterations in the hydromorphological conditions of the river system run back to the earliest cultivation of land. The river Meuse was also the artery of Europe’s mainland first industrial revolution. A chain of industrial and human settlements (larger towns) borders the river and the use of the river as major waterway goes back in time even much further to Roman times. As the historic reference condition of the river Meuse is hard to define and especially quantitative data mostly lacks for historic situations (Micha & Borlee 1989), references have to be searched elsewhere. For this purpose all large rivers of the European Western Plains ecoregion (as defined by the WFD) were screened for the presence of actual references for the river Meuse. The four large rivers of this

ecoregion draining the adjacent Western Highlands ecoregion, Meuse, Loire, Allier and Dordogne show comparable gravel reaches just downstream their Western Highlands stretches (Figure 5.1). They are rain-fed rivers with no annual snow melt discharge peaks in spring but exceptional peak flows with short duration (flash flows) in periods with high precipitation.

Through the case study dealing with these four western European large rivers, we tried to address the following issues : 1) how to select reference sites in large rivers on the basis of hydromorphology, 2) what riparian vegetation measures can be included in the reference conditions and more widely in the ecological status evaluation, and 3) how these measures relate to morphological alterations, evaluated especially by the width-depth ratio. Finally, by evaluating the minimum requirements for a sustainable riparian functioning, indicative values are proposed for the setting of “good ecological status” boundary conditions in large rivers.

## Defining criteria for Hydromorphological Reference Conditions in large rivers

According to the WFD (annex V), reference conditions shall represent the values of the biological quality elements at “high status”, i.e. where “there are no, or only very minor, anthropogenic alterations to the values of the physico-chemical and hydromorphological quality elements”. Reference conditions may be based on existing reference sites, or on modelling, or can be derived using a combination of these methods including historical data.

The REFCOND guidance (Wallin et al. 2003), resulting from a wide discussion among European experts, gives a consensual interpretation of the reference concept:

- “Reference conditions (RC) do not equate necessarily to totally undisturbed, pristine conditions. They include very minor disturbance which means that human pressure is allowed as long as there are no or only very minor ecological effects;
- RC equal high ecological status, i.e. no or only very minor evidence of disturbance for each of the general physico-chemical, hydromorphological and biological quality elements;

- RC can be a state in the present or in the past.”

This interpretation offers more realistic possibilities for defining a reference state, as it refers to the effective ecological impact of physical alterations; in this sense, both have to be evaluated simultaneously to assess a “very minor” ecological effect, i.e. hardly distinguishable from the natural variability of the system.

However, for rivers morphodynamics, it is difficult to refer to a particular “state”. Rivers are highly dynamic systems, primarily controlled by physical factors. Three key words could define the river ecosystem functioning: processes, dynamics, and reversibility. In a “healthy” river, functional processes (hydromorphological, biogeochemical, ecological) maintain a physical and biological dynamic state, which ensures the reversibility of the system after natural and anthropogenic disturbances. Stable systems are either a typological exception (like lake outlets), or the result of an anthropogenic regulation (Roche et al. 2005). In this sense, hydromorphological reference situations can be searched in reaches where the fundamental physical processes are not altered. Reference conditions can then be defined as the range of variability (spatial and temporal) of the observed physical and ecological structures. These RC are not fixed over time. Long term (> 100 years) morphological evolutions are observed due to natural climatic changes, and to land cover alterations. But if the connectivity is maintained, and the biodiversity conserved at the basin scale, the biocenosis will adapt itself permanently to a physical system in dynamic equilibrium (Roche et al. 2005).

To focus on the current possible causes of alteration of the fundamental processes, rather than to a past “state”, will help to define RC.

A “pristine” state, without any impact of human activities in the river basin, offers no perspectives in the definition of reference conditions for our western European rivers. However, we can define a “natural” state if we accept the assumption that, due to the intrinsic resilience of river systems, man can live in a basin without significantly degrading the river’s ecological functioning and biodiversity. Such a natural state will correspond to a “free” river, with very limited impact of artificial structures. Hydro-sedimentological, biogeochemical, ecological processes are still active, and only slightly altered by land use in the catchment; the morphodynamic processes and the connectivity with the floodplain are maintained, although sometimes spatially limited (Wasson, 1992). For many modified rivers, this natural state

refers to conditions before the large regulation activities of the 19th century.

We propose that criteria for reference thresholds of hydromorphological conditions in large rivers correspond to the beginning of the fundamental structures and processes alteration. This could be evaluated by looking both at the pressures acting at the basin and reach scales, and at the morphological responses at the reach scale. Criteria for the pressures could be:

- (1) at the basin scale, the regime and fluxes of water and sediments are not significantly altered by impoundments or land use, as compared with a natural vegetation cover.
- (2) at the reach scale, the fundamental morphodynamic processes are not significantly altered by artificial lateral constraints, and the river has the necessary “space of freedom” to maintain the possibility of a dynamic adjustment.

For the morphological features at the reach scale, the following criteria have to be met:

- (3) the morphological type correspond to what could be expected as result of a dynamic equilibrium in the present climatic conditions, owing that the condition (1) is fulfilled;
- (4) all the important side channel structures are still significantly present;
- (5) Lateral connectivity is maintained at the reach scale;
- (6) Type specific riparian ecosystems are still present in significant areas.

