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# HYDROMORPHOLOGICAL PRIORITIES OF RIVER RESTORATION PROJECTS IN ROMANIA

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**ABSTRACT**
This paper conducts a synthesis on river restoration projects completed in Romania in order to establish their goals, especially for hydromorphology. The synthesis relies on information from RESTORE and NWRM databases, scientific papers on restoration projects, as well as on comparing maps of 1900 to satellite images of 2014. For each case study, we took into account: area, year of implementation, status of protection of the site, natural unit, river basin, hydromorphological features (channel pattern, fluvial form), human pressures, alterations, and measures; we deducted also goals and reference conditions preferred by the projects. We found 14 completed projects in Romania: eight on the Lower Danube and the delta (islands in an anabranched pattern or floodplain lakes), three on the Prut River (floodplains with fluvial lakes), one on the Jijia River (floodplain and previous river course), one on the Argeş River (gravel pits in the floodplain of a wandering river), and one on the Neajlov River (floodplains with fluvial lakes). The dominant local main human pressures were: embankments, chenalization, dranaige (for agriculture, fisherie, flood defence and navigation), and mining (gravels and sands). The active structural measures were taken at the river reach scale by reshaping channels, redesining embankments or building a dam. The overall goals of these restoration projects were to improve water quality and to extend wetlands by overflowing. Concerning the reference conditions, eight projects preferred a hydromorphological restoration towards an historical state baseline; five favored the co-existence of natural and anthropic states, while one choose an anthropic desired image different from the historical state. The first two kinds of interventions seem also to be focused on river processes, i.e. lateral connectivity. To improve restauration actions in Romania, we suggest an increase of restoration efforts in order to identify other altered hydromorphological processes with priority to restoration, further encourage hydromorphological process-based restoration while considering present-day reference conditions and enhance the transfer of knowledge.

**Keywords**: river restoration, hydromorphology, fluvial landform, reference condition, lateral connectivity, Romania.

## 1 INTRODUCTION

River restoration describes a variety of modifications of river channels and adjacent riparian zones and floodplains, and of the water, sediment, and solute inputs to rivers (Bennett et al. 2011). The goal is to improve hydrologic, geomorphic, and/or ecological processes within a degraded river basin (Wohl et al. 2005).

Restoration of hydromorphological components and processes may be a goal of river restoration. Hydromorphological components refers to channel pattern, depth, width, flow velocity, structure, substrate of the riverbed, and the composition of the riparian zone. Hydromorphological processes comprise water and sediment flow, channel adjustments, bank processes like erosion and accumulation, wood delivery and vegetation succession, and influence the features and dynamics of river channels and their floodplains (Poppe et al. 2016). Some examples of hydromorphological goals in restoration projects are: re-meander, re-braid, adding or trapping sediments, raising bed-level, increase or decrease of banks' dynamics (Morandi 2014). Hydromorphological processes drive longitudinal and lateral connectivity of water and sediments within river networks and corridors, and the related habitats (Gurnell et al. 2016), which is crucial in the context of the restoration (Kondolf et al. 2006).

At a national level, it was demonstrated that countries privileged certain directions in river restoration projects. As example, the most commonly stated goals for river restoration in the United States are to enhance water quality, to manage riparian zones, to improve in-stream habitat, for fish passage, and for bank stabilization (Bernhardt et al. 2005). In France, the top goals in river restoration projects were: to improve the habitat, as well as the ecological continuity, to reduce bank erosion, channel incision, floodplain terrestrialization, and to improve flow regime and water quality (Morandi et al. 2014). For Romania, we do not have a global image on the restoration goals; previous papers presented river restoration projects separately or by their ecological benefits especially in the Danube Delta (Schneider 2014, 2015; Hein et al. 2016).

Therefore, this paper conducts a synthesis on river restoration projects completed in Romania and determines the main goals in terms of hydromorphology in order to set new priorities in river restoration activities.

## 2 DATA AND METHODS

To create a synthesis of restoration actions in Romania, firstly, we used the databases of RESTORE (River: engaging, supporting and transferring knowledge on river restoration) (RESTORE 2016) and of NWRM (National Water Retention Measures) (NWRM 2016) projects. These databases are interactive tools sharing measures and schemes aiming to protect water bodies and resources, uploaded voluntarily by a contact person from a major actor implicated in the river project. Secondly, we used various scientific publications, with focus on restoration projects (Table 1).

