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Joaquim Farguell

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Introduction and aims of study

1 Human impacts on river ecosystems and river dynamics have been very intense in the second half of the 20th century. River channel alterations in width and depth, disconnection from floodplains by channelization, river morphology alteration (Gregory and Chin, 2002), limitation of riverine hydro-geomorphological processes and the river ecology (Gurnell *et al*., 2007; Islam *et al*., 2025), disruptions to the natural flow regime (Poff *et al*., 1997; Beechie *et al*., 2013), degradation of the quality of river water (Papadaki *et al*., 2023) and changes in river flood frequency and magnitude (Anim *et al.* 2018) are among the main examples of human impacts on river systems. Rivers from the Iberian Peninsula, for example, have decreased in width and riverbed depth due to channelization and lowering the riverbed by anthropic activity, especially in the last 50 to 60 years (Scorpio *et al.* 2024). However, an environmental movement initiated during 1960's and 1970's in the US and rapidly spreading to other countries, saw the rivers as

important environmental resources rather than hazards that needed to be managed and controlled, and led to the development of restoration projects throughout several locations in the world (Bennett *et al.*, 2011; Smith *et al.* 2014). River restoration enhances river ecosystems and promotes biodiversity, which in turn improves the river ecosystem and provides environmental services to mankind.

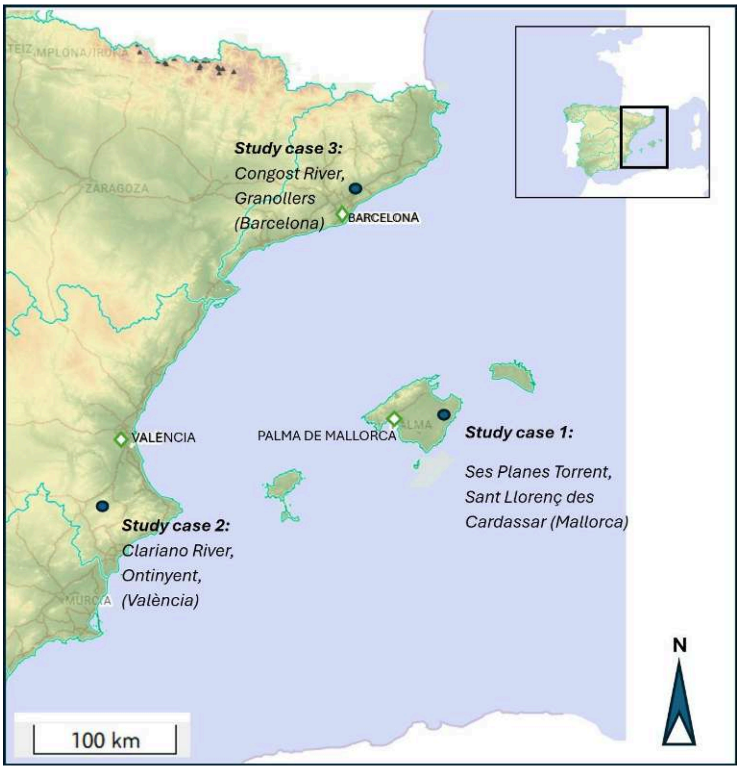
2 However, the concept of river restoration is diverse, and it is basically dependent on the aim or the restoration objective set (Wohl. 2005; Kondolf, 2011; Wohl *et al.*, 2015). From a hydrological and geomorphological perspective, river restoration stands for recovering river processes, allowing space to the river to flood and reconnect with its floodplain (Ciotti *et al.*, 2021; Kondolf *et al.*, 2021; McCabe *et al.* 2025). and enhance river resilience that is, the capacity of the river of recover river processes and maintain them through time, in a way that it improves its morphology, dynamics and the fluvial environment (Kondolf *et al.*, 2016; Thoms and Fuller, 2024; Wohl *et al.*, 2024; Ollero, 2025). In contrast, river interventions are based on "*rehabilitations*" or "*greening*", consisting in tree planting or gardening operations on riverine areas, focused on the conversion of river space in leisure areas or river parks, or simply focusing on obtaining biodiversity above all, without considering the natural processes involved in river dynamics. Currently, this is the main trend in dense urban areas, where there is a lack of open spaces, and managers and municipalities set the goal in the wealth of citizens (Farguell and Santasusagna, 2024; Santasusagna, 2019) but rises a debate whether this *gardenscape* and domesticated river model should suit urban life in upcoming years (Santasusagna, 2024).