## **In search of a hydromorphological reference for the river Meuse.**

### **Studied sites**

In the Meuse catchment's area, human activities causing hydromorphological alterations run back to the earliest land cultivation, and the use of the river as major waterway goes back to Roman times. In more recent times, the River Meuse was the artery of Europe's mainland first industrial revolution. A chain

of industrial and human settlements including large towns borders the river. For the heavily altered studied reach of the Meuse river, historical quantitative data are lacking, and reference conditions have to be searched elsewhere. For this purpose, all large rivers of the European Western Plains (ecoregion 13 as defined by the WFD) were screened for the presence of actual reference sites for the River Meuse. Three river reaches in the ecoregion 13, draining like the Meuse the adjacent Western Highlands (ecoregion 8), were selected as possible reference situations as they exhibit more natural morphological features; these reaches belong to the rivers Loire, Allier and Dordogne (Figure 5.1).



Figure 5.1 Location of the studied river reaches in North-West Europe with the upstream catchments delineated on an altitude background.

The studied reaches of the four rivers were selected on the basis of the general morphological character of valley form, slope, discharge and sinuosity. The chosen stretches are located around kilometre 300-400 of the rivers. For the Meuse with its narrow upstream basin and large subcatchment of the Ardennes Massive drained by the middle part of the river, the studied downstream reach is around km 450 just downstream Maastricht. For the Dordogne coming from the 'Parc des volcans d'Auvergne' in the Massif Central, the stretch Souillac-Vitrac just before

kilometre 300 was chosen. For the Allier and Loire flowing northwards from the Massif Central, reaches around km 370 were chosen, between Châtel-de-Neuvre and Moulins for the Allier, and around Lamenay for the Loire.

### **Comparison of the sites typology**

In order to define hydromorphological reference conditions, we first had to ensure that these four reaches could be classified in the same morphological river type. For this purpose, we examined the geophysical and climatic characteristics of the basins, and the size, hydrological regime and morphological characteristics of the studied reaches.

The basin's characteristics are summarized in table 5.1. The altitude range is higher in the Loire, Allier and Dordogne rivers (300 – 1700m), flowing out from the French Massif Central, than in the Meuse (100 – 700m) coming from calcareous hills and then crossing the Ardennes massif. In the framework of the EU funded REBECCA project, an ongoing work for the definition of hydrocoregions allowed the characterisation of litho-morphological structures at the European scale; from these data we evaluated the percentage of each basin that could be classified as middle mountains, hills and plains, with the corresponding lithological features. All four basins are dominated by crystalline (granitic and metamorphic) rocks, but the proportion is lower in the Meuse basin (55%) than in the three others (> 80%). The rivers coming from the Massif Central have a large proportion (58% to 72%) of their basin classified as middle mountains, while the Meuse basin correspond to hilly landscapes (88%). The Meuse, Loire and Allier reaches are situated in clayed or phreatic alluvial plains, while the Dordogne alluvial valley entrenches a calcareous plateau. The climatic conditions are comparable in the four basins, with 800 to 1000 mm of annual rainfall.

Table 5.1 Upstream basin characteristics (altitude, lithology, precipitation from REBECCA data).

Altitude (m)	Meuse	Loire	Allier	Dordogne
min	20	190	215	89
max	687	1.631	1.726	1.756
<b>mean</b>	<b>273</b>	<b>568</b>	<b>711</b>	<b>666</b>
std	117	291	308	290
Litho-morphological regions	Meuse	Loire	Allier	Dordogne
Crystalline middle mountains		58%	65%	72%
Crystalline hills	55%	24%	19%	14%
Calcareous hills	33%	2%		14%
Calcareous tabular plains	4%			
Clayed plains	5%			
Phreatic alluvial plains	3%	16%	16%	
Precipitation (mm)	Meuse	Loire	Allier	Dordogne
min	744	715	701	893
max	1.201	906	1.058	1.049
<b>mean</b>	<b>992</b>	<b>797</b>	<b>820</b>	<b>954</b>
std	108	44	78	32

sources altitude: MNT KM USGS,

precipitation: Climatic Research Unit, university of East Anglia

At the reach scale (Table 5.2), upstream catchment was calculated from the upstream point of the selected reach. The catchment areas vary from 8700 km<sup>2</sup> for the Dordogne to 20200 km<sup>2</sup> for the Meuse. The hydrological regimes are similar (Figure 5.2), all four rivers are rain-fed without high snow melt discharge peaks in spring, but exceptional short duration peak flows are possible in high precipitation periods. Due to a larger basin area, winter discharges are higher in the Meuse. Floodplain width is the average of the natural floodplain area; for the Meuse the disconnection by winter dikes isolates large parts of this floodplain. The floodplain natural width, the wavelength and sinuosity lie in the same range.

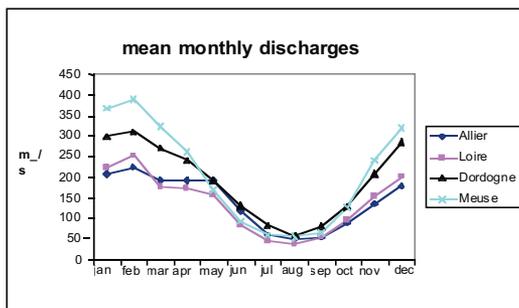


Figure 5.2 Hydrological regime at the reach scale.

Table 5.2 Hydrological and geomorphological characteristics of the selected reaches.

