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Where have all the sediments gone? Reservoir silting and sedimentary justice in the lower Ebro River

Santiago Gorostiza [a,b,*], Giacomo Parrinello [b], Daniel Aguettaz-Vilchez [b], David Saurí [a]

[a] Departament de Geografia, Universitat Autònoma de Barcelona, 08193, Bellaterra, Barcelona, Spain
[b] Centre for History at Sciences Po, 27 Rue Saint-Guillaume, 75337, Paris cedex 07, France

A B S T R A C T

At the intersection of natural and social sciences, interest in river sedimentary fluxes and their alteration by human activities is increasing in the context of general retreat of delta formations. Since the 1950s, the construction of large dams in the main course of rivers has produced, among other impacts, a radical decrease in sedimentary fluxes — a key factor in the worldwide sedimentary crisis. While sediment accumulates in reservoirs, the resulting sediment scarcity downstream contributes to land subsidence and coastal erosion, endangering livelihoods in low lying areas such as river deltas. Focusing on the case of the Ebro River and delta (Spain), this article builds on Katherine Dawson's notion of sedimentary justice to examine the articulation of a social demand to mobilise the sediments trapped in reservoirs to counter delta subsidence and coastal erosion. Using a historical perspective and paying attention to matters of both sediment quantity and quality, we show how this demand has developed hand in hand with the emergence of a scientific interpretation of the Ebro delta's origins that emphasises non-human forces and the importance of sedimentary fluxes before human interferences. Activists have taken up this argument to demand the restoration of sedimentary fluxes, exposing corporate hydropower interests and insisting on the mobilisation of sediment trapped in reservoirs. Overall, by scrutinizing the power relations embedded in the immobilization of river sediments, this article contributes to recent work that integrates the materiality of sediment to the hydrosocial framework of analysis and argues that sedimentary justice provides new avenues to incorporate the non-human world to the literature on environmental and water justice.

1. Introduction

In January 2020, the Eastern seaboard of the Iberian Peninsula was hit by *Gloria*, one of the most intense storms of recent decades. Damages to agriculture, tourism, and public infrastructure along the coast of Catalonia (Spain) amounted to some 70 million euros. One of the worst affected areas was the Ebro River delta, about 120 km south of Barcelona. In the delta, home to 62.000 inhabitants and to one of the most important wetlands of the Western Mediterranean, the storm surge penetrated 3 km inland inundating 3300 ha of rice fields and irrigation canals and destroying aquaculture facilities (Blay & Àvila, 2020). Images showing almost the entire delta covered with water made a great impression on public opinion and raised fears that the worse scenarios regarding the impacts of climate change were already happening. Accompanied by an acute sense of urgency, *Gloria* attracted the attention of national and international media to the sediments transported by the Ebro River or, more precisely, to the scarcity of these sediments and its role in increasing exposure of the delta to storm surges and coastal erosion. In the aftermath of the storm, local actors pointed to the management of upstream dams as responsible for the meagre load of sediments transported by the river (see Burgen in *The Guardian*, 2020). In a context of worldwide retreat of delta formations (Syvitski et al., 2009), the retention of sediments in river reservoirs and the possibilities to mobilise these sediments to preserve the delta's morphology were raised as deeply political issues in front of declining liquid flows and sediment transport in the Ebro (see Fig. 1).

Similar to many other rivers throughout the world, the history of the Ebro during the second half of the 20th century shows how (some) humans have become major actors in altering river sedimentary fluxes, one of the signs indicating the beginning of a new geological era (Chakrabarty, 2021; Syvitski & Kettner, 2011). More than 100 billion metric tons of sediment have been trapped in reservoirs worldwide since the 1950s (Syvitski et al., 2005), drastically reducing sedimentary fluxes and directly contributing to the worldwide retreat of delta formations (Syvitski et al., 2009; Vörösmarty et al., 2003). In the Ebro case, the dams built in the river during the 1960s contributed to a radical decrease of sediment reaching the mouth (Vericat & Batalla, 2006). Since the 1970s, the reduction in the Ebro's sediment load has been documented in scientific studies and was invoked in political debates about the protection of the delta's ecological value (Folch, 1976). From the 1980s

* Corresponding author. Departament de Geografia, Universitat Autònoma de Barcelona, 08193, Bellaterra, Barcelona, Spain.
E-mail addresses: Santiago.gorostiza@uab.cat (S. Gorostiza), giacomo.parrinello@sciencespo.fr (G. Parrinello), daniel.aguettazvilchez@sciencespo.fr (D. Aguettaz-Vilchez), david.sauri@uab.cat (D. Saurí).

