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Analysis of hydromorphological and vegetation dynamics for the study of the reference condition and the ecological deficit of a large river-floodplain system: Upper Rhine River

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Abstract

Analysis of river-floodplain processes is a key tool for the establishment of reference conditions in large modified rivers and the basis of process-based river restoration. Since most large rivers lack pristine reaches, there is a need for the study of historical situations prior to major impacts in the river system.

Therefore, in order to comprehend the reference condition and the current ecological deficit in a section of the Upper Rhine River, trajectories of habitat change (hydromorphological and vegetation dynamics) are identified for different time intervals, by analysing changeless, regression and progression patches.

The results identify key processes of the river-floodplain system of this Upper Rhine river section that are now lost and whose recovery should be the objective of future process-based restoration measures.

Keywords: Upper Rhine, reference condition, connectivity, habitat structure, processes

Introduction, scope and main objectives

When planning river restoration/rehabilitation measures, the crucial starting point is investigating how a river-floodplain system deviates from the natural state or "reference condition" (Geerling *et al.* 2006). Thus, reference conditions in the frame of heavily modified rivers are those associated with no or very low human pressure, but not necessarily "pristine" states (WFD CISWG 2, 2003). From this concept, the ecological deficit can be described as the deviation from reference conditions (based on Muhar *et al.* 2007).

The recent tendency in scientific research for the selection of reference conditions is based both on: historical data relating to the studied river system, and/or information from rivers of a similar nature (Hohensinner *et al.* 2004; Buijse *et al.*, 2005).

Regarding the former approach, historical analyses of the studied river system can produce valuable reference data for reconstructing the character of the riverine system prior to river engineering works as well as its evolution until its present situation (Petts, 1998).

Therefore, the aim of the present study is examining the reference condition and the current ecological deficit in terms of natural processes of a section of approximately 10 km of the Upper Rhine downstream Iffezheim (Germany). It is expected that the knowledge of the former river dynamics of the degraded Upper Rhine will give scientists and managers the necessary insight in potential process-based river restoration options.

Methodology/approach

Study site

A 10 km length section of the Upper Rhine River from downstream Iffezheim's dam until the mouth of the river Murg (tributary of the Rhine River on the right), in the border between Germany and France:

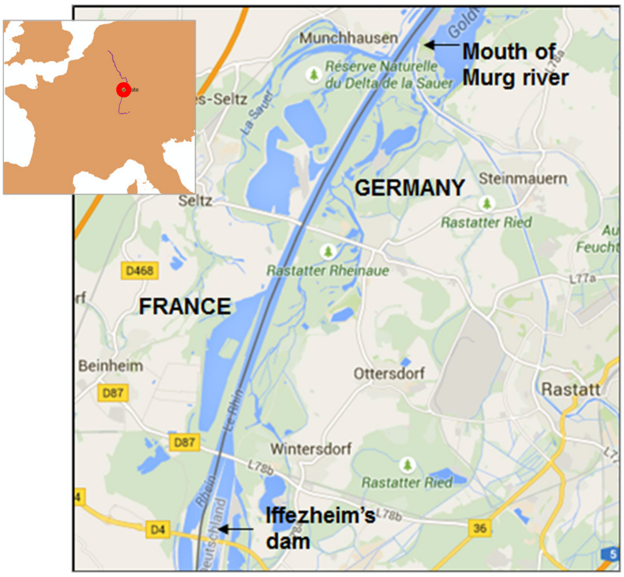

Fig. 2: Location of the case study

Methodology

The selected methodology is based on a **temporal evolution study (diachronic analysis)** of the interaction of hydromorphological processes and vegetation successional evolution within the floodplain in the studied section of the Upper Rhine River in four important periods:

I) Reference conditions (in hydromorphological terms) prior to Tulla's correction works (1840's);

II) After Correction (1850-1930);

III) After Regulation, Canal d'Alsace and chain of hydropower plants (1930-1980); and,

IV) Current situation (after Iffezheim's dam construction, from 1980 until now).

The first step consists on the **delineation of the total active channel area (TA) and of landscape elements,** based on historical maps (1828, 1838, 1852, 1872 and 1937) and on orthophotos (1986 and 2014)**.**

The total active channel area (TA) is the area occupied by water channels, islands and bare sediments (Belletti *et al.* 2013), considering the maximum expansion of water bodies during the considered time periods.