	Allier	Loire	Dordogne	Meuse
Length, distance from source (km)	336-368	370-402	280-306	450-485
Upstream catchment area (km <sup>2</sup> )	12400	14200	8700	20200
Floodplain width (m)	1400	1100	950	1250
Wavelength (m)	1850	2050	2100	1900
Sinuosity	1.39	1.24	1.27	1.35
Max. measured discharge (m <sup>3</sup> /s)	1200	2080	2300	3200
Mean annual maximum discharge (m <sup>3</sup> /s)	710	980	1100	1250
Mean annual minimum discharge (m <sup>3</sup> /s)	21	18	21	10
Mean annual discharge (m <sup>3</sup> /s)	120	140	170	170
Slope, elevation difference between stations at the start and end of the reach divided by river length	0.6	0.68	0.73	0.49
Width, average values (m) for the studied reaches over the bankfull sections	150	120	110	100
Depth, average values (m) for the studied reaches over the bankfull sections	4	5	5	7
Width-depth ratio, W/D	38	24	21.5	14.5
Bankfull discharge, Q <sub>bf</sub> (m <sup>3</sup> /s)	850	1100	1200	1600
Stream power, $\omega = \gamma \cdot Q_{bf} \cdot S$ (W/m) with $\gamma = \rho \cdot g = 6.25$ , Q <sub>bf</sub> = bankfull discharge and S = slope	3188	4675	5475	4900
Natural stream power, $\omega_n = \gamma \cdot Q_{an} \cdot S$ (W/m) with Q <sub>an</sub> the mean annual maximum discharge	2663	4165	5019	3828
Specific streampower, $\omega$ /width	21	37	50	49
Natural specific stream power, $\omega_n$ /width	18	35	46	38
Bed texture D <sub>50</sub> values in mm	4	7	12	35
Bar texture D <sub>50</sub> values in mm	1 - 5	1 - 5	5 - 10	1 - 25
Bank texture (in mm, 25-75percentiles)	0.5-1.4	0.3-1.1	0.3-0.9	0.1-1
Embankment (% of linear length)	2	11	14	90

Gauging stations Allier (Châtel-de-Neuvre) 1986-2002, Loire (Gilly-sur-Loire) 1955-2002, Dordogne (Souillac) 1973-2001, Meuse (Smeermaas) 1978-2002, (sources: ministère de l'écologie et du développement durable, données bassins ; Meuse, DIHO)

For the four reaches, river hydromorphological parameters are derived starting from the general bed geometry with the frequently used width-depth ratio, then integrating hydrometrics with the measure of bankfull discharge, and the derived 'streampower' measure, integrating the slope of the reach, and with a annual discharge measure a natural streampower measure, as the bankfull dis-

charge is severely altered by alterations. Even more geometry is integrated with the 'specific streampower', the streampower per unit of bed width. The measure of bankfull width varies strongly for meandering reaches. For the four stretches, the values ranged between: Allier 120-200, Loire 110-150, Dordogne 90-125, Meuse 80-120. Local hydromorphological conditions are entered with the bed substrate characteristics of bed and bar texture. Sediment substrate of bars shows  $D_{50}$ -ranges from 1-25mm for the surveyed Meuse bars, for the Allier and Loire values are between 1-5mm ( $D_{50}$ ), along the Dordogne there are also coarser sediment bars present ( $D_{50}$ : 5-10mm). Especially the Allier has a large fraction of sandy bed load, which is not washed out as quickly as in the narrowed channels of the other studied river stretches. Added to these river parameters, the human modifications in the form of embankments were recorded. The Allier reach is a nature reserve area (Reserve Val d'Allier) and bank protection is only present near civil works of bridges. For the Loire and the Dordogne, most meander bends are consolidated and local encroachments are present to protect infrastructure like campings. The Meuse is a highly normalised stretch.

The specific streampower is very high in the incised river reaches of the Meuse and the Dordogne. For the Dordogne, this high value is due to the stronger slope of the stretch. As the bankfull discharge is affected by this incision process, a 'natural streampower' measure was calculated with the mean annual discharge value. The bankfull discharge ( $Q_{bf}$ ) is estimated from field survey results and cross-sections of the river. Starting from the 2-year recurrent discharge peak, for the Allier but also for the Loire these values were lowered to the 1,5 year recurrent flows, as there is a frequent contact between the river and floodplain, and bed incision is not clearly present in the cross-sections. For the Meuse, the bankfull discharge is calibrated with the measurements over the reach. The strong bed incision (average 3-4 meter over the reach for the last 100 years) results in bankfull discharges corresponding to a less recurrent discharge (once in 3 years). For the Dordogne the river bed lies also deep in its valley floor and the 2-year peak discharge was retained as  $Q_{bf}$ .

So, natural streampower for the Meuse is lower than for the Loire, yet, actual streampower is higher. This can be observed in the high scouring for the Meuse river bed, with only coarse gravel remaining and forming an armoured layer ( $D_{50}$ : 35mm).

On the basis of their basin characteristics, we can infer that the rivers flowing out from the Massif Central (Allier, Loire, Dordogne) pertain to the same type, but the

litho-morphology of the Meuse basin is slightly different, with a lower altitude and less crystalline rocks, which could influence the river morpho-dynamics. All four reaches have similar size, hydrological regime and floodplain width, but we have to verify that their natural morphological type would be the same. This can be first inferred from the sinuosity (close to natural values for the Meuse main channel), which lies in the same range for the four reaches. From the comparison of the natural stream power and the bank's granulometry, where sand predominates (Table 5.2), we can also expect a similar potential river bed dynamic. However, the best evidence is given by historical maps (around 1800) of the Meuse and Loire reaches (Figure 5.3): both rivers had the same morphological features before large regulation activities took place. We can thus consider that the four reaches belong to the same morphological type.



Figure 5.3 Historical maps (1800) of the Meuse (left) and the Loire (right) stretches (upper 10km of the selected reaches) show the resembling hydromorphic conditions before the larger regulation activities took place.

## Identification of a potential reference reach

In this phase we have to look for the hydromorphological pressures and impacts, and screen for the criteria we've listed under par. 2. In table 5.3 the relation between the main hydromorphological pressures and impacts for the selected rivers, and the in this paper discussed measures for the hydromorphological conditions, are presented.

