RESTORATION OF FLUVIAL DYNAMICS IN LARGE RIVERS: BENCHMARKING AND RESTORATION TARGETS

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Within the context of large European river-floodplain systems, this study presents a methodology for the identification of benchmarks and current biogeomorphic deficits, as the basis for the proposal of process-oriented restoration targets. Trajectories of change in space and time of the interactions between morphodynamics and vegetation at segment level have been analysed in the Upper Rhine River (Germany and France) and the Middle Ebro River (Spain). Results indicate similarities between them, with balances of progression and regression processes in the benchmark periods, and deficits such as loss of rejuvenation processes whose recovery must be the objective of restoration. A sustainable view on river management and restoration should aim at more resilient riverine systems, capable of balancing societal needs and natural processes, especially in the context of climate change adaptation.

1 INTRODUCTION

Although large river-floodplain systems are potentially highly diversified environments worldwide, the degree of disconnection that most of them present has greatly diminished the natural interactive processes that structure the riverine landscape [1]. From the biogeomorphologic perspective adopted in the present work, fluvial dynamics are associated with interactions in space and time between hydromorphological processes and vegetation [2].

Analysis of multitemporal river-floodplain processes is a key tool for the identification of near-natural situations (benchmarks), which for large rivers can be associated with periods of low human pressure, and in turn for the detection of those deviations from benchmarks (deficits) that are occurring at the present time. This analysis can be the base for the selection of a sustainable process-oriented restoration target, aimed at promoting the self-adjustment of riverine ecosystems with minimal intervention [3].

The present study aims at answering the following questions: (i) how can processes be compared in two large rivers in terms of historical benchmark and current situation?; (ii) are there similarities in their biogeomorphic deficits?; (iii) based on those deviations, what type of restoration target can be selected for each one?; (iv) is it possible to apply the same methodology to other large rivers?

2 METHODS

2.1 Study sites

The study site in the Upper Rhine River is a free-flowing gravel-bed river segment located downstream from Iffezheim dam (border between France and Germany). Originally an example of transition braided-meandering section, it was channelized in the first half of the 1840's into a single channel. Currently it is declared as Heavily Modified and it is delimited by rip-raps and levees. Most of the study area is part of nature reserves, both in the German (Rastatter Rheinauen) and French (Delta de la Sauer) sides.

The study site in the Middle Ebro River is a free-flowing gravel-bed river segment located downstream from the town of Castejón (Spain). It is a naturally meandering section but the concave banks are fixed with rip-rap and levees of up to 3 m high that have suppressed channel mobility. The study area encompasses groves that are protected under regional laws as nature reserves and natural beauty spots, but they appear isolated, with no longitudinal continuity.

Both river segments have been selected due to their potentiality for adopting process-based restoration measures, based on their natural, although disconnected and aged, biodiversity, and their still valuable hydrological dynamics, thus offering a good potential for process-based river restoration [4].

Table 1. Main characteristics of the study sites in the Upper Rhine and Middle Ebro Rivers.

	Upper Rhine	**Middle Ebro**
Study area (ha)	2,571.6	1,016.7
Segment length (km)	10.2	10.4
Channel slope (m m^{-1})	0.0004	0.0003
Mean discharge (m^3/s)	1,257	230.7
Catchment area (km^2)	48,276	25,194
River type (original)	Transition braided-meandering	Meandering
River type (current)	Straightened (Heavily modified)	Meandering
Flow regime	Alpine	Mediterranean

2.2 Multi-temporal analysis of fluvial processes

For the two study sites, we selected historical periods associated to a near-natural condition (benchmark) and to the current situation, i.e. after the most recent hydromorphological impact. Therefore, for the Upper Rhine River the benchmark period was established until 1840’s (before the channelization), and the current situation later than 1980 (after the construction of the Iffezheim dam). For the Middle Ebro River, the benchmark period was determined until 1947 (before the operation of the Ebro reservoir) and the current situation later than 2002 (after the operation of the Itoiz reservoir).

Ecotope maps were created for the selected historical periods with available maps and aerial images, by identifying natural habitats (water, gravel/sand bar, grassland, shrubland, forest) and anthropic elements (cropland, forest plantation, settlement, gravel pit, industry, linear infrastructure). Then the ecotope maps were intersected in order to determine the main trajectories of change, based on the methodology by Díaz-Redondo *et al.* [4]: changeless (areas that show no change), progression (growth towards the development of floodplain forests), regression (involve re-setting of floodplain habitats) and anthropization (exclusively human-induced changes).