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to the 2000s, in response to state-sponsored water transfer projects from the Ebro River to other regions in Spain, an alliance between social movements and scientists warned about the consequences that reduced water flows could have in the quantity of sediments reaching the river mouth and therefore in delta subsidence, pointing to the intimate connection between liquid flows and solid transport (Ibáñez et al., 1999; Ibáñez & Prat, 2003). Given the deteriorating scenario in the delta during the 2000s, social movements in the Ebro launched the *Campanya pels Sediments* ("Campaign for Sediments") aimed explicitly at making visible the lack of sediments reaching the delta and demanding political action to restore the transport of sediments immobilized in the Ebro reservoirs (Segarra, 2020).

By exploring the case of the Ebro River since the 1960s, this paper unravels the politicisation of sediment scarcity through the lens of sedimentary justice, described by Dawson (2021a) "as an entry point through which to unearth the power relations that govern deeply uneven claims over sediment". Considering mobility as one of the central facets of sediment (Dawson, 2021a), we focus on the immobilization of sediments produced by large reservoirs and the gradual emergence of scientific and political proposals to revert the resulting sediment scarcity downstream. By examining who benefits and suffers from the disruption that reservoirs cause to sedimentary fluxes we also explore an important facet of the social and historical lives of sediment, following Parrinello and Kondolf's (2021) call for more sediment-centric perspectives in social discourses. The concept of sedimentary justice (Dawson, 2021a) makes evident that the water bias that Parrinello and Kondolf (2021) observe in river and water history literature also applies to water justice and to critical accounts of water policy in Spain, which, for the most part, have given little or no attention to sediment (Boelens et al., 2016; Sauri & Del Moral, 2001; Swyngedouw, 2015). Similarly, while hydrosocial studies have increasingly paid attention to the materiality of rivers, for the most part they have focused on the study of water flows, not on sediment (de Micheaux, Mukherjee & Kull, 2018). Overall, the Ebro case illustrates how the politicisation of sediment scarcity has developed hand in hand with the transition from a hegemonic discourse that portrays rivers as carriers of water for irrigation, drinking, and electricity production, to a new framing where water is much more than H2O, and where sediments become crucially visible to social movements and institutional actors (Kondolf et al., 2019).

Key to our study, the politicisation of sediment scarcity in the lower Ebro hinges on the examination of different interpretations regarding the delta's origins and morphology. The morphology of river deltas involves submerged and emerged parts that, in the Mediterranean, are mostly the product of complex and changing interactions between water flows and sedimentary fluxes, sea level oscillations, and the bathymetric characteristics of the coast (Caldwell et al., 2019; Cencini, 1998). Interpretations about the origins of deltas assign varying degrees of significance to human and non-human forces that influence sedimentary fluxes. In the case of the Ebro, the traditional and long-established interpretation of the origins of the delta portrayed it as a product of historical human agency in the river basin since Roman times, emphasizing how human-induced erosion related to deforestation and agricultural activity boosted sedimentary fluxes and built the delta during the last few centuries (Bayerri, 1935; Deffontaines, 1951; Kleinpenning, 1969; Pena, 1964). During the last decades, several researchers have challenged this view of the delta as human-made and have instead emphasised the importance of non-human forces influencing sedimentary fluxes, arguing that older deltaic features were present before the sea rose at the end of the last glacial period and that the progradation of the current delta goes back approximately 6000 years (Cearreta et al.,

