Human impacts leading to biomorphological changes in the Isère river (France) over the last century

Les impacts anthropiques ayant conduit aux altérations biogéomorphologiques de l'Isère (France) au cours du XXe siècle

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RÉSUMÉ

Au cours des 200 dernières années, les rivières des pays industrialisés ont été fortement impactées par diverses interventions d'origine anthropique, qui ont conduit à des changements biogéomorphologiques visibles. L'Isère, rivière du sud-est de la France, a été endiguée au XIXe siècle ; elle est sujette à une modification importante de ses apports hydrologiques et sédimentaires depuis le milieu du XXe siècle, en lien avec les aménagements hydroélectriques et les extractions sédimentaires. Nous avons analysé quantitativement les trajectoires spatiales et temporelles des modifications de l'espace fluvial sur un tronçon de 33 km, à partir de photographies aériennes depuis 1930 et de données topographiques issues de profils en travers et intégré cela avec les théories morphodynamiques analytiques. Des bancs alternés sont apparus après l'endiguement, et ils ont évolué au cours du XXe siècle en termes de dimension, d'espacement, de vitesse de migration, et de degré de végétalisation. Une fois la végétation établie, la couverture végétale a persisté sur les bancs, provoquant la transition d'une dynamique morphologique sans végétation à une dynamique amoindrie avec végétation. Le fonctionnement actuel du lit de l'Isère présente un défi pour les gestionnaires chargés de protéger les populations du risque d'inondation. Cette étude a pour objectif de guider les décisions de gestion pour les rivières endiguées au régime hydrologique influencé, qui présentent le développement de bancs alternés.

ABSTRACT

Over the past 200 years, rivers in industrialized countries have been significantly altered by human interventions causing observable biomorphological changes. The Isère river (SE France) was channelized in the 19th century and, after the mid-20th century, its flow and sediment transport regimes have become increasingly influenced by hydropower development, as well as by sediment mining. We quantitatively analysed temporal and spatial biomorphological river trajectories within a 33 km reach, based on aerial images captured since the 1930s and cross-sectional data and integrated it with analytical morphodynamic theories. Alternating bars appeared after channelization and have changed in length, height, spacing, migration rates, and degree of vegetation encroachment during the 20th century. Once established, vegetation cover persisted across bar surfaces, leading to a transition from an unvegetated, dynamic to a vegetated, less-dynamic state, with bar surfaces grown up to 4m. Despite repeated attempts to artificial removal of vegetation, the system could not recover the previous gravel bar state. The new state is a challenge for river managers because of the increase in flood risk for human activities. Outcomes of this study can support decision making in relation to vegetated alternate bars development within regulated, channelized rivers.

KEYWORDS

Alternate bars, channelization, evolutionary trajectories, flow regulation, sediment mining

1 INTRODUCTION

Over the past 200 years, rivers in industrialized countries have been significantly impacted by human interventions and pressures. Direct effects on fluvial processes and their morphological consequences arise from anthropogenic activities such as dam and weir construction and removal, changes in the flow regime, channel realignment, gravel mining, whereas indirect effects can result from land cover changes within the catchment. Identifying the specific effect of different controlling factors becomes complex where several factors overlap in time and space and influence channel processes. To this aim, integration of historical analyses with modelling approaches can be of help to disentangle some of these complex cause-effect relationships.

Extensive channelization has affected many river systems worldwide. For example, widespread levee construction has occurred along European rivers since the mid-1800s and is currently being widely implemented in many developing countries. Several responses have been observed to channelization, with some reaches developing long, regular sequences of alternating bars which can remain completely bare (e.g. the Alpine Rhine, Adami et al., 2016) or become vegetated (e.g. Toshibetsu river, Japan). Very few multi-temporal studies have studied adjustment trajectories of channelized rivers and even less in the case of those with vegetated bars.

The Isère river (southeast France) is a striking example of a channelized river that has been subject to multiple stressors over the last 160 years, during which migrating gravel bars have appeared and gradually transformed to much higher steady bars covered with vegetation (see Figure 1). Major human impacts on the Isère have been described in previous studies (e.g. Allain-Jegou, 2002; Vautier, 2000). This study investigates temporal and spatial trajectories of these changes within a 33 km reach upstream of Grenoble in Combe de Savoie in relation to human interventions. The results are relevant to current challenges related to flood risk management.

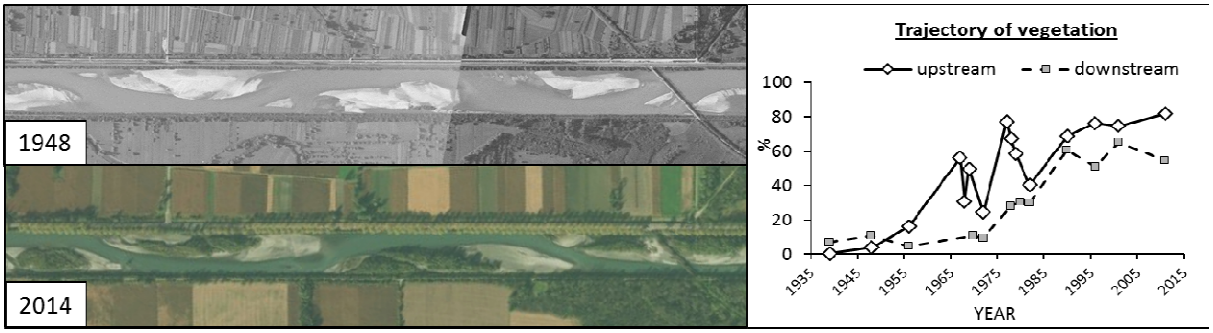

Figure 1: representative images of the Isère river study site in the first half of the 20th century and more recently (left); temporal trajectory of vegetation development (vegetation area/total bar area) in the subreaches upstream and downstream the confluence with the Arc river (right).