3 RESULTS

3.1 Diachronic analysis of benchmarks and biogeomorphic deficits

For both the Upper Rhine and the Middle Ebro Rivers, the benchmark periods present a near balance between progression and regression areas, with a slight dominance of progression (Figure 1). However, the Middle Ebro already showed a high percentage of total area with anthropization processes, corresponding to cultivation in the floodplain. When analysing the current situation against the benchmark period, we can identify that regression processes are almost non-existent and that there is a growth in changeless areas for both rivers, increase that it is especially significant in the Middle Ebro River.

The analysis of changeless areas shows that, for the Upper Rhine, natural habitats are predominant both in the benchmark period and in the current situation. It is necessary to highlight the presence of other anthropic elements (settlements, industry, gravel pits), and the predominance of stable forest areas in the current situation. In the Middle Ebro River, changeless areas are mainly croplands in both the benchmark and the current situation. Similar to the Upper Rhine, the proportion of forest has also increased in the current situation.

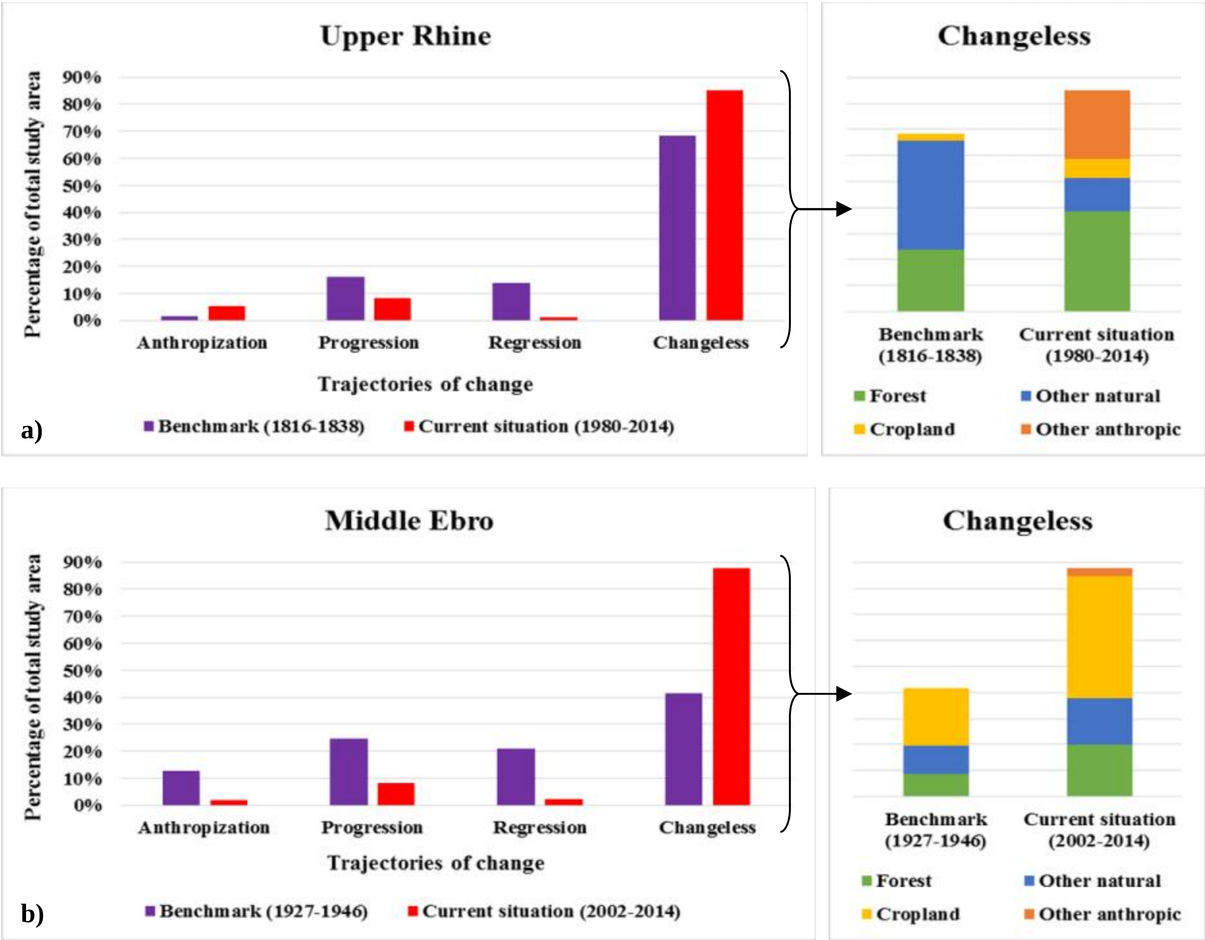

Figure 1. Left, percentages of total study area corresponding to trajectories of change in the benchmark and current situation periods for (a) the Upper Rhine River and (b) the Middle Ebro River. Right, the distribution of habitat percentages within the changeless area.

3.2 Restoration targets

Once the current deficits are identified, it is necessary to check the existing boundary conditions for both riverine systems. In the case of the Upper Rhine, the main limitation would be focused on allowing current navigation activities, whereas, in the case of the Middle Ebro, that would be the condition of not increasing flood risk in downstream populations. Therefore and, after reviewing literature and restoration projects in other European large rivers [5], the proposed restoration target for these large river segments are mainly directed towards the promotion of regression dynamics (lateral channel mobility by bank erosion and channel declogging; riverbank vegetation regeneration). Besides, while regaining lateral hydrological connectivity, the study area will also increase its water storage capacity (Table 2).

Table 2. Process-based restoration objectives and measures for the Upper Rhine and the Middle Ebro segments.

Process-based restoration objectives for both river segments	
• Increase erosion processes and allow for rejuvenation of habitats	
• Improve riparian vegetation composition and structure by disruption and regeneration of mature stages	
• Enhance lateral hydrological connectivity between the river channel and its floodplain (additionally increasing floodplain's natural water retention capacity)	
Measures for the Upper Rhine River	**Measures for the Middle Ebro River**
• Partial rip-rap removal	• Partial levee opening
• Widening of side arms	• Total levee removal