Table 5.3 Hydromorphological pressures and impacts emphasized in the paper.

	object	measure	specification
hydromorphological pressure	dams, weirs	flow variability, sediment granulometry	upstream pressure with possible downstream hydrological and morphological impact
	embankment	embankment%	local pressure with more or less local impact
hydromorphological impact	bankfull width	Q <sub>bf</sub>	encroachment of the channel
	depth	width-depth ratio	bed incision
landscape impact	riparian dynamics	riparian dynamics indicator	erosion-sedimentation zones
biological impact	riparian forest communities	riparian forest extent	area/river kilometre
	riparian forest recruitment	young forest stages	area/river kilometre
	target species	target species populations	# populations/river kilometre

The flow variability can be measured in a periodical variation of flow with a Coefficient of flow Variation,  $Q_t/Q_{t-1}$ , as defined by Growns & Growns (2001), or in a mirror of amplitude ranges as in the Range of Variability Approach (Richter et al.1996). Sediment granulometry is important in view of the meandering processes for the erodibility of riverbanks, emphasized to the bank granulometry, or can be regarded with respect to actual sedimentation and morphological character of the reach.

Impacts to bankfull dimensions are already described as caused by normalisations.

The riparian landscape dynamics for the four reaches, were related to the hydromorphological pressures measured in the embankment and the hydromorphological impacts in the most common used river parameters in the description of hydromorphological character: width-depth ratio, bankfull discharge ( $Q_{bf}$ ), streampower and specific streampower.

We can verify whether the Allier can be retained as reference reach, based on the criteria we've listed under par. 2. Although there are some weirs and impoundments in upstream sections, they do not significantly affect the flow regime or sedimentological character of the river at the studied reach. At this reach scale, morphodynamic processes are more or less natural for this meandering reach, there is no sign of normalisation or embankment impacts, no artificial levees are present and there is a large natural riparian corridor present. These observations can be supported with an aerial photograph of the studied Allier reach, contrasting to the heavily modified situation of the Common Meuse reach (Figure 5.4). The Allier can thus be proposed as potential reference reach.





Figure 5.4 Aerial photographs of the Allier and the Meuse study areas in the present situation (photographs 2003).

## Defining reference conditions and selecting measures for the biotic integrity of the river corridor's hydromorphological character

### Survey of riparian forest communities for the four reaches

Alluvial forests have virtually disappeared from most of the large river valleys of North-western Europe, making way for cultivated land and meadows. Large gravel bed rivers are edged by riparian formations of willow and poplar (*Salicion albae*), further in the floodplain replaced by elm and ash alluvial forests (*Ulmo-Fraxinetum*) and higher elevated grounds gradually develop oak forests (*Querceto-Ulmetum*). The riparian forests of *Salix* and *Populus* are designated priority habitat in Europe's Natura2000 conservation strategy (Habitats Directive, EC, 1992).

We distinguished 5 communities within the riparian softwood forests of the *Salicion albae* for these large gravel rivers (nomenclature follows Schnitzler 1997):

- *Salix purpurea* thicket or young *Populus nigra* formations.
- Willow thickets dominated by *Salix alba*.
- *Salici-populetum* forests.
- *Salicetum albo-fragilis*.
- Dry *populetum*s

Characteristic species in these communities are *Populus nigra* and *Salix purpurea*. These species play a key role in the morphological development of the riparian zone of large gravel rivers. The accretion of bars and islands depends on these species for their capacity to catch sand and hold the developing sediment zones (Hughes et al. 2001, Van Looy et al. 2005a). With their highlighted problems of gene flow and recruitment limitation (Imbert & Lefèvre 2003, Vanden Broek et al 2004), emphasis on these species and their populations and habitat potential is important in the scope of this study.

Stand conditions, population dynamics and genetics of these species are subject of many research programmes and networks have been installed to develop conservation strategies for these species and the ecosystems they belong to (Lefèvre et al. 2001, Guilloy-Froget et al. 2002). Successful conservation strategies for these species need to consider the current status of existing populations as well as the physical dynamics of the natural habitat formed by the river. For Black poplar a European conservation programme for this species has been installed and for the Meuse a reintroduction programme initiated (Vanden Broeck et al. 2004)

In the riparian forests of the Loire and Dordogne the presence of the exotic species Box alder (*Acer negundo* L.) is noteworthy. It is present in the riparian forests of the Loire and most common along the Dordogne, as it is remarkably widespread present along the rivers of the western part of this ecoregion. It is mostly restricted to the *Salicetum alba* communities, although it can also develop monospecific stands at intermediate levels between the *Salicion* softwoods and the hardwood forests.

### *Survey and Analysis*

Field mapping of land use and vegetation type was carried out on a topographic map basis. In a preliminary step the boundaries of the floodplain were derived from a topographic map survey and checked in the field. They coincide with the regularly (once every 10 year) flooded valley floor; irregularly flooded areas in extreme peak events are not included in this analysis.