Regarding landscape elements, they can be subdivided as follows (based on Ward *et al.* 2002 with modifications):

- **Natural habitats:** surface water bodies (natural, regulated and artificial), gravel bars, grasslands and forests.
- **Anthropic elements:** croplands, settlements, gravel pits and industry.

Then, **trajectories of habitat change**, obtained by intersections of habitat areas between two periods, define **hydromorphological and vegetation dynamics and sources of change** (based on Whited *et al.* 2007 with modifications):

- **Changeless:** areas that do not show any change.

- **Progression** (involve growth towards the development of floodplain forests):
  - Initial patches: areas that progressed from water bodies to gravel/sand bars. These areas indicate a hydromorphological process of aggradation.
  - Colonization patches: areas that progressed to grasslands. These can be Natural: a change from water bodies or from gravel/sand bars to grasslands; or Land abandonment: human induced change from croplands or settlements to grasslands.
  - Transition patches: areas that progressed to forests. These can also be Natural: a change from water bodies, gravel/sand bars or grasslands to forests, or due to Land abandonment: human induced change from croplands or settlements to forests.
- **Regression** (involve a re-setting of the floodplain habitats):
  - Colonization-Clearance: human induced change from forests to grasslands.
  - Initial-Aggradation: creation of gravel/sand bars from any other habitat category.
  - Erosion-Channel shift: new areas of water bodies previously occupied by other habitats.
- **Anthropization:** categories associated exclusively associated human induced changes:
  - Cultivation: any habitat area converted to croplands.
  - Urbanization: any habitat area converted to settlements.
  - Industrialization: any habitat area converted to industrial areas.
  - Regulation: any habitat area converted to regulated water bodies.
  - Artificialization: any habitat area converted to artificial water bodies.

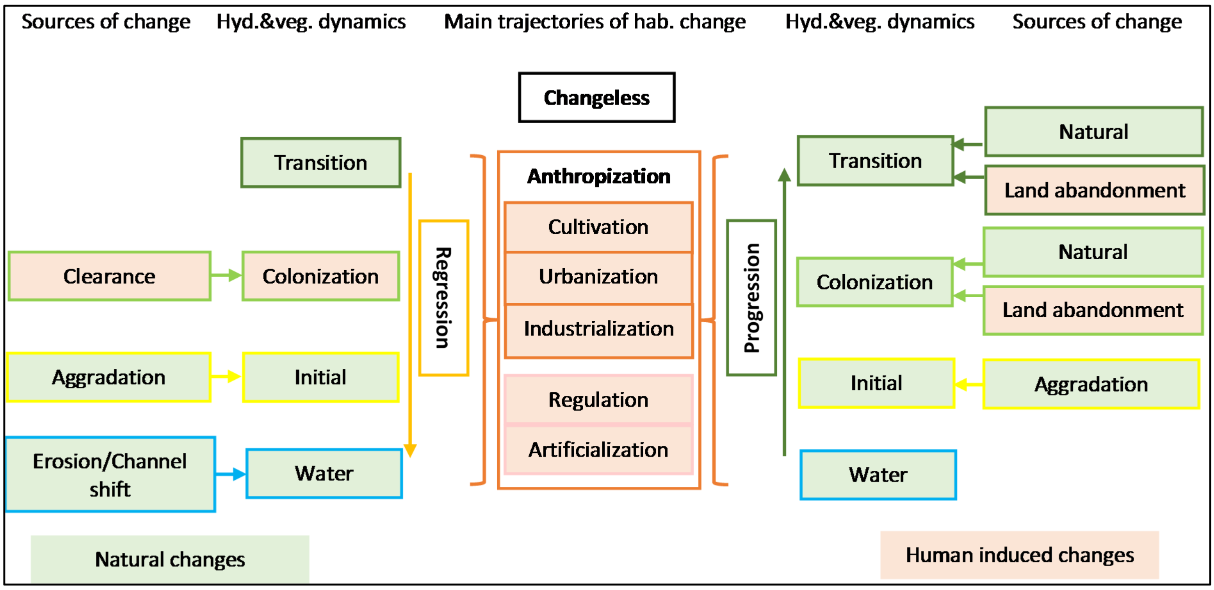

Fig. 3: Diagram with the main trajectories, dynamics and sources of change

Results

For the situation associated to reference conditions (1828-1838), it can be observed that natural areas occupied more than 95% of the total active channel area (see table 1 and figure 4) and that progression and regression processes were almost in equilibrium, with a tendency to progression (see table 2).