2 STUDY SITE AND METHODS

Major straightening and embanking of the river Isère was completed in 1858 with several subsequent modifications and additions. Following channelization, the river developed a planform of alternate bars within the embanked channel. This planform has subsequently evolved over a period during which a range of other human interventions and pressures have affected the study reach. Hydropower development started as early as 1867 but the construction of the large Tignes reservoir in 1952 was the beginning of a very intensive construction period for hydropower dams causing major flow regime alteration. Additionally, two major inter-basin transfers were constructed between the Arc and Isère rivers. The Isère-Arc diversion (implemented in 1953) caused a drastic decrease in high and mean flows and likely reduced bedload input upstream of the Arc confluence. The second large inter-basin transfer from the Arc to the Isère was implemented in 1980. In addition, sediment mining of the river bed was particularly active from the late 1940s to the early 1980s. Since the 1980s, sediment weirs have been installed for stabilizing the longitudinal profile of the Isère, which affected sediment transfer through the study reach. In addition, in different locations and at different dates, colonizing vegetation has been removed from many bar surfaces to maintain conveyance of high flows.

Information on the morphological evolution of the reach and possible influencing factors was extracted and analysed from four types of historical data sources covering the past 80 years: flow records; aerial images; historical documents, and topographic data. In particular, sequences of aerial images were studied to investigate morphodynamic responses to specific human activities that directly or indirectly

affect fluvial processes. The entire reach was split into two subreaches, one upstream and the other downstream of the Arc confluence. Flow regime alteration was analysed using the IARI hydrological alteration assessment method to compare the monthly flow regime over 4 different time periods. Sediment mining sites and information on extracted volumes were found in archives while aerial images provided additional information on locations and impacts. The results were integrated with morphodynamic analytical theories to get quantitative insight on the properties of alternate bars, especially under the initial, unvegetated state.

3 RESULTS AND DISCUSSION

Vegetation encroachment had already commenced by the 1950's in the upstream sub-reach, accompanying the Isère-Arc diversion and the beginning of an altered flow regime from hydropower development. There is evidence of intensive vegetation removal from bars since the late 1960s, after which vegetation re-established within a few years (Figure 1). Over the entire reach the percentage of the total bar area that became vegetated follows a similar, logistic-like temporal trajectory, increasing from near-zero and then stabilising at a near-constant value up to 80% - 90% of the total exposed area. The time interval in which the bars transitioned between these two markedly different, seemingly stable states is approximately 20 to 30 years. Aerial images also show that, once they became vegetated, alternate bars first stopped migrating within just a few years, and further elongated after a following 10-20 years period since their migration ceased. Integration of the historical analysis with morphodynamic theories indicate that such transition can be mainly attributed to vegetation establishment, which also triggered an impressive increase in bar heights (up to 4m). Reach-scale lowering of the river bed has also been observed, which appears to be associated with the combined effects of a changed flow regime, reduced sediment supply and sediment mining. Sediment mining has led to some local substantial (>3 m) river bed incision. This incision has increased the elevation of vegetated bar areas relative to flow disturbances and has probably also increased the elevation of established vegetation above likely water table levels within the bars. Overall, the transition between the two states has led to increased flood risk of the surrounding area, and the riparian ecosystem within the embankments is progressively being replaced by a terrestrial ecosystem. The river system shift to the new vegetated state seems hardly reversible, causing many management efforts carried out since the mid-20th century (mainly removal of vegetation and sediments) to be ineffective in turning the river back to its initial gravel bar state, characterized by a much lower flood risk.

4 CONCLUSION

We quantified the multidecadal (80 years) biomorphodynamics of alternate bars in a 33 km reach of the Isère River in SE France. Evidence supports how changes in the river flow regime; mining of river bed sediment; and the removal of vegetation from bar surfaces have led to substantial biomorphological changes within a relatively short time scale (20-30 years). Such changes can be described in terms of the shift from a bare-gravel migrating alternate bars state to a less dynamic configuration, characterized by much higher and longer non-migrating vegetated alternate bars, with considerable increase in flood risk. Little success has been achieved so far by increasingly costly management measures, aimed at reversing such transition to the hydraulically safer initial state. Results suggest viewing such co-evolution of the river and the interacting human system in the light of the river overcoming a key threshold in its evolutionary trajectory, beyond which restoring the initial state cannot be achieved solely by mechanically re-imposing it through vegetation and sediment removal. Instead, the corresponding threshold in the anthropic stressors needs to be identified so that targeted measures can be designed to ensure durable solutions. By quantifying such transition across contrasting states, this study may support detection of these thresholds and related decision making in relation to vegetated alternate bar development in channelized rivers.

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