Bridging rivers and floodplains: Restoration efforts to improve lateral connectivity

Relier les rivières et les plaines inondables: Efforts de restauration pour améliorer la connectivité latérale

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RÉSUMÉ

Les systèmes fluviaux mondiaux sont de plus en plus menacés par les interventions humaines, provoquant des perturbations des régimes d'écoulement naturels, du transport des sédiments et de l'intégrité écologique. En réponse, les efforts de restauration privilégient la reconnexion des rivières à leurs plaines inondables pour renforcer les processus hydromorphologiques et la résilience écologique. Cette étude examine deux projets de restauration sur le fleuve Ter, en Catalogne, un système gravement impacté par des altérations hydrologiques et des déficits en sédiments causés par des activités humaines telles que l'extraction de graviers et la construction de barrages, entraînant une incision marquée du lit fluvial. Le premier projet (Gambires), achevé en 2022, a restauré un tronçon où des chenaux secondaires étaient presque totalement déconnectés du chenal principal. Cela a impliqué de réduire l'altitude d'une île en enlevant des sédiments, de les redistribuer dans le lit de la rivière et de rétablir la connectivité d'un chenal secondaire. Le deuxième projet (Colomers), prévu pour 2025, améliorera la connectivité latérale grâce à une modernisation des infrastructures de drainage le long de la berge. Ce projet favorisera la création de chenaux secondaires, améliorera la connexion des plaines inondables, renforcera la biodiversité et contrôlera les espèces exotiques envahissantes. Ces initiatives visent à restaurer la fonctionnalité hydromorphologique et l'intégrité écologique du corridor riparien du fleuve Ter.

ABSTRACT

River systems worldwide are increasingly threatened by human interventions, leading to disruptions in natural flow regimes, sediment transport, and ecological integrity. In response, restoration efforts are prioritizing the reconnection of rivers with their floodplains to enhance hydromorphological processes and ecological resilience. This study examines two restoration projects on the Ter River in Catalonia, a system significantly impacted by hydrological alterations and sediment deficit due to human activities such as gravel mining and dam regulation. These impacts have led to pronounced riverbed incision, highlighting the need for targeted restoration efforts. The first project (Gambires), completed in 2022, focused on a river reach where a secondary channel had become almost entirely disconnected from the main channel due to severe riverbed incision. Restoration involved removing sediment from an island to reduce its elevation, redistributing the sediment into the riverbed, and reestablishing the connectivity of a secondary channel. The second project (Colomers), scheduled for 2025, will include enhancing lateral connectivity by upgrading a drainage infrastructure along the river embankment. This will promote the creation of secondary channels, improve floodplain connectivity, increase biodiversity complexity, and help control invasive exotic species. Together, these projects aim to restore hydromorphological functionality and the ecological integrity of the Ter River's riparian corridor.

KEYWORDS

Floodplain connectivity, Hydromorphological processes, River embankment, Riverbed incision, River restoration

Connectivité des plaines inondables, Digue, Incision du lit fluvial, Processus hydromorphologiques, Restauration des rivières.

1 INTRODUCTION

River channels and floodplains are interconnected parts of a river system, each playing a vital role in maintaining the system's balance. While river channels efficiently transport water and sediment, floodplains act as natural buffers, promoting sediment deposition and groundwater recharge, mitigating floods, and supporting diverse ecosystems. Within a broader context of climate change, urban and agricultural development, coupled with practices like gravel extraction, dam construction, and river channelization, have led to significant changes in river dynamics and hydromorphological processes. These alterations, which include an imbalance between erosion and sedimentation, riverbed incision, loss of lateral and longitudinal connectivity, and reduced ecological function, pose serious threats to both human communities and fluvial ecosystems.

To address these issues, restoration efforts are increasingly focusing on reconnecting rivers with their floodplains and restoring natural hydromorphological processes. Catalonia (NE Spain) provides a case study of a region where most rivers are experiencing significant channel incision processes. In addition, a persistent drought in the Catalan Inner basins have led to a lack of competent floods, which are fundamental for maintaining the sediment balance of fluvial systems. In particular, the Ter River has suffered from a chronic sediment deficit since the late 19th century, resulting in severe channel incision and degraded riparian ecosystems. Here, we present two restoration projects implemented on the Ter River to address these issues. The first project (Gambires) was completed in 2022 and focused on improving connectivity and hydromorphological dynamics within two fluvial islands, as well as restoring their degraded riparian habitats. The second project (Colomers) is underway and aims to restore the connectivity between the river channel and its fluvial terraces within the Colomers meander, currently isolated by a river embankment.

2 STUDY AREA: THE TER RIVER BASIN

The Ter River is one of the largest rivers of the Internal Catalan Basins (NE Spain). It originates in the Eastern Pyrenees and drains an area of ~3000 km^2 before flowing into the Mediterranean Sea (Figure 1). There are 3 consecutive reservoirs in the middle part of the basin (Sau, Susqueda and El Pasteral), with a joined storage capacity of 400 hm^3. Mean annual discharge (upstream of the reservoirs) is 17 m^3/s and, as a Mediterranean river, shows a highly seasonal annual cycle.