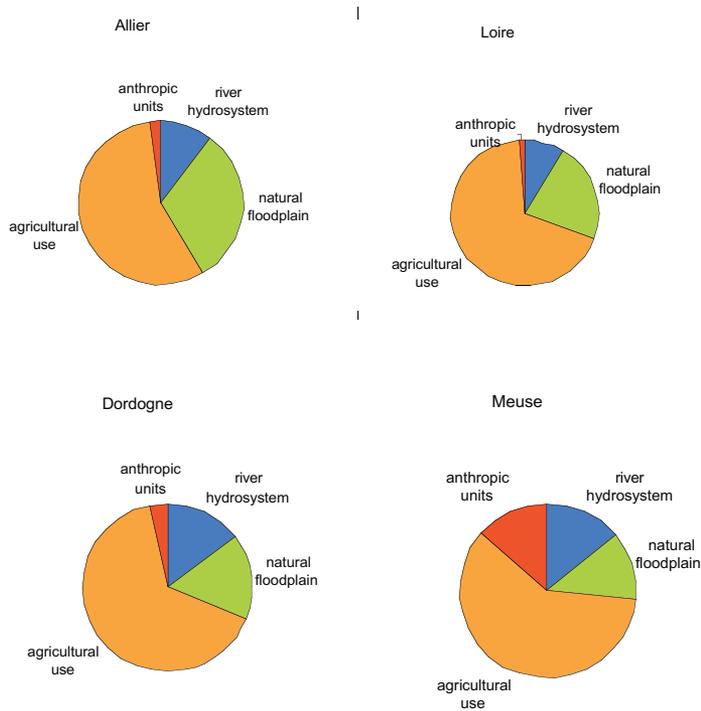
The field work consisted in the verification of land cover units as they were present in the topographic map. The natural areas of the floodplain and riverbed were mapped for vegetation units. As this mapping was to a more detailed level (patches of minimum 500m<sup>2</sup>), the field survey took around 2 weeks for every stretch. For the Meuse the mapping was executed in the summer of 2000, for the Dordogne in 2001. The maps of the Loire and Allier were derived from the project 'Information system on the evolution of the river bed of the river Loire and its tributaries' (SIEL). Within this project a vegetation map was elaborated for the whole river Loire and Allier. Vegetation mapping of the floodplain and river bed of the river Allier and Loire was done in 2000 and 2001 (by the group Mosaïque Environnement, finalised Allier 26/9/2001, Loire 7/11/2001).

Data of the field survey was gathered in spread sheet tables for the 4 stretches. For each patch, the land use, vegetation type and GIS calculated area and perimeter were retained for the analysis.

In a first phase, differences in the riparian landscape for the different stretches were screened, further detailed in the selection of riparian forest patch frequencies and areas. To derive comparable measures of forest development, the riparian forest variables were divided by the stretches length to have a value per running river kilometre.

In the second phase, the river variables for the four stretches were analysed. The hydromorphological pressure parameters and the responses in physical variables and landscape characteristics were compared over the reaches. Finally, the selected river and riparian landscape dynamics measures were related to measures for the riparian forest development, to give indications for the necessary river freedom for viable riparian forest communities. All marked correlations are Spearman correlation test results, obtained in Statistica.

## Reference conditions and measures for the riparian landscape and biological integrity



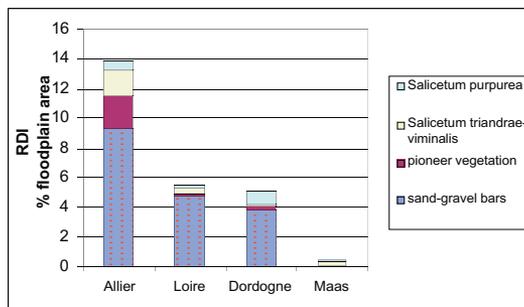
**Figure 5.5** Land use of the river-floodplain system for the four studied reaches, classified in 4 categories.

The land use and vegetation survey results, presented in the charts of figure 5.5 (and appendix tables S5), allow a general description and comparison of the land use in the river corridor for the reaches. The Allier reach has more than 31% natural floodplain, the Loire 22%, the Dordogne 16% and the Meuse only counts 12%. For the near-natural river Allier, the natural river dynamics result in large proportions of river bed area with young forest stages and higher rate of *Salicetum* forest compared to the Loire. Of the Allier's higher floodplain, large parts are in intensive agricultural use. In the Loire valley, as a consequence of the regulation activities (banning of meander and channel migration) more hardwood forests and a large fraction of floodplain meadows (38%) in agricultural use as hayfields are present.

The Dordogne shows a further decrease in natural area, but still has a well developed riparian forest corridor, whereas most of the floodplain is intensively cultivated. Along the Meuse this corridor is absent as a consequence of the total embankment of the reach. The higher rates of running water for the Dordogne and the Meuse are explained by the narrower floodplains, caused by the disruption of parts of the floodplain area by the construction of dikes and for the Dordogne also partly due to the more mountainous/hilly surroundings (see table 5.1).

#### *A measure for riparian landscape dynamics*

Riparian landscape dynamics were measured in the rate of open sand, young forest stages of *Salicetum purpurea* and *Salicetum triandrae-viminalis* and pioneer vegetation that colonizes the open sediments (Figure 5.6, see also Appendix tables S5). The totals of these categories as percentages of the total floodplain show the dynamics of the riparian landscape for the different reaches. As we can show for the proposed measure the correspondence to the derived measures for hydromorphological pressure (embankment) and physical response (width-depth ratio), we propose this measure as indicator and call it the Riparian Dynamics Indicator (RDI).



**Figure 5.6** Riparian Dynamics Indicator values for the four reaches, composed of survey units in percentage of the river-floodplain system.

The width-depth ratio correlates ( $r^2: 0.99$ ,  $p: 0.01$ ) with the riparian landscape dynamics (Figure 5.7d). A less strong correspondence was present with embankment (Figure 5.7a), showing the same grouping for the reaches. For this latter trend an exponential curve fits the data better. This gives an indication of the strong impact embankments can generate, even if they only represent some 10% of the bank length. With just the encroachment/consolidation of some meander

bends, which is the case for the Loire and the Dordogne, the river's hydromorphological functioning is highly impacted. The strong responses of the riparian zone can be explained by the changed sedimentological conditions following altered flow conditions and the river incision trend. The linear response of the width-depth ratio offers better opportunities to be used as an indicator for a gradual impact assessment.