**Table 1.** Sources of information for restoration projects

| Project number | Project name | Source |
|---|---|---|
| 1 | Babina | Schneider 2014, 2015; Hein et al. 2016; NWRM 2016; RESTORE 2016 |
| 2 | Cernovca | Schneider 2014, 2015; Hein et al. 2016; RESTORE 2016 |
| 3 | Popina | Schneider 2014, 2015; Hein et al. 2016; RESTORE 2016 |
| 4 | Fortuna | Schneider 2014, 2015; Hein et al. 2016; NWRM 2016; RESTORE 2016 |
| 5 | Sf. Gheorghe | Schneider 2014, 2015; Hein et al. 2016; RESTORE 2016 |
| 6 | Holbina-Dunavăț | Schneider 2014, 2015; Hein et al. 2016; NWRM 2016; RESTORE 2016 |
| 7 | Fundu Mare | NWRM 2016 |
| 8 | Gerai | NWRM 2016 |
| 9 | Ciobârciu | NWRM 2016; RESTORE 2016 |
| 10 | Pochina | NWRM 2016; RESTORE 2016 |
| 11 | Vlăşcuța | NWRM 2016; RESTORE 2016 |
| 12 | Mața-Rădeanu | NWRM 2016; RESTORE 2016 |
| 13 | Mătăsaru | RESTORE 2016 |
| 14 | Comana | NWRM 2016 |

For each restoration project, we took into account: area, year of implementation, status of protection of the site, natural unit, river basin, hydromorphological features (channel pattern, fluvial form), human pressures, alterations and measures. Based on alterations and measures, we deducted the main goal of the restoration activities.

Additionally, we determined reference conditions used in restoration projects. We took into account forms and processes. We separated three categories: (1) historical reference conditions when the form (e.g., dimensions) is modified towards historical conditions by eliminating human pressures responsible for the modifications; (2) intermediary reference conditions when the fluvial form (e.g., dimensions) within restoration sites maintains anthropic elements, therefore the human pressure; (3) desired images when the restored form has essentially an anthropic origin. We characterized processes as being related or not related to river dynamics. To compare forms, we used recent satellite images (Google Satellite image, year 2014, resolution 6.25 $m^2$ per pixel) and maps from early $20^{th}$ century demonstrative for quasi-natural conditions (Military Survey Maps, year 1900, scale 1:20000). To compare forms and deduct processes, we relied also on descriptions of projects from previous sources.

## 3 RESULTS

We found 14 completed restoration projects in Romania (Fig. 1a). All the projects overlay protected areas, at international (Man and Biosphere and/or Ramsar – 9) and/or European level (Natura 2000 – 14) (Fig. 1a). The pilot project was conducted in mid-90s and the latest one was completed in 2011 (Fig. 1b). These projects concern mostly small areas, with a sum of 20732 ha and an average of 1480 ha (Fig. 1b).

The restoration projects are located on the Danube River (8), on the Prut River (3) and the tributary Jijia River (1), on the Argeş River and the tributary Neajlov River (1) (Table 2). As physico-geographical features, the lowlands were preferred: Danube Delta (6), Moldavian Plateau (4), and Romanian Plain (4). As channel pattern, they correspond to anabranched river reaches (8), meandering reaches (4), sinuous (1) and wandering ones (1). As fluvial landforms, the projects were implemented within rivers' floodplains including lakes (8), islands (6) and river channels (1).