3 In this sense, many river restoration or re-naturalization works in Spain are related to the mitigation of flood events or managing flood risk and river resilience in the context of the "Anthropocene" (García *et al.*, 2021; Ollero *et al.*, 2021). This is an important consideration given that the impacts of flood events are expected to increase mostly due to changes in land use and the increase of torrential rainfall events, especially in the Mediterranean area (Blöschl *et al.*, 2020; Llasat, 2021). According to this, and especially after the catastrophic flood event occurred in Valencia in October 2024, an intense discussion of what should be done in our rivers to decrease flooding risk has emerged.

4 Restoration strategies vary depending on the specific goals of each project (Kondolf, 2011; Guimarães *et al.*, 2021). Fluvial restoration practices are relatively new in Spain and have increased since the implementation and development of the Water Framework Directive (González Del Tánago *et al.*, 2012; Magdaleno, 2020).

5 Within this context, the aim of this study is to explore how fluvial restoration has been applied in three different case studies located in the Mediterranean side of Spain and evaluate whether these interventions are focused on the increase in fluvial resilience or river self-healing or, on the contrary, is not considering the changes that are occurring.

Figure 1. Location of the case studies.



Methods

6 Although several cases could have been selected to fit in this research, the final selection is related to the occurrence of an event that harmed and affected urban areas and have undertaken a reconstruction process. A close follow up of these studies has been performed to find out enough information related with the event and the reconstruction process to assess the solutions implemented in each case.

7 The case studies shown in this paper have been selected to show a range of the different approaches of river restoration that municipalities have applied in their towns or villages to solve a river problem. The first two case studies involve a severe flood event that affected the urban area of the municipalities. However, different approaches were considered depending on the area affected. In the first case, an exact reconstruction of the urban area prior to the event was executed and no river restoration nor rehabilitation processes were considered. This reflects that the river is seen as a menace, and hard infrastructures were the main solutions applied to avoid further flooding problems.

8 In the second case, however, the municipality decided to execute a change in land use of the flooded area, transforming it from urban to a public flooding park. The river is not the main character in this case either, but some considerations in providing additional space to the river for flooding have been implemented. The third case shows a proper river restoration approach, not directly related with a flood event, but focusing on the restoration of the hydro-geomorphological river processes as a base to develop a biodiversity river ecosystem within an urban and peri-urban area.

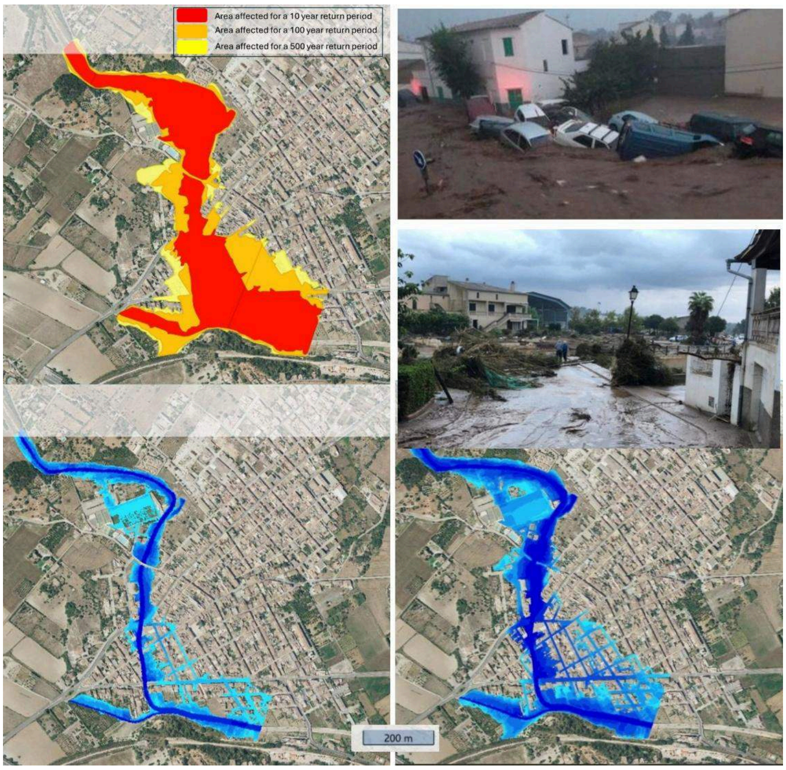
9 The description and exploration of the study cases have been evaluated through academic references and additional data sources like technical reports describing the improvements or “corrections” introduced in the study areas, and also from newspapers, in which a description of the event has been extracted if no academic study was found. The images used throughout the text have been extracted from digital newspapers and television archive sites. Aerial images have been obtained from Google Earth and the Catalan Cartographic and Geologic Institute (2025). The maps used in relation to the flooding extent for different return periods, as well as the maps indicating the risk of flooding and the potential water stages, were obtained from the National System for Flooding Cartography Zones produced by the Ministry of Ecological Transition and Demographic Challenge (MITECO, 2020). Hydrometeorological data used in case 2 have been provided by the public water authorities of the Valencia region (Confederación Hidrográfica del Júcar, 2025) and hydrological data have been treated and represented using Microsoft Excel to represent the flood hydrograph of the event to illustrate its magnitude and the speed of the rising and falling limb of the graph and its relationship with rainfall. The location of the case studies is in Fig. 1.