Regarding the afterwards progressive ecological deficit (1852-2014), there is a clear increase of anthropic habitats (figure 4) with a consequent reduction of natural habitats and that is due to channelization (1840), regulation (1930-1980) and expansion of croplands and artificial water bodies.

Table 1: Evolution of landscape elements within the total active channel area

Ladscape elements		1828	1838	1852	1872	1937	1986	2014
Natural	Water bodies, Natural	38.65%	32.75%	10.08%	11.94%	9.07%	9.51%	7.56%
	Gravel/sand bars	8.18%	14.64%	15.07%	2.13%	0.47%	0.03%	0.02%
	Grasslands	17.85%	15.38%	14.27%	6.69%	17.35%	5.16%	8.93%
	Forests	31.30%	32.97%	38.60%	46.16%	42.78%	39.51%	43.37%
Anthropogenic	Water bodies, Regulated	0.00%	0.00%	9.28%	9.92%	9.92%	10.90%	10.89%
	Water bodies, Artificial	0.00%	0.00%	0.00%	0.00%	0.08%	15.34%	16.02%
	Gravel pits	0.00%	0.00%	0.00%	0.00%	0.00%	2.37%	1.35%
	Croplands	3.64%	3.13%	11.10%	21.40%	18.21%	14.75%	7.86%
	Settlements	0.00%	0.01%	0.00%	0.00%	0.00%	0.86%	1.69%
	Industry	0.00%	0.00%	0.00%	0.00%	0.00%	0.05%	0.81%
	Infrastructures	0.39%	1.11%	1.59%	1.75%	2.12%	1.53%	1.51%
TOTAL ACTIVE CHANNEL		100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