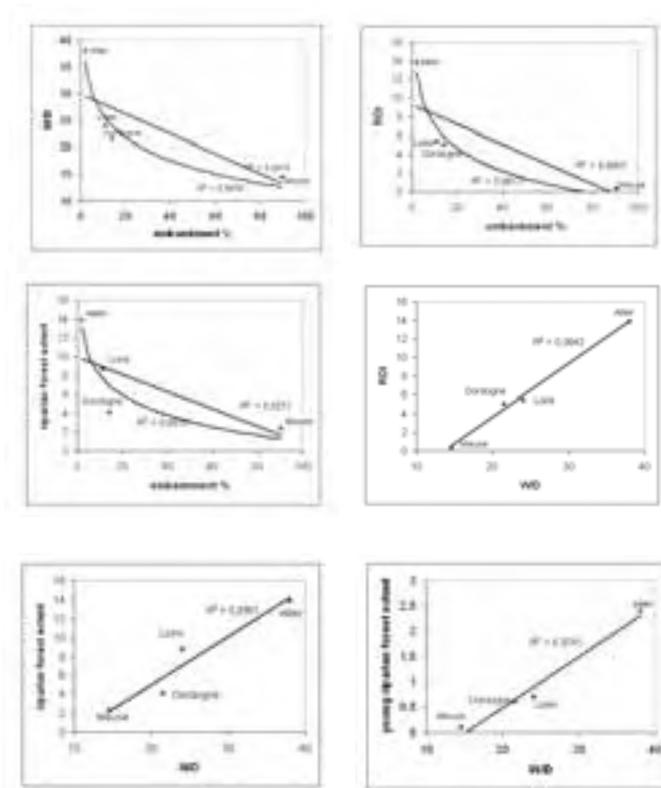


Figure 5.7a–f: Indicators for river hydromorphological alterations: width-depth ratio (a), RDI (b) and riparian forest extent (c) responses to embankment, and the correspondence between the physical geometry (W/D) and landscape (RDI, d) and biotic system (riparian forest e, f) responses are plotted. Linear regression functions with  $R^2$  for Pearson correlation testing are added, for embankment an exponential function is also shown.

### *Biological quality measures*

With the width-depth ratio and RDI as measures for the river freedom and the responses to the hydromorphological pressures, we looked for the best riparian forest development indicator (area, frequency, perimeter, perimeter/area). Area and frequency showed a correlation to the width-depth ratio ( $r: 0,99$ ,  $p: 0,013$  and  $r: 0,95$ ,  $p: 0,049$  respectively), perimeter and perimeter/area ratios are not correlated. Especially the estimates of riparian forest area (area per riverkm stretch) for mature (Ripfor) and young phase (RipforY) show good correspondences (Figure 5.7e-f).

The perimeter/area ratio (especially for the young river forest stages) varies also with the dynamics of the river reach, but not significantly (appendix tables S5). With the high dynamics of the Allier, many thin stretches of riparian formations are present. Along the Dordogne and Loire, the riparian stretches of forest are responsible for the high perimeter values, in the floodplains perimeter/area ratios for forest patches decrease strongly, especially in the cultivated Dordogne reach. For the highly fragmented Common Meuse reach, natural patch forms are rare.

The young stages of these gravel river riparian forests (Figure 5.7f) show the high recruitment potential for the Allier. Loire and Dordogne are close to each other in this diagram, which is more conform to the observed trend in hydromorphological conditions (Figure 5.7d). Where for the Loire the recruitment is a little bit less, there is still a large amount of adult poplar forest guaranteeing the survival for the species.

### *Boundary conditions*

The bending point in the embankment curve was above mentioned to correspond to the value of 10% embankment, as critical level for impacts of this hydromorphological pressure. This value corresponds to width-depth ratio 25 and riparian dynamics RDI 8, and for the riparian forest measures Ripfor 6 and RipforY 0,6. This value we retain as boundary condition for a good status, and with the corresponding measures for forest development, we can try to derive riparian forest metrics as ecological quality ratios.

From the near-natural Allier to the heavily modified Common Meuse, with intermediate positions for Loire and Dordogne, the gradual deviation with regard to the little disturbed reference condition is highlighted in the correlation between river freedom, landscape dynamics and the biotic measures of riparian forest area/fre-

quency. It is present in hydromorphological and natural processes of sedimentation and forest development as well as in species. On the species level the presence of the exotic species Box alder (*Acer negundo*) is of increasing importance in the riparian forests of the Loire and Dordogne. In the near-natural riparian conditions of the Allier, this exotic invading species remains absent. This observation confirms the general rule of invading species taking profit of altered and deteriorated system conditions. High levels of alien species were moreover recorded for the Garonne basin in riparian zones with increased human disturbance, increased habitat fragmentation and a greater departure from natural hydrological patterns (Décamps et al. 1988; Planty-Tabacchi et al. 1996). For the indigenous characteristic species of these communities, the situation is the opposite. Strongest populations of *Salix purpurea* and *Populus nigra* are present along the Allier, whereas both species have become almost extinct along the Meuse.

From our analysis, measures and boundary conditions for viable populations and habitat networks for the species can be derived. The presence of a sufficient number of habitat patches is necessary for these species, as recruitment limitation in combination with observed gene flow was recorded their principal threat along gravel rivers (Barsoum 2001, Imbert & Lefèvre 2003, Van Looy et al. 2005a). Along the Allier there is no limitation what so ever, forest patches of all size and age classes are present. This situation is qualified as reference condition. For the Loire and Dordogne situations become more critical. The Loire shows quite a large area of adult riparian forests, but a strongly deviating share of younger stages. The Dordogne comes close to the Meuse for its riparian forest extent, yet, for the Dordogne a minor but still viable population is present, which is indicated by the strong recruitment.