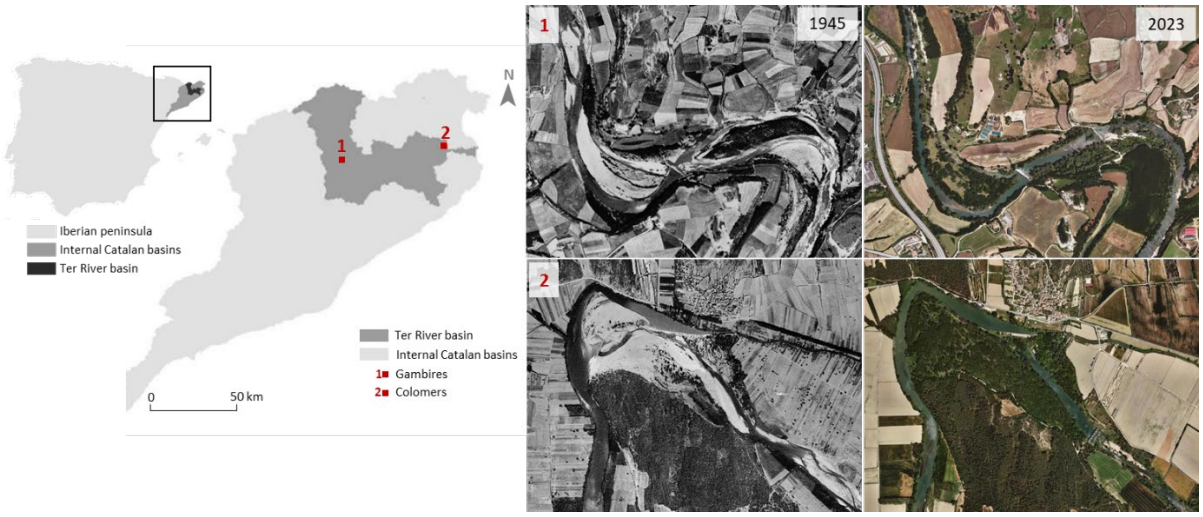

Figure 1. Location of the Ter River basin within the Internal Catalan basin. The numbers indicate the location of the two restoration projects implemented in the Ter River basin (1: Gambires; 2: Colomers). The photos show the historical changes in the study reaches between 1945 and the present (Source: Geological and Cartographic Institute of Catalonia).

The Ter River has experienced significant degradation since the late 19th century due to human activities such as gravel extraction, dam construction, river channelization, and industrial and agricultural development. These interventions have disrupted the river's sediment balance, forcing it to adjust its morphology over time. This prolonged adjustment has caused severe incision in some areas, leading to the complete loss of active sedimentary units. In certain sections, the river now flows directly over bedrock, with key morphological elements like lateral and central bars having disappeared. This disconnection from the floodplain has enabled vegetation to encroach into the channel, narrowing its width and further disrupting its natural dynamics. This encroachment exacerbates the problem by stabilizing the channel's altered form and reducing habitat diversity.

3 STUDY CASES

3.1. Gambires

The study reach includes the meanders and islands of Gambires and El Sorral, located in the middle Ter, upstream of the 3 main reservoirs. In the 1980s, intensive gravel mining from the main channel partially disconnected the secondary channel of the Gambires Island. Consequently, water circulation through the secondary channel was limited to 20% of the time, occurring only when discharge exceeded 32 m^3/s. Significant morphological changes were also observed, including: channel incision and narrowing, loss of sinuosity, reduced floodplain connectivity, and increased stability (e.g., bed armoring and vegetation colonization of former sedimentary areas). Such changes led to the degradation of the ecological conditions, such as the death of alder communities on the left bank due to reduced groundwater level. Within the framework of a LIFE Program funded project (LIFE ALNUS), a restoration project was implemented between December 2021 and June 2022. This project aimed at rehabilitating the hydromorphological, hydrodynamic, and fluvial connectivity of two fluvial islands (Gambires and El Sorral), each approximately 8 hectares in size, where riparian habitats were significantly altered. Restoration works undertaken in each island are described below.

3.1.1. The Gambires Island

- The Gambires Island elevation was lowered by means of sediment removal, which lowered the island's elevation, increased flood frequency, and reduced the distance between the surface and groundwater levels.
- The removed sediment was sieved. Coarse sediment (diameter > 64 mm) was repurposed for gravel injection upstream of Gambires Island to reverse channel incision, enhance lateral hydraulic connectivity, and raise groundwater levels. Fine sediment (diameter < 64 mm) was returned to the island's excavated area. A permeable rubble-mound breakwater was constructed to protect the riverbed gravels during extreme floods. The selected sediment particle size was chosen to replace gravels lost from past gravel-mining activities in the reach.
- The island experienced a substantial proliferation of invasive species, mainly black locust (*Robinia pseudoacacia*) and box elder (*Acer negundo*), which had colonized the island's open areas. As part of the required operations for gravel extraction, these invasive species were cleared and removed from the areas impacted by the works.
- The excavated in the island was filled and covered with topsoil. Later, alder (*Alnus glutinosa*), ash (*Fraxinus excelsior*), and a variety of willow species (*Salix sp*.) were planted in this area.
- The secondary channel was reconnected to mitigate channel incision, improve hydraulic complexity, and elevate groundwater levels. This secondary channel, formerly functional, contributed to the heterogeneity and complexity of the river system by increasing the wetted perimeter.