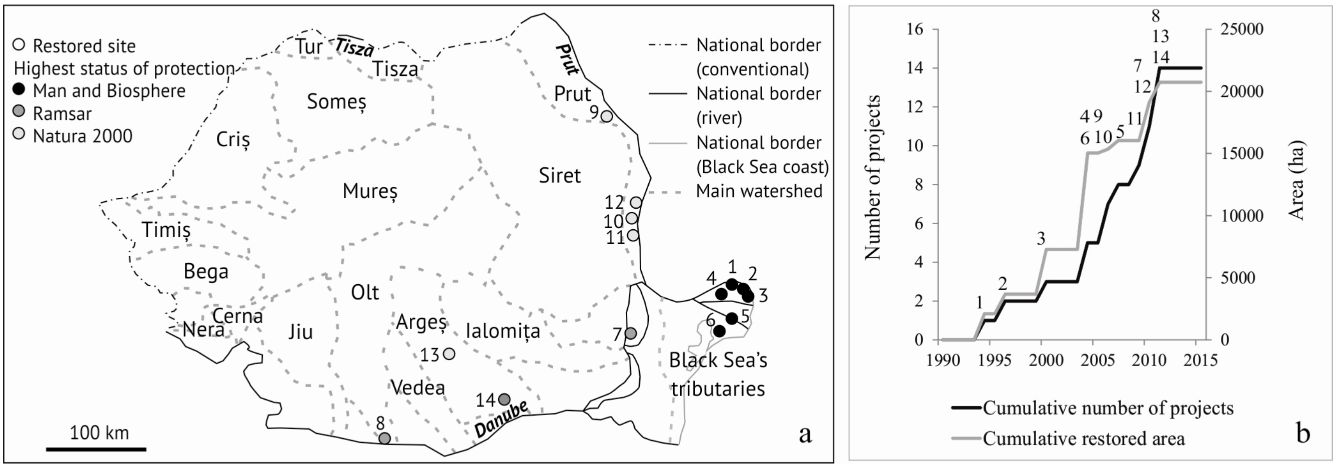


**Fig. 1.** Restoration projects completed in Romania: status of protection (a), year of implementation, and area (b). 1: Babina; 2: Cernovca; 3: Popina; 4: Fortuna; 5: Sf. Gheorghe (multiple sites); 6: Holbina-Dunavăț; 7: Fundu Mare; 8: Gerai; 9: Ciobârciu; 10: Pochina; 11: Vlăşcuța; 12: Mața-Rădeanu; 13: Mătăsaru; 14: Comana

**Table 2.** Hydromorphological features of restoration sites (project number according to Fig. 1)

| Project number | River | Natural unit | Channel pattern (2014) | Fluvial landform (2014) |
|---|---|---|---|---|
| 1 | Danube River | Danube Delta | Anabranching | Island |
| 2 | Danube River | Danube Delta | Anabranching | Island |
| 3 | Danube River | Danube Delta | Anabranching | Island |
| 4 | Danube River | Danube Delta | Anabranching | Island |
| 5 | Danube River | Danube Delta | Anabranching | Island |
| 6 | Danube River | Danube Delta | Anabranching | Island |
| 7 | Danube River | Romanian Plain | Anabranching | Floodplain (lakes) |
| 8 | Danube River | Romanian Plain | Sinuous | Floodplain (lake) |
| 9 | Jijia River (Prut River basin) | Moldavian Plateau | Meandering | Floodplain Channel |
| 10 | Prut River | Moldavian Plateau | Meandering | Floodplain (lake) |
| 11 | Prut River | Moldavian Plateau | Meandering | Floodplain (lake) |
| 12 | Prut River | Moldavian Plateau | Meandering | Floodplain (lake) |
| 13 | Argeş River | Romanian Plain | Wandering | Floodplain (lakes) |
| 14 | Neajlov River (Argeş River basin) | Romanian Plain | Anabranching | Floodplain (lake) |

Within the restoration sites, the dominant local human pressures were the embankment (8), chenalization (3), drainage (2), and mining (1) (Table 3). In ten cases, these works aimed at transforming floodplains and islands into agricultural polders or fish ponds and/or at defending against floods. In one case, the works conducted to improve navigation (i.e., creation of an artficial channel) was responsable for the alteration. In one other case, the extraction of gravels and sands created pitts filled with water. In another case, the modifications of the main channel conducted to flow alteration and sediment accumulation on the adjacent channels.

The main goals of restoration actions were improving water quality (7) and recreating wetlands (7) by increase water flow (Table 4). Therefore, the actions taken were reshaping channels (9) and removing, breaching or reshaping dykes or other embankments (6). We conclude that all the projects characterized by active measures and they were implemneted at river reach scale.

As respects the hydromorphological reference conditions of these restoration projects, we found three situations (Table 5). (1) Eight projects prefered, as reference conditions, the historical quasi-natural state from early 20th century; they aimed at restoring past wetlands by eliminating local human pressures while encouraging processes related to river flow. (2) Five projects maintained forms modified by human interventions while improving processes related to river flow. (3) One project preserved artificial forms and their functionnality. However, the first two categories encourage also processes related to river flow, i.e.

lateral connectivity. By contrary, the last category focus on processes within the site, ignoring the connection to the river.