When we determine the rate of the recruitment that survives in the further development, we can determine this critical level. For the Common Meuse, we determined only 10% survival of young phases (Van Looy et al. 2005a), occurring in locations with favourable hydromorphological conditions of width-depth ratio  $> 25$  and morphological activity corresponding to local RDI  $> 8$ . For the Loire and Dordogne, only 30% of the young phases was present in locations with these criteria. For the Allier 70% of the young phases is in favourable locations for developing mature riparian forest. For the Loire and the Dordogne, with only 0,6 ha/rkm young forest of which some 70% is expected to fall off,

only 0,2 ha/rkm effective regeneration is to be expected. This is surely a critical level and as the recruitment limitation was previously recorded, the measure of the young forest stage can be selected as the most relevant.

Aim of the study was to identify biological measures with potential use as ecological quality ratio. Therefore, from the presented results, measures can be tested for their significance. Proposed measures are: 1) Riparian forest extent (Ripfor) in overall area of riparian forest types/river kilometre (as we concluded for the Allier riparian forest to be high status of development, with a value of 13.9, we can derive an Ecological Quality Ratio score by dividing with 15), 2) Young forest stages (RipforY) in area of young riparian forest stages per river kilometre (values x 4), 3) Target species measure (RipforT) in number of populations (patches) of Popnigra + Salpurp per river kilometre.

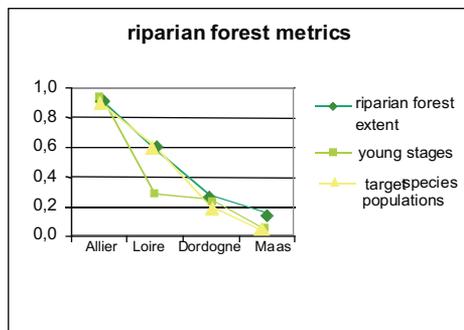


Figure 5.8 Riparian forest metrics derived from the observed biological measures of forest extent of young and mature riparian forest and the patch frequency of target species.

The young stages measure does not show a linear decrease as the other two (Figure 5.8), but the trend conforms more to the other hydromorphological variables for riparian quality we introduced (see Figure 5.7def) - the riparian land use dynamics (RDI) and the width-depth ratio (W/D). As indicator for hydromorphological integrity we propose the young riparian forest stages measure. Young stages and target species' populations attain really low levels in the Meuse reach. This is obvious for a highly regulated reach as we try to identify an indicator for the hydromorphological quality.

## Discussion

### Reference conditions for hydromorphological and biological aspects of large rivers

The terms ‘minor evidence of disturbance’ and ‘acceptable pressure’ have to be applicable for the reference and for the biological quality element at high ecological status. For large regulated rivers like the Meuse, the definition of reference conditions in terms of specific hydromorphological and biological elements is problematic due to a lack of historic data and insufficient knowledge of species-environment relationships. So, important necessary information lacks to define measures for effective ecosystem restoration. The defining of reference conditions can also be based on data of actual references. But actual references for large rivers are also problematic as in the same river basin large river types are unique and between river basins biogeographical differences appear. To what extent river references for large ecoregions can be pointed out and reference conditions derived is an ongoing discussion (Warry & Hanau 1993, Giller 2005). In this paper we tried to follow existing guidance documents to define reference conditions for large rivers. Emphasis was on the relationship between biological elements and the hydromorphological conditions. For specific river types over large geographical areas the best responding groups to the main pressures have to be identified, as different taxonomic groups show different responses to environmental changes and pressures (Heino et al. 2005); riparian forests are in this respect already documented as a key community for the evaluation of hydromorphological alterations in large rivers (Naiman et al 1993, Naiman et al. 1997, Deiller et al 2001, Hughes 2003). However, a hydromorphological assessment is in the WFD only explicitly required for the classification of “high status” and the definition of reference conditions. But we assume that for large rivers, riparian vegetation is an essential component of the “ecosystem structure and functioning” and thus could be included as well in the ecological status evaluation (Gregory et al. 1991, Naiman & Décamps 1997).

We screened four rivers in the same ecoregion, with the little perturbed Allier as candidate reference situation, and the heavily modified Common Meuse at the other extreme. The riparian vegetation we specified in riparian forest types, with qualifying critical species *Populus nigra* and *Salix purpurea*. Furthermore we detected temporal sequences of forest development, since the recruitment

and settlement of young stages are important aspects with regard to hydromorphological conditions (Schnitzler 1997, Splunder 1998, Van Looy et al. 2005a). As we disposed over a wide range of relevant data for the four selected river reaches, the analysis gave a satisfactory result for pressure responses in measures of landscape and hydromorphological dynamics and in relation to biotic communities, of riparian forest in this case. So, as the Allier showed minimal evidence of disturbance over the investigated parameters, generally we can conclude that the Allier can be used as reference and provides data on reference conditions.