Figure 2. Addition of gravel and pebbles to the riverbed to improve connectivity with the secondary channel

3.1.2. El Sorral Island

- At the El Sorral Island, hydro-morphological dynamics was restored by removing a weir previously used for gravel-mining activities. A passive approach was used to allow natural processes to re-establish channel features.
- Following the removal of the weir, the ground along the path on El Sorral Island was decompacted to improve soil quality. Manual planting of alder, ash, and willow species was then carried out to restore the natural vegetation.

During the project, probes were also installed to continuously monitor river water and groundwater levels in the Gambires and El Sorral islands. This data will help provide further understanding of river and aquifer dynamics.

The probes are still active for ongoing monitoring and analysis. However, since the completion of the restoration works, persistent drought conditions in Catalonia and the resulting lack of high flows have hindered the evaluation of channel adjustments. This has limited the ability to fully assess the medium-term impacts of the project.

3.2. Colomers

The Colomers meander, located in the Lower Ter (~40 km downstream from El Pasteral reservoir), extends 2.5 km and covers 8 ha. The project site, located on the right bank within the meander's inner curve, comprises alluvial terraces separated from the main river channel by a 1.2-km embankment that reaches the Colomers weir, currently used for irrigation purposes. Despite the barrier, some infiltration from the embankment into the lowest parts of the terraces is evident. At the upstream end, there are remains of protective structures constructed in the 1970s, which are currently in poor condition, partially buried by sediment, and serve no purpose. The Colomers meander includes some protected areas of recognized ecological interest: it is located within a designated natural interest area (PEIN) and it is included within the Natura 2000 site known as Riberes del Baix Ter (code ES5120011).

This restoration project is framed within a stewardship agreement between the Catalan Water Agency (ACA) and the Ter Consortium (Consorci del Ter) and aims at improving river connectivity by restoring the lower terrace system of the Lower Ter on the right bank of the Colomers meander. A preliminary analysis was conducted to select the most suitable alternative, considering economic, social, and environmental factors. The selected solution prioritizes passive restoration and natural adaptation. The following works were identified:

- Enhance lateral connectivity with a drainage system and a collector in the embankment.
- Increase habitat structural complexity.
- Promote the establishment of autochthonous riparian vegetation species that are currently underrepresented by: (i) clearing sections occupied by poplar plantations (*Populus sp.*); (ii) removing non-native species such as giant reed (*Arundo donax*), box elder (*Acer negundo*), and black locust (*Robinia pseudoacacia*); and (ii) planting willow (*Salix sp.*) cuttings on the spillway embankments within the project area.

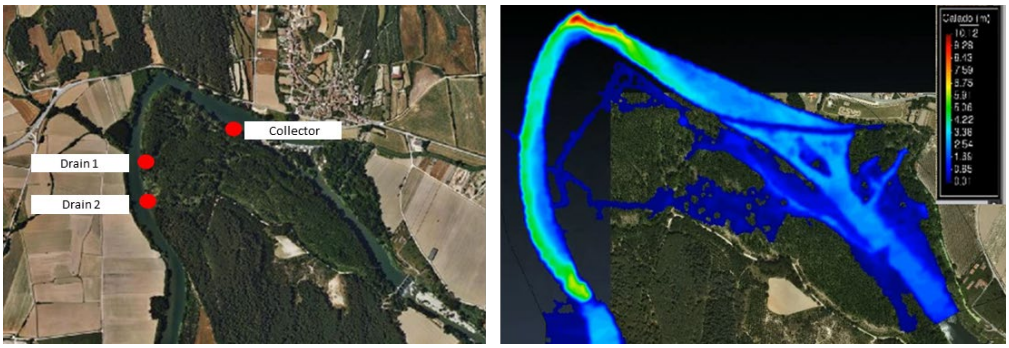

Figure 3. Projected drainage system (left) and simulated water levels in the meander during a flood event (right).

Hydraulic modeling with IBER 2D (Bladé et al., 2014) guided the evaluation of alternatives and the design of the chosen alternative. The selected solution includes two overflow structures and a drainage system, creating three strategically placed permeability points tailored to the embankment's inundation dynamics and the site's topography (Figure 3). The elevations of the permeability elements are precisely calibrated to allow water passage during high flow events while minimizing water diversion under normal flow conditions.

Projected works will start in January 2025.

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