**Table 3.** Human pressures and alterations in restoration sites (project number according to Fig. 1)

| Project number | Local main pressure | Pressures from upstream | Description of the alteration |
|---|---|---|---|
| 1 | Embankment | Reservoir dams<br>Embankment<br>Channelization | Islands were embanked to be transformed into agricultural polders. |
| 2 | Embankment | Reservoir dams<br>Embankment<br>Channelization | Islands were embanked to be transformed into agricultural polders. |
| 3 | Embankment | Reservoir dams<br>Embankment<br>Channelization | Islands were embanked to create fish ponds. |
| 4 | Embankment<br>Chenalization | Reservoir dams<br>Embankment<br>Channelization | Water was diverted by chenalization to create fish ponds. |
| 5 | Chenalization | Reservoir dams<br>Embankment<br>Channelization | Due to the fluvial arm's rectification, islands formed anthropically between the former and the current fluvial channel. |
| 6 | Chenalization | Reservoir dams<br>Embankment<br>Channelization | Water was diverted by chenalization to create fish ponds. |
| 7 | Chenalization | Reservoir dams<br>Embankment<br>Channelization | The flux of water and sediments was altered, therefore the deposition became dominant. |
| 8 | Drainage | Reservoir dams<br>Embankment<br>Channelization | Small drainage ditches diverted the water into two channels collectors and then into the Danube. |
| 9 | Embankment | Embankment | An old course was deviated for flood defense and agriculture and the former channel was embanked. |
| 10 | Embankment | Reservoir dams<br>Embankment | The lake was embanked to be separated from the river for various purposes. |
| 11 | Embankment | Reservoir dams<br>Embankment | The lake was embanked to be separated from the river for various purposes. |
| 12 | Embankment | Reservoir dams<br>Embankment | The lake was embanked to be separated from the river for various purposes. |
| 13 | Mining | Reservoir dams<br>Embankment | The floodplain was used for gravel and sand mining resulting gravel pitts. |
| 14 | Drainage | - | The surface of lakes decreased significantly with the purpose to increase arable land. |

**Table 4.** Restoration actions in the analyzed sites (project number according to Fig. 1)

| Project number | Restoration activities | | Scale | | | Types of measures | |
|---|---|---|---|---|---|---|---|
| | **Goal** | **Measures** | **Basin** | **Reach** | **In-stream** | **Passive** | **Active** |
| 1 | Overflowing and recreating wetlands | Breaching dykes | No | Yes | No | No | Yes |
| 2 | Overflowing and recreating wetlands | Breaching dykes | No | Yes | No | No | Yes |
| 3 | Water transfer and improvement of water quality | Breaching dykes<br>Reshaping channels | No | Yes | No | No | Yes |
| 4 | Water transfer and improvement of water quality | Reshaping channels | No | Yes | No | No | Yes |
| 5 | Overflowing and recreating wetlands on islands | Reshaping channels | No | Yes | No | No | Yes |
| 6 | Overflowing and improvement of water quality | Breaching dykes<br>Reshaping channels | No | Yes | No | No | Yes |
| 7 | Water and sediment transfer and maintaining wetlands | Reshaping channels | No | Yes | No | No | Yes |
| 8 | Overflowing and recreating wetlands on islands | Reshaping channels | No | Yes | No | No | Yes |
| 9 | Overflowing and recreating wetlands | Removal of embankment | No | Yes | No | No | Yes |
| 10 | Water transfer and improvement of water quality | Reshaping channels | No | Yes | No | No | Yes |
| 11 | Water transfer and improvement of water quality | Reshaping dykes | No | Yes | No | No | Yes |
| 12 | Water transfer and improvement of water quality | Reshaping channels | No | Yes | No | No | Yes |
| 13 | Water transfer between lakes to improve water quality | Reshaping channels<br>Removal of invasive species<br>Reforesting | No | Yes | No | No | Yes |
| 14 | Overflowing and recreating wetlands | Building a dam to overflow upstream<br>Construction of a fish scale | No | Yes | No | No | Yes |

**Table 5.** Reference conditions of restoration projects (project number according to Fig. 1)

| Project number | Form restored | | | Process restored | Reference conditions |
|---|---|---|---|---|---|
| | Quasi-natural | Altered | Anthropic | | |
| 1 | Increase wetlands' area towards early 20th century state | | | Lateral connectivity of the river | Historic |
| 2 | Increase wetlands' area towards early 20th century state | | | Lateral connectivity of the river | Historic |
| 3 | Recreate channels' dimensions towards early 20th century state | | | Lateral connectivity of the river | Historic |
| 4 | Recreate channels' dimensions towards early 20th century state | | | Lateral connectivity of the river | Historic |
| 5 | | Increase wetlands' area while maintaining an altered island | | Lateral connectivity of the river | Intermediary |
| 6 | Recreate channels' dimensions towards early 20th century state | | | Lateral connectivity of the river | Historic |
| 7 | Maintaining wetlands' area and recreate channels' dimensions towards early 20th century state | | | Lateral connectivity of the river | Historic |
| 8 | Increase wetlands' area towards early 20th century state | | | Lateral connectivity of the river | Historic |
| 9 | Increase wetlands' area towards early 20th century state | | | Lateral connectivity of the river | Historic |
| 10 | | Maintaining lake's form, modified by human pressures | | Lateral connectivity of the river | Intermediary |
| 11 | | Maintaining lake's form, modified by human pressures | | Lateral connectivity of the river | Intermediary |
| 12 | | Maintaining lake's form, modified by human pressures | | Lateral connectivity of the river | Intermediary |
| 13 | | | Maintaining gravel pits | Connectivity between lakes | Desired image |
| 14 | | Maintaining drainage system while increasing wetlands | | Lateral connectivity of the river | Intermediary |