The gradient of disturbance/human alterations to the hydromorphological characteristics over the selected reaches, is clearly measured in the width-depth ratio. The normalisations and embankments of large rivers resulted in incision of the bed (Piégay et al. 2005). The changed channel geometry, for which the width-depth ratio is generally acknowledged as a good descriptor (Raudkivi, 1998), leads to altered hydromorphological conditions. The introduced riparian dynamics indicator (RDI) marks this pressure gradient very well, and conforms to other proposed descriptors for reference conditions of dynamic river reaches (Ward et al. 1999, Middelkoop et al. 2005). The RDI gives a good estimation of the morphological active riparian zone. Including the newly vegetated sediments in this measure is necessitated from practical viewpoint; if we want to use remote sensing data, gathered in late summer as this is the best period for low flow regime, then the sediment zones are covered with ephemeral pioneer vegetation and young tree seedlings. Furthermore the young pioneer vegetation and especially the young riparian forests play an important role in the hydromorphological activity (Hughes et al. 2001, Baptist et al. 2005), in the way that they not only hold substrates, they also induce and promote local sedimentation. As it is a landscape indicator, it bridges the distance between the physical and biological impact of hydromorphological pressures.

The ecological status with regard to hydromorphological conditions proved in our study well-assessed with the riparian forest measures of forest extent for mature and for the young forest stages. As the riparian forests are closely related to the hydromorphological processes of bar and island formation, they are good indicators for the hydromorphological conditions of large gravel rivers (Kollman et al. 1999, Tabacchi et al. 2000, Hughes et al. 2001). The forest area proved the best indicator and gave a good measure (ha/rkm) for riparian forest and its young

phases. Same as Turner et al. (2004), we found patch attributes and edges no strong predictors for riparian forest development.

From the boundary condition analysis, it is clear that not the actual forest extent, but rather the rate of river freedom and riparian dynamics is the critical boundary condition. As we defined a riparian dynamics indicator, the critical boundary condition for riparian forest development is best measured in the RDI value 8. We can also refer to the erodible corridor concept to stress the need for allowing a minimum of riparian dynamics to obtain viable riparian forest communities (Piégay et al. 2005). The aerial photograph of the Allier (Figure 5.4) shows very well what is measured in the RDI.

Where we detected gradual and linear relations between hydromorphological and biological quality indicators, it was the analysis of the target species that revealed the critical boundary conditions.

These conditions nevertheless are best measured in physical variables (Radwell & Kwak 2005).

We can further refer to the correlated river parameter of width-depth ratio, in order to try to derive guidelines for the necessary freedom of the river for the development of riparian forests. Here we find a measure of 25 for the width-depth ratio corresponding to a sufficient riparian dynamics and a sustainable recruitment level, as is present for riparian forest and especially the young riparian forest stage along the Dordogne (Figure 5.7f). This conforms to other studies for reference conditions for the Common Meuse (Van Looy et al. 2005b).

### **Monitoring proposal**

From this research of indicators of hydromorphological and biological quality, we can conclude that the measurement of riparian forest can be restricted to the riparian strip, and so avoiding the difficulty in identification of floodplain borders and the distinction of forest types. The here defined criteria and measures might be useful to derive metrics for the WFD ecological quality assessment, as they showed responses over the whole pressure gradient. Since we only looked at four rivers we could not integrate a statistically relevant set of data to define ecological class boundaries, more data on rivers of this type is

necessary to develop WFD proof metrics. Still this kind of metrics offers good perspectives for the integration of hydromorphological and biological responses to human alterations.

A monitoring protocol can be proposed to prove the feasibility and utility of this quality assessment. The derived measures of riparian forest extent, can be measured from remote sensing data (satellite imagery or aerial photography) and simple telemetric techniques. Especially the patch areas can be easily detected with aerial/satellite images. The defined measures (RDI, Ripfor, RipforY) can be derived from an analysis of a digitally delineated riparian corridor. A 50m strip on both sides of the bankfull main channel is proposed in the guidance (CEN 2003). If more detailed information on composition and species populations is required, this needs further control with a field survey. This information can be demanded to evaluate the habitat conservation status for the Habitat Directive (EC 1992), as most of these reaches and their riparian forests are designated protection areas in the Pan-European NATURA2000 network.

In a wider riparian buffer of 5-10x bankfull width, the hydromorphological and biological assessment can be restricted to a screening of larger changes in landscape structures and patterns. These relevant structures could be patches of forest or floodplain channels/oxbow lakes with a frequent survey of changes in shape and detection of signs of erosion-sedimentation processes. With a 6-10 year recurrence period for the survey of a 10 km river stretch, a practical and little expensive evaluation method for this large river type's hydromorphological and riparian vegetation quality can be installed.

## Conclusion

A complete understanding of the ecological ramification of river regulation lacks the fundamental knowledge of the complexity and dynamics of intact river systems (Ward et al. 1999). This observation marks the starting point of this research for reference conditions for hydromorphological quality. We first set the picture of hydromorphological modifications and ecological quality referring to the European Water Framework Directive. The gathered hydrological and geomorphological data for the set of four large gravel rivers present in the same ecoregion, together with some information on the alterations during the last centuries, allowed the selection of comparable reaches and the determination of a reference system and reference conditions for the hydromorphological character. The reach of the River Allier proved a good reference and reference conditions were successfully derived for large gravel rivers of Europe's Western Plains ecoregion. For the hydromorphological reference conditions the width-depth ratio proved the best indicator. The embankment gave important indications to the pressure-impact responses of the large rivers, as we revealed a non-linear, exponential response to this pressure.

The analysis of the biotic community of riparian forests, which correlated significantly to these hydromorphological conditions, resulted in a set of quantitative measures for the reference condition and a monitoring proposal. The measures we derived from the riparian forest analysis showed clear responses to hydromorphological pressures (indicated by embankment and width-depth ratio). The target species analysis showed the critical boundaries and as the set of four rivers spanned the whole range from high to bad ecological status, a measure could be derived applicable for assessment and monitoring purposes in the WFD implementation. The derived measures further allow the evaluation of restoration programmes and conservation efforts for large rivers.

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