Case Studies in the Mediterranean Iberian Peninsula

Case 1: Ses Planes Torrent, Sant Llorenç des Cardassar (Mallorca): *“An example of reconstruction without adaptation”*

10 Sant Llorenç des Cardassar (8,045 inhabitants), located on the eastern side of Mallorca Island (Fig. 1), suffered a catastrophic flood event on October 9th, 2018.

Figure 2. Aerial image of the location of Sant Llorenç des Cardassar.



a) areas affected in relation to a flood event of 10, 100 and 500 years return period; b) images of the flood event (extracted from local newspapers); and expected water height for a 10-year return period (c), and for a 100-year return period (d).

Source : maps extracted from (SNZI, 2020) and images extracted from *Mallorcadiario.com*

11 Total rainfall was estimated at 249 mm within 10 hours, in a 23 km^2 ephemeral stream catchment. The consequent peak discharge was estimated at 442 m^3s^{-1} and caused 13 casualties (Estrany *et al*., 2020).

12 The river runs dry most of the time, but on that day the river stage rose more than 4 m above the riverbed and reached up to 3.3 m in the area depicted with a return period of 100 years (Fig. 2a and 2d). Several buildings collapsed or were severely damaged during the event (Estrany *et al.*, 2020). The flood risk area modelled by the Spanish ministry (SNZI, 2020) indicated the flood risk maps for different return periods and illustrated that most of the village could be affected under these severe events (Fig. 2a). Effects from the event can still be seen in images extracted from Google Earth (Fig. 2b, 3a and 3b), in which some small buildings next to the channel disappeared and have not been replaced.

Figure 3. Image of one of the bridges crossing the channel. Both images are taken from Google Maps Street View.

a) 2013 and b) 2024. Note the disappearance of the garages and the traffic sign placed in image a) respect the same location in image b).

13 According to Lorenzo-Lacruz *et al*., (2019), bridges acted as a water retention obstacle, favouring water overflowing and running through adjacent streets. In addition, the estimated flow velocity due to the presence of a concrete channel dramatically increased hazards, given that it could reach values as high as 7 m s^{-1} at some points (Lorenzo-Lacruz *et al*., 2019). The channelization and the concrete transformation of the torrent section took place after a flood in 1989, in which a rainfall event of 156 mm in 2 h affected several areas of the village (Lorenzo-Lacruz *et al*., 2019). The maximum capacity of the river section is 161 m^3s^{-1}, which is a value much smaller than the 307 m^3s^{-1} simulation obtained by the authors (Lorenzo-Lacruz *et al*., 2019), and the 442 m^3s^{-1} measured in the hydrometric station of the torrent during the event (Estrany *et al*., 2020).

14 The disaster was generated by a very high-risk exposure of buildings and infrastructure to floods, even though the flood risk planning showed a high level of risk exposure (Estrany *et al*., 2020). The lack of early warning systems and a lack of protocols and regulations to instruct people how to act before such extreme events also contributed to the disaster (Estrany *et al*., 2020), as well as the lack of awareness of the inhabitants (Lorenzo-Lacruz *et al*., 2019).

15 From the studies cited it could be derived that the channelization was insufficient to hold a flood of this magnitude and that the bridges and channel corners acted as water stoppers for flow and debris (Lorenzo-Lacruz *et al*., 2019). The "improvement" proposal of the river section was to increase its width when the channel crossed the highway located downstream from the village, to "facilitate or enhance the drainage". Fig. 4 shows a snapshot of a video promotion of the "enhancement" of the river channel

when crossing the highway. However, 7 years after the event, the project presented has not been built and no further actions within the river channel when crossing the town have been considered.

Figure 4. A snapshot of the enlargement of the river section project downstream of Sant Llorenç.

This is the only “improvement” project presented after the occurrence of the severe event (Consell de Mallorca, 2024).

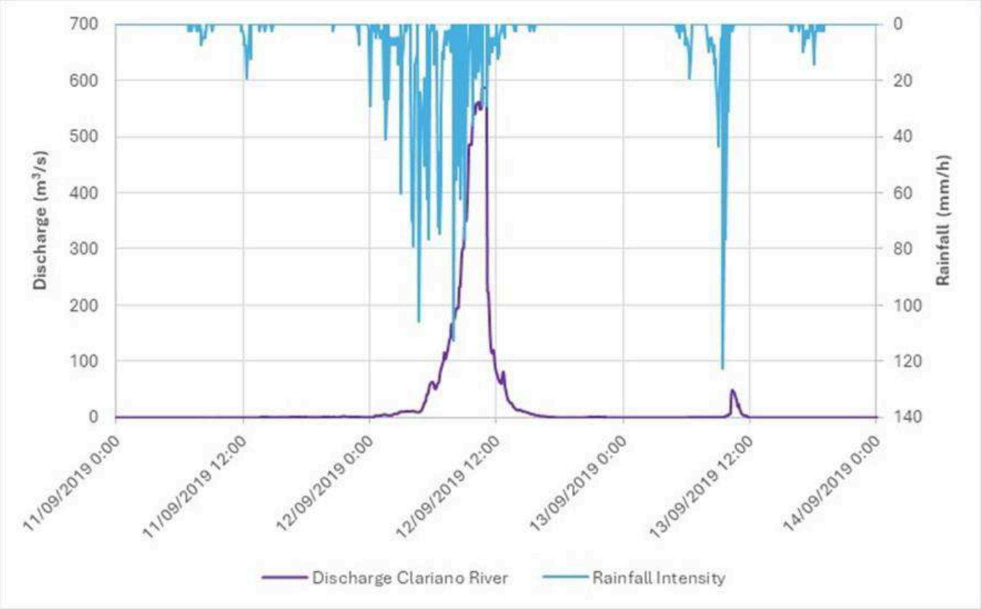
Case 2: The Clariano River at Ontinyent (València): “A restoration based on de-urbanisation to reduce flood risk”

16 The Clariano River is an example of a river restoration in which the aim of the restoration project was the reduction of the flood risk in a particular quarter (the *Cantereria* Quarter) of the city of Ontinyent, a town with 36,400 inhabitants and located 90 km south from València city (Fig. 1). The *Cantereria* Quarter was constructed during mid 1950’s and consisted of a row of houses, workshops and garages located along a strip next to the river. In fact, it was built within the river channel (Fig. 5b). It occupied a section 575 m long and had a surface area of 30,000 m^2. The solution promoted by the local administration to reduce flood risk was to demolish the buildings and move its inhabitants to other areas within the city of Ontinyent.

17 This area has recently suffered two major flood events in a very short period: on September 12^{th}, 2019, and again in January 2020. The event in 2019 shows a very high rainfall intensity record, exceeding 100 mm/h in different occasions during a 12-hour period (Fig. 5). The total rainfall amount was around 350 mm in Ontinyent, but upstream rain gauges registered 400 mm and slightly over. It is likely that the rainfall amount was underestimated given that the event exceeded the measurement capacity of rain gauges. Therefore, a very fast, continuous in time, and steep increase of river discharge occurred, reaching a peak of 580 m^3/s (Fig. 5 and 7a). The mean daily discharge of the Clariano River before the event was 0.115 m^3/s.

18 According to flood models developed by the Spanish Ministry of Environment, the peak discharge recorded in the hydrometric station during the event was expected to occur under a flood event within the range of 50 and 100 years of return period (Table 1).

Figure 5. Flood hydrograph of the event occurred on September 12th, 2019 at Ontinyent.