• Construction of connecting structures between side arms	• Partial rip-rap removal
• Artificial excavation of fine sediments in side channels	• Reactivation of disconnected side channels

4 DISCUSSION AND CONCLUSIONS

Most large rivers present different degrees of disconnection with their formerly considerable floodplains and, thus, their biogeomorphic processes are greatly impaired. When planning river restoration measures, the crucial starting point is investigating how a river-floodplain system deviates from the natural state or benchmark. However, the analysis of benchmarks based on natural processes evolution is almost non-existent for large rivers. With the aim of comparing near-natural conditions (benchmarks) and current situation alterations (deficits), a multi-temporal analysis of habitat structure and river-floodplain dynamics has been undertaken in the Upper Rhine River downstream from Iffezheim dam (border France-Germany) and in the Middle Ebro River downstream from Castejón (Spain).

Our study has proved similarities for both river segments in the selected benchmark period, where comparable ratios of progression and regression can be associated with a balance between habitat destruction and creation forces in a very dynamic system [6]. However, the current situation is marked by the disappearance of regression processes and a great stability in both riverine systems, especially in terms of forest area for the Upper Rhine, and cropland area for the Middle Ebro. These two river segments are good examples of the situation of many large rivers, whose floodplains still keep a proportion of high natural biodiversity but where natural rejuvenating processes are almost absent and succession dominates.

The returning to a pre-disturbance state appears unrealistic and the recovery of, at least partially, some of those natural processes is, by all means, a great challenge. Potential sustainable restoration targets must balance partial rehabilitation of riverine dynamics with the limitations posed by current human uses. Hence, we propose a similar restoration target that revolves around enhancing rejuvenation processes and lateral water connectivity. Nonetheless, measures integrating that target are different for the Upper Rhine and the Middle Ebro. The partial removal of rip-rap in the main channel and widening of side channels in the former allow for a possible re-connection of existing lateral arms, remnants of past braiding characteristics. As for the latter, the removal of structures in the main channel are intended to promote concave bank erosion and consequent channel mobility typical of meandering systems. All these measures fit within the scope of three relevant EU Directives: the Water Framework Directive, the Floods Directive and the Habitats Directive. Moreover, when a large fluvial system recovers part of its lateral connectivity, mobility and regeneration mechanisms, it also regains resilience to future perturbations, such as climate change.

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