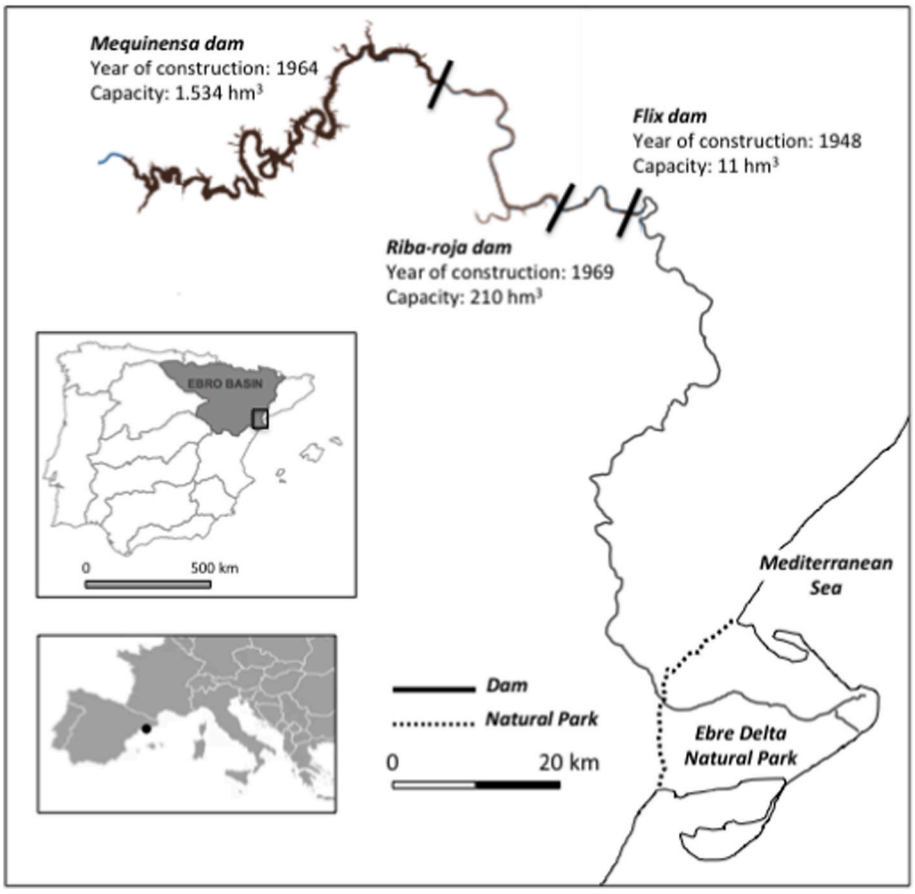

Fig. 1. The lower Ebro River, including the locations of the dams in the main stem of the river and the Ebro Delta Natural Park. Source: Authors.

2016; Ibáñez et al., 1999).

This argument concurs strongly with the move towards geologising the social sciences brought about by the Anthropocene concept, attempting to bridge geological and human history (Chakrabarty, 2009). In the Ebro case, human agency as the main driving force in the formation of the delta is in question. Moreover, for movements such as the Campaign for Sediments defending the mobilisation of sediments trapped in reservoirs, the (partly) non-human origins of the delta is also a compelling argument for legitimizing both the power of sedimentary fluxes and the conservation of the delta that critically depends on them. Hence researchers and activists portray the transfer of sediment trapped in reservoirs and the restoration of sedimentary fluxes now restrained as the only solution to prevent the disappearance of the Ebro delta in the mid and long term (Canicio & Ibáñez, 1999; Cearreta et al., 2016; Ibáñez et al., 2019; Segarra, 2020). In this regard, the Ebro case shows that geological and historical interpretations of the delta's past have political implications in present-day debates.

In theoretical terms, this case study advances the concept of sedimentary justice (Dawson, 2021a) as part of the social and political life of sediments, connected to the material turn in Geography and more broadly, in the social sciences (Bremner, 2020, 2021). By scrutinizing the power relations embedded in sediments trapped in the Ebro reservoirs, we engage with Lafaye de Micheaux, Mukherjee and Kull's (2018) call to incorporate the study of sediment to the hydrosocial cycle framework of analysis as a way to move past the land/water divide (De Micheaux et al., 2018; Linton & Budds, 2014; Lahiri-Dutt, 2014). Following de Micheaux et al. (2018), we combine our engagement with political ecology of water with insights from critical physical geography in order to make visible the deep interconnections between biophysical and social systems. Accordingly, our historical account of the politicisation of sediment scarcity not only focuses on the interrelationships between biophysical and social and historical processes (Lane, 2014) but also pays attention to the politics of environmental sciences (Dufour et al., 2017; Lave, 2015; Lave et al., 2018).

For our article we draw on archival and oral sources, which we complemented with a survey of the press. We consulted the archives of the Ebro River basin authority (Confederación Hidrográfica del Ebro), the Diputació de Tarragona (the administrative body of the Tarragona province) and several municipal archives in the delta. In addition, we carried out semi-structured interviews with activists involved in the *Campanya pels Sediments*, as well as with the engineer who led the first detailed studies about sediment transfer in the lower Ebro in the 2000s and several persons involved in the creation of the Ebro Delta Natural Park during the 1970s and 1980s (Aguettaz-Vilchez, 2020). These interviews also opened the door to reports produced for the Catalan or Spanish administration, conserved by the interviewees or at specific public libraries such as that of the Institut Cartogràfic de Catalunya.