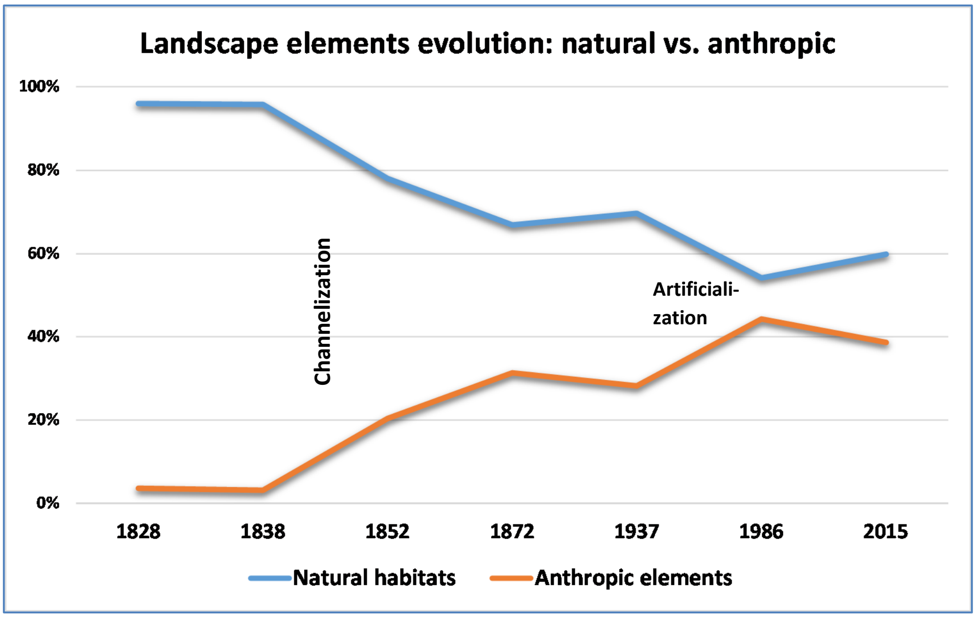

Fig. 4: Evolution of natural and anthropic landscape elements

Table 2: Habitat trajectories within the total active channel

Main trajectory	Process-Cause of change	1828-1838	1838-1852	1852-1872	1872-1937	1937-1986	1986-2014
Regression	Initial-Aggradation	2.05%	3.38%	0.54%	0.31%	0.05%	0.00%
	Channel shift-Erosion	10.04%	4.01%	6.30%	4.11%	4.21%	0.53%
	Colonization-Clearance (H.I.)	0.97%	5.23%	1.33%	6.43%	0.95%	1.12%
Progression	Initial-Aggradation	10.58%	9.41%	0.44%	0.09%	0.02%	0.00%
	Colonization-Land abandonment (H.I.)	0.04%	0.26%	0.81%	4.87%	0.65%	5.37%
	Colonization-Natural	0.92%	1.96%	1.02%	2.04%	0.18%	0.43%
	Transition-Land abandonment (H.I.)	0.05%	0.08%	0.36%	2.21%	2.05%	1.71%
	Transition-Natural	8.66%	19.90%	14.14%	5.67%	6.98%	4.56%
Changeless	Changeless	65.56%	37.86%	62.17%	69.51%	63.52%	79.32%
Anthropization	Artificialization (H.I.)	0.00%	0.00%	0.00%	0.08%	14.45%	4.21%
	Cultivation (H.I.)	1.12%	8.66%	12.05%	4.66%	3.41%	0.26%
	Industrialization (H.I.)	0.00%	0.00%	0.00%	0.00%	2.19%	1.19%
	Regulation (H.I.)	0.00%	9.24%	0.85%	0.04%	0.87%	0.00%
	Urbanization (H.I.)	0.00%	0.00%	0.00%	0.00%	0.48%	1.29%
TOTAL ACTIVE CHANNEL		100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

(H.I.): Human induced

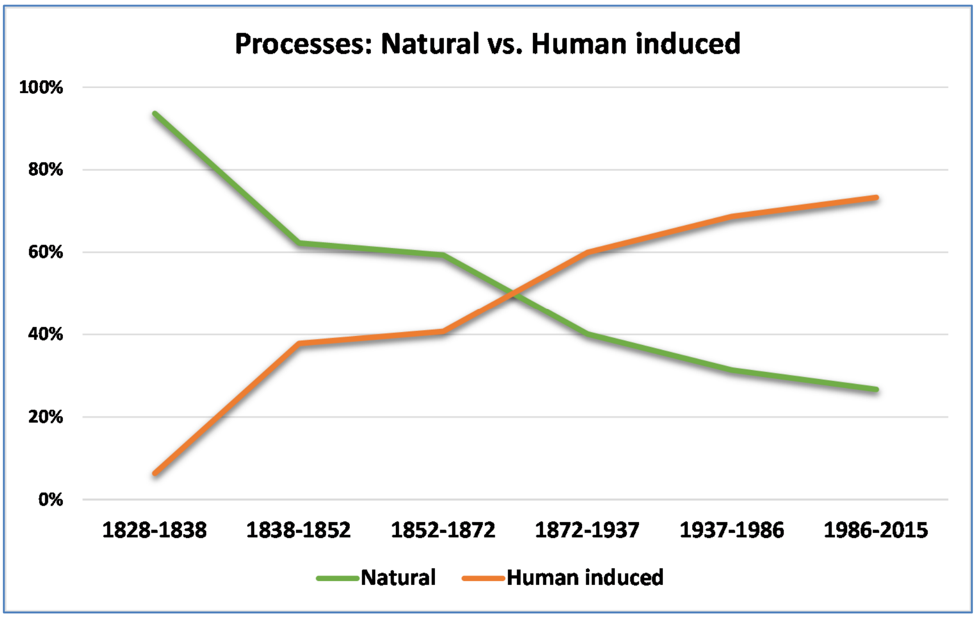

Fig. 5: Evolution of natural and human induced processes

Conclusions

The main conclusions can be summarized as follows:

- **Reference condition:** prior to major engineering works (1840's), the situation of the river-floodplain system can be comparable to a nearly natural system in hydromorphological terms, i.e. predominance of natural elements and of natural hydromorphological and vegetation dynamics with almost an equilibrium of progression and regression processes.

- **Ecological deficit:** 175 years of human interventions have led to an anthropization of landscape elements and to the replacement of dynamic processes (channel shifts, aggradation) by unidirectional trends (artificialization, industrialization):
  - The greatest progressive loss on natural processes has occurred with initial-aggradation dynamics, which are absent by 2014; and the greatest increase of anthropogenic processes is associated to artificialization, a consequence of gravel extraction along the second half of the twentieth century until now.
  - The periods of greatest change are 1838-1852 and 1937-1986 (see previous table 2 and figure 5); in the former period the change is mainly associated to the cultivation of previous inaccessible areas (anthropization processes) and to the transition of large areas to forests (progression); in the latter period, the main change is the creation of artificial water bodies (anthropization processes).

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