Data provided by Confederación Hidrográfica del Júcar (2025).

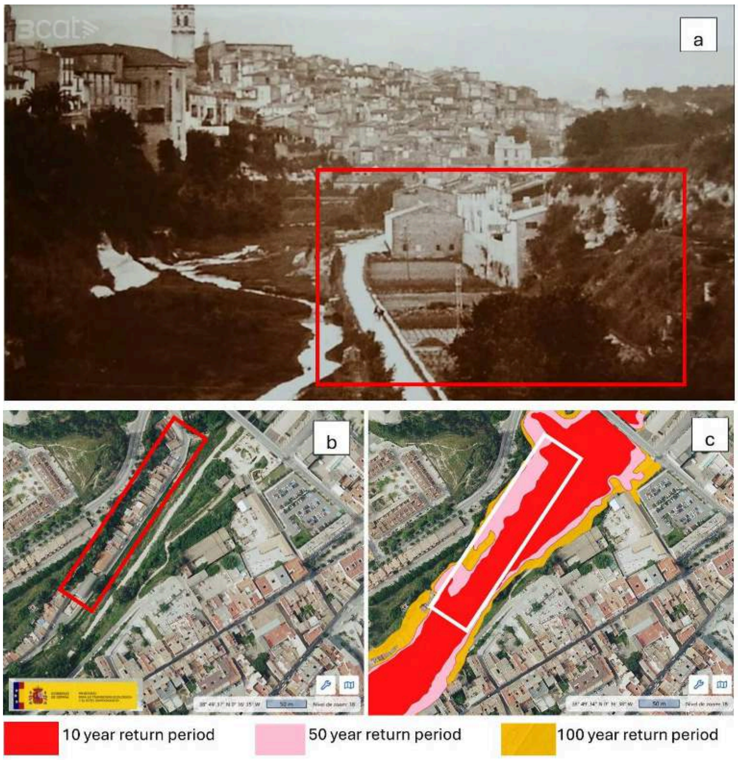
19 The magnitude of the 2020 event is unknown, as the river discharge measuring station did not work properly during the event. The closest information was provided by the discharge entering a reservoir (El Bellús), located a few kilometres downstream from Ontinyent. The peak discharge recorded was, in this case, 300 m^3/s. Although it is likely that the peak discharge would have been greater than this value, this magnitude exceeds the 25-year return period flood and again caused flooding problems and evacuations in the *Cantereria* Quarter (Table 1).

20 These consecutive flood events forced the local government to decide how the increasing flooding risk in this area should be managed. They decided to acquire the houses by means of expropriations and demolish them (Fig. 6b); that is, to undergo through a de-urbanisation process. The buildings were excluded from a patrimonial list of the town, allowing the demolition (TVdO, 2021). The inhabitants were compensated economically according to the price of the property register, which was lower than the price that these houses would have had in a free property market. This decision, despite confronting neighbours and administration, was a new approach and a new way to face and tackle the increasing risks of global warming on riverine areas.

21 The local administration brought down 40 buildings and returned to the river "what belongs to the river", in the words of the mayor of the city (La Sexta, 2024). However, the space returned to the river has not been added to the river channel section but has been transformed into a "floodable public park" (Fig. 6c) that opened to the public in November 2024.

22 This kind of decision is unusual in Spain, where the mainstream thinking has been building walls and channelizing rivers for decades. The *Cantereria* Quarter has more houses in the flooding area of the river, but no further decisions have been taken in this case yet.

Figure 6. Cantereria Quarter, Ontinyent (València) in a) 1940's. The houses were built during 1950's occupying an orchard area within the river floodplain; b) Aerial image of the quarter during low flow conditions; and c) Areal flooded area for 10, 50 and 100 years return period, which represent a water stage of 5, 6 and 12 m respectively from the centre of the river channel (Table 1). Compare this figure with Figure 7a.