The article is structured as follows. First, we situate and discuss the convergence of interests on sediments at the intersection of natural and social sciences, more specifically political ecology and critical approaches to physical geography. In this context, we delve into the concept of sedimentary justice (Dawson, 2021a) and its connections to political ecology and water justice. After this section, we adopt a historical narrative to show how the politicisation of sediment scarcity in the Ebro unfolded during the last half century, from the construction of the large reservoirs that disrupted sedimentary fluxes in the 1960s to the launch of the Campaign for Sediments. In this narrative we pay special attention to how different actors mobilised the importance of non-human forces influencing sedimentary fluxes in the Holocene and their role in the origins of the Ebro delta. This vision challenges the notion that the delta was the direct result of human activity in the Ebro basin; highlights the important role of non-human processes in the production of sediments but, most importantly, points to the management of the reservoirs built during the 1960s as the main responsible of current sediment scarcity in the delta.

2. The material and social life of sediments

Encompassing a wide and highly heterogeneous number of substances at the crossroads of geology, hydrology, and climate, sediment constitutes a basic component of river flows and of river life itself. The historical relationships between river sediments and human societies have been marked by a dialectic between associated benefits and risks. Both usually have a distinctive spatial component: erosion in the upper parts of catchments represents a hazard while sedimentation may create problems downstream but mostly it may be considered as a resource in terms of soil fertility and ecosystem dynamics (Apitz, 2012), among other beneficial effects. All major civilizations flourishing near great rivers have experienced this dual role of sediments as a blessing and a curse (Morris, 2012; Saikia, 2019; Zhang, 2016).

On the one hand, sediment appears in the form of fertile soils, building materials, space for human habitation, and home to complex webs of biotic resources at the interstices of terrestrial and aquatic environments (Apitz, 2012; Beiser, 2018; Walling & Fang, 2003). On the other hand, however, sediment can turn into a formidable enemy as the piling up of silt creates "perched" rivers circulating above floodplains and making necessary the construction and continuous maintenance of dikes to contain floods. Excessive sediment loads silting reservoirs and raising riverbeds can become an obstacle for navigation and for dams. In some cases, industrial activities developed since the late 19th century polluted waters and eventually sediments, which turned into hazardous materials when reaching agricultural fields. Sedimentation thus could turn into a major chemical hazard due to industrial pollution, one of the first documented examples being that of the Ashio Mine in Japan, in the early 20th century (Stolz, 2014). Therefore, in addition to quantity, the quality of sediments could be also an issue of concern.

More recently, the interest in sediment and its environmental, social, and political implications has been approached in relation to climate change, and especially in low-lying areas where their presence is considered vital for offsetting the effects of subsidence, marine erosion, and sea level rise as well as for producing rich biotic environments (Bravard, 2018; Kondolf et al. 2018; Vörösmarty et al., 2003). A convergence of interests by the social and natural sciences on sediments can be currently detected, echoing the more developed sociohydrology perspective in water studies (Best et al., 2022; Sivapalan et al., 2012). In the social sciences, some authors argue that debates about human agency in global changes have reversed the indifference with which earth processes have been traditionally received by social scientists (Clark & Yusoff, 2017). Among such processes, the sediment cycle is increasingly approached from a material perspective emphasizing physical properties and dynamics of sediment seen as enabling, constraining, or simply moving along social and political action (Bremner, 2020, 2021; Clark & Yusoff, 2017). Sediments may be used to accomplish certain specific social and political goals at each stage of the sediment cycle (Bremner, 2020). For example, sand imported from Cambodia and used for land reclamation in Singapore expands the national "territory" in this city-state (Beiser, 2018; Jamieson, 2021). However, sediment may also disrupt those goals (Bremner, 2020). The agency of sediment appears in issues ranging from the transformation of Rhône and Mississippi deltas (Duperrex, 2019) to the changing landscapes of riverine islands in the lower Ganges (Lahiri-Dutt, 2014; Mukherjee & Lahiri-Dutt, 2021), and to intervening in the class and gender divides in North Bihar, India (Cortesi, 2018). In all these contributions, social scientists including political geographers (Hommes et al., 2022), are willing to explore routes towards the hybridization of the social with the material breaking up land and water, and nature and society binaries.

A similar path towards hybridization seems to be pursued in the case of the natural sciences and especially in critical physical geography which emerged as both a reaction to the progressively dominant position of the social sciences in new socionatural disciplines such as political ecology and as an interest in exploring the relationships between

biophysical and social systems (Lave et al., 2018). In the case of sediments, this interest arises from increasing human interferences in the sediment cycle. The construction of large dams in many river courses throughout the world has caused a drastic reduction in sediment transport reaching deltas and other low lying