## 4 DISCUSSION

We found 14 river reach scale completed restoration projects in Romania. By their location, they indicate an attraction for the Lower Danube and the delta, which regroup more than half of the projects (8). The other projects are on the Prut River (3) and the tributary Jijia River (1), on the Argeş River (1) and the tributary Neajlov River (1). Their main goals were improving water quality by water transfer and recreating wetlands by overflowing. As reference conditions, eight projects preferred an historical quasi-natural state; five projects choose an intermediary state and one project aimed a desired image different from the natural conditions.

The low number of restoration projects and their surrounding locations suggest a problem in communicating knowledge on river restoration: either the transfer of knowledge is better between neighbor actors or the created database is incomplete for Romania. In either case, Bernhardt et al. (2005) and Castillo et al. (2016) suggest the necessity to create a coordinated database that systematically catalogue river restoration projects, including the documentation of results, in order to assess the current state of river restoration and to transfer knowledge. These fundamentals should be also implemented in Romania in order to have more reliable results when synthesizing river restoration case studies and set new goals in this domain.

Concerning the restoration goals, Romania focused on lateral reconnection for overflowing and water quality by reshaping channels and removing or redesigning embankments. In Europe, similar country profiles have the Netherlands (19 projects) and the Czech Republic (3 projects), while France (35 projects), Austria (28 projects), UK (361 projects) and Finland (27 projects) encouraged also these practices without being so restrictive; Sweden (18 projects) reinforced sediment transport and Switzerland (7 projects) increased the braiding activity (Morandi 2014; RESTORE, 2016). This variety of restoration possibilities suggests that Romania should also open towards finding solutions for other types of river alterations such as the decrease of the braiding activity over the last century (Ioana-Toroimac 2016).

As respects the reference conditions, the three models chosen in Romania – historic quasi-natural conditions, intermediary between natural and anthropic states and desired image – correspond to three kinds of interventions known in river restoration according to Palmer et al. (2005) and Wohl et al. (2015) – field of dreams, hybrid keystone and system function or leitbild. The first model is rather avoided at international scale; the negative aspect of historic reference conditions derives from river's difficulty to self-maintain in present-day conditions and from the contradiction of preserving a historical non-dynamic state; however, the positive aspect refers to the relevance at a river reach scale, which is easier for implementation and monitoring of results (Wohl et al. 2015). The other two models are promoted at an international scale for process-based restoration and river self-sustaining over the long-term (Kondolf et al. 2006). In Romania, the preference for historic reference conditions might be explained by the position of sites in large wetlands with international protection status such as the Danube Delta; additionally, this choice seems adequate by showing sustainability of river processes by flooding. By contrary, Romania's example of leitbild is not appropriate for river processes restoration. However, on long term and at the national spatial scale, it is important for Romania to encourage hydromorphological process-based restoration while considering present-day reference conditions (Wyzga et al. 2012).

## 5 CONCLUSION

Romania has a relatively low number of restoration projects (14) when compared to other European countries. They focus on a variety of channel patterns and landforms modified by human interventions: islands in an anabranched pattern, floodplains with fluvial lakes in meandering, wandering and sinuous patterns. However, these projects seem to lack of diversity concerning the goals and measures of restoration; they promote water quality and wetlands' extension by overflowing. They characterize also by an attraction for the Danube, which is the main focus for more than half of the projects.

Therefore, we suggest an increase of restoration efforts in Romania towards three main directions: (1) a re-evaluation of priorities for restoration among altered hydromorphological processes at the national spatial scale; (2) an increase of diversity among goals and methods adapted to priority hydromorphological alterations; and (3) a communication improvement on restoration projects – goals, methods and long-term results – in order to promote the transfer of knowledge.

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