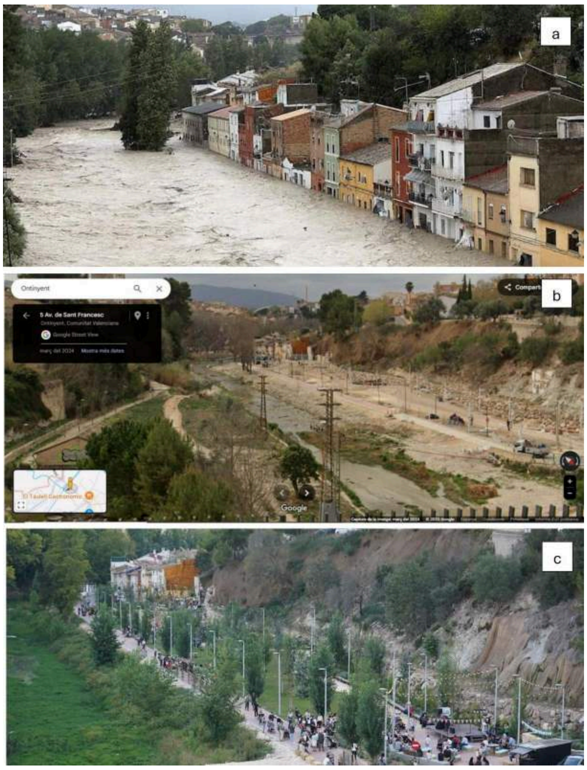


Source: 3cat.cat (2024) and SNCZI (2020).

Table 1. Estimated water stage and discharges for different return periods (SNCZI, 2020).

Return Period	T=2	T=5	T=10	T=25	T=50	T=100
Estimated water stage (m)	-	-	4,8	-	6,4	11,8
Estimated discharge (m^3/s)	55	130	188	271	300	828

Figure 7. a) *Cantereria* Quarter under flooding conditions (September 2019); b) Demolition and removal of the houses (March 2023); c) Flooding urban park inauguration (November 2024).



Sources: a) La Vanguardia (September 15th, 2019); b) Google Earth, March 2023; c) Google Earth, November 2024.

23 The case study is interesting given that not only the exposure and vulnerability have been physically reduced, by removing houses and people, but also, agreement among different administrations (Spanish Government by means of the Confederación Hidrográfica del Júcar, and the local government), as well as funding sources (European Union and the Regional Government of Valencia), have resulted in the achievement of the project.

Case 3: Granollers (Barcelona): "Induced hydro-geomorphological changes in a renaturalized urban river"

24 Of the case studies presented, the restoration of processes in the Congost River in Granollers is probably the best example of a combination of river re-naturalization with a recuperation of proper fluvial hydro-geomorphological river processes. Granollers is a city of 60,000 inhabitants, located 30 km north from Barcelona and belonging to its metropolitan area (Fig. 1). The Congost River flows through the city and it was channelized and disconnected from its floodplain due to the severe floods in the metropolitan area in 1962, which resulted in more than 800 casualties and persons disappearing (La Vanguardia, 1962). During 1970's the river was channelized to prevent flooding and gradually the floodplain became occupied by industrial polygons and buildings due to the city growth and expansion (Fig. 8).

Figure 8. Evolution of the river channel at Granollers from 1945 (left) to 2022 (right). The river channel has been reduced from 300 m wide in 1945 to 80 m in 2022.

Source: own authorship using aerial images from the Cartographic and Geological Institute of Catalonia (2023).

25 The municipality of Granollers started to remove concrete structures in the river stretch downstream from the main urban nuclei during the period 2007-2010 to increase the biodiversity and transform the artificial-concrete channel to a “better shaped river”. The removal of such structures allowed the river to recover lateral mobility as well as longitudinal connectivity. After just over a decade, the river has recovered its own natural processes by eroding the artificial banks and redistributing the sediment along the river section (Fig. 9). The river started to create proper river morphology according to the slope, the sediment available and its calibre, and the flood regime. A trend in the recovery of the initial braided channel morphology, still visible in 1945 (see Fig. 8a), is detected in Fig. 9b. The ecological status of this river stretch, in comparison to the river section that was not re-naturalized, has improved (Farguell *et al.*, 2024a).

Figure 9: a) Example of the unrestored and b) restored Congost River section in Granollers.

Source: Google Earth 2023.

26 The assessment demonstrated that the re-naturalized section had improved in several indicators such as the amount and diversity of macroinvertebrates, the quality of the riparian forest, the morphology of the river channel and the sediment mobility, while the urbanized section obtained lower scores (Farguell *et al.,* 2024a). Despite this, the re-naturalization achieved was moderate. The main reason was that in addition to the physical and ecological improvement, the river is still constricted by the channelization, which limits the recovery of the floodplain and the development of a real riparian forest (Farguell *et al.,* 2024b).

27 Current research in this section monitors the channel evolution and changes after flood events, the degree of resilience, an identifies the main effects of re-introducing river processes in a channelized river. However, further works are currently being undertaken by the municipality, now in the non-renaturalized section, to improve the river view in the inner urban area. These works may interfere the resilience of the river system downstream and will produce further changes. The Congost River has become, therefore, a living lab to observe the effects on urban river systems of the re-introduction of hydro-geomorphological processes.

Discussion and conclusions

28 The cases summarized in this study exemplify the degree of human intervention on river systems, or, in other words, the degree of *anthropization* of river systems in three examples of Mediterranean rivers in Spain. All phases described here illustrate an initial river modification, basically related with flood risk prevention by channelization and disconnection of the river from its floodplain, and currently, a phase in which diverse river restoration approaches have been undertaken.

29 In case 1, for instance, the flooded area was restored "*as it was*", meaning that no changes in the existent channelization were introduced after the flood event and leaving the concrete channel section geometry as it was. Sediments and debris accumulated in the channel were removed and "cleaned". Despite the channel structures built "to prevent the river from flooding", intense occupation of new areas has increased exposure, and such structures have spatial and temporal limitations (Pérez-Morales *et al.,* 2018). The analysis of the event suggested that the artificial channelization of the stream increased the water speed, the number of bridges crossing the river enhanced the disaster, and flood risk is more related to exposure and vulnerability rather than increased hazard (Lorenzo-Lacruz *et al*., 2019).

30 In case 2, however, a de-urbanisation and a renaturation of a flooding area have been applied to reduce flood risk and exposure and vulnerability of the population. The subsequent changes in the land planning of the city, from a private urban land use to a public park land use, is beyond the scope of this work but opens an interesting and completely new administrative procedure within Spain. It is not the only case in which local authorities plan to reconsider land uses and change from urban to a public or a non-building land use to face the increasing flooding risk that has been hitting these places twice in a very short time spam. In fact, Olcina (2024) described a whole new approach developed after the flood event that occurred in 2018 in the Segura River in the Murcia area (southeast Spain). The project, called RENHACE (an acronym for "rebirth"), was designed to increase the resilience of the Segura River to face the increasing menace of flood events due to climatic change. According to Olcina (2024), the plan is a step forward in public policy for flood risk prevention within Spain because it involves citizens and government agencies to provide and select the best solutions in terms of river infrastructure, river flood emergency plans, economic resilience and social aspects. Yet, it is a long-term achievement given that the number of properties and the built-up surfaces in flood-prone areas have increased more than 250% since 1975, especially in areas under a 10-year return period (Pérez-Morales *et al*., 2018). De-urbanisation examples can be found in French cities, in which the reduction of vulnerability is associated with the removal of the urbanization of the waterfront (Rode, 2024). However, how the proposed solution works and how different flood magnitudes may affect the de-urbanised area remain yet unknown.

31 Finally, in the third case, hydro-geomorphological fluvial processes have been restored to achieve an improvement of the fluvial ecosystem, an increasement of longitudinal and lateral fluvial continuity and restore a proper fluvial channel morphology. Furthermore, additional de-urbanization processes are currently being undertaken in the core urban part of the city. Despite this improvement, which is likely to be the one that provides river resilience because the river itself is the one that "heals" from the profound human interventions (Wohl *et al*., 2015, 2024; Kondolf *et al*., 2013), it is still under anthropic effects given that the river lacks a proper space to fully re-develop and re-connect with its floodplain (Farguell *et al*., 2024a). Providing space to the river is possibly the best solution in terms of river restoration. It increases river resilience by increasing the self-adjusting capacity of the river in terms of stream hydraulics (Batalla, 2021), contributes to develop freshwater biodiversity, and facilitates flood hazard management because more flooded area decreases speed water and the magnitude of the harmed area (McCabe *et al*., 2025; Ollero, 2025).

32 Now, we are experiencing the opposite process. The main aim of these "retro-interventions" is the improvement of the river landscape and enhancing the river ecosystem in urban areas. Such improvements enhance the aquatic ecosystem and provide environmental services to urban inhabitants, even though the restorations are not fully achieved. In this sense, Dufour and Piégay (2009) referred to the impossibility to restore the river as it was prior to the human intervention, but the aim should be focused on human benefits rather than seeking environmental perfection.

33 Anthropization of rivers and river systems are not only limited to physical transformations of the river channel and river space. It also implies that governments should provide economic funds to design and implement the restoration projects and find the equilibrium between the recovery of ecological processes and social needs.

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ABSTRACTS

River systems are among the environments that have been mostly, highly, and intensively altered and modified by mankind. The extent of such extreme modifications and alterations of river systems, especially those that flow through urban areas, forms part of what we globally call the Anthropocene, which is defined by the substantial and sometimes irreversible modification of the planet's surface by human action.
But it is not just that. Human societies have realized that the conservation of nature, and consequently the health of river spaces, also provides ecosystemic benefits and improves the quality of life of inhabitants, especially in cities. The recovery of altered river spaces to reintroduce nature into cities is also part of the Anthropocene, as it is human intervention once again modifying a previously modified space.
The debate at this point is to choose the type of intervention we want to apply to an altered river system.
The recovery of river spaces is diverse, and it depends exclusively on the objective set, which in turn depends on the situation that has led to considering a restoration.
The aim of this paper is to show different examples of restoration in the Mediterranean side of the Iberian Peninsula, where interventions within river channels were all meant to improve the life quality of inhabitants as well as the fluvial ecosystem. However, different approaches were considered, and discussion about whether these examples are a "greening" or a real "river restoration" arises. Some of the cases are thought to avoid further flooding, while others seek to transform the fluvial space into leisure and open spaces for inhabitants' amusement.
The conclusion is that, in terms of river systems, the Anthropocene encompasses everything. The examples shown tell us that it was humans who altered the river system and now want to improve it to reduce or mitigate flood hazards, and re-naturalize it, but in no case can we avoid our footprint. Therefore, what we are doing now is another modification on top of modifications, which ultimately continues to be part of this Anthropocene period.

Les systèmes fluviaux comptent parmi les environnements les plus profondément, fortement et intensivement modifiés par l'homme. L'ampleur de ces transformations extrêmes des cours d'eau, en particulier ceux qui traversent les zones urbaines, fait partie de ce que nous appelons globalement l'Anthropocène, défini par la modification substantielle et parfois irréversible de la surface de la planète par l'action humaine.
Mais ce n'est pas tout. Les sociétés humaines ont compris que la conservation de la nature, et par conséquent la santé des espaces fluviaux, procure également des bénéfices écosystémiques et améliore la qualité de vie des habitants, notamment en ville. La reconquête des espaces fluviaux altérés pour réintroduire la nature dans les villes fait aussi partie de l'Anthropocène, puisqu'il

s’agit encore d’une intervention humaine modifiant un espace déjà transformé.
Le débat, à ce stade, consiste à choisir le type d’intervention que nous voulons appliquer à un système fluvial altéré. La restauration des espaces fluviaux est diverse et dépend exclusivement de l’objectif fixé, lequel dépend à son tour de la situation qui a conduit à envisager une restauration.
L’objectif de cet article est de présenter différents exemples de restauration sur le versant méditerranéen de la péninsule Ibérique, où les interventions dans les chenaux fluviaux visaient toutes à améliorer la qualité de vie des habitants ainsi que l’écosystème fluvial. Cependant, différentes approches ont été envisagées, et la discussion s’ouvre sur la question de savoir si ces exemples relèvent d’un simple « verdissement » ou d’une véritable « restauration fluviale ». Certains cas visent à prévenir de futures inondations, tandis que d’autres cherchent à transformer l’espace fluvial en lieux de loisirs et espaces ouverts pour le plaisir des habitants.
La conclusion est que, en matière de systèmes fluviaux, l’Anthropocène englobe tout. Les exemples présentés montrent que ce sont les humains qui ont altéré le système fluvial et qui souhaitent maintenant l’améliorer pour réduire ou atténuer les risques d’inondation et le renaturaliser, mais en aucun cas nous ne pouvons effacer notre empreinte. Ce que nous faisons aujourd’hui constitue donc une nouvelle modification par-dessus des modifications, ce qui continue finalement à faire partie de cette période de l’Anthropocène.

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Mots-clés: Anthropocène, cours d’eau, systèmes fluviaux, altérations, mitigation, récupération, Espagne
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AUTHOR

JOAQUIM FARGUELL

Department of Geography and Institute of Water Research, University of Barcelona, Barcelona, Spain
ORCID 0000-0003-1944-6427
jfarguell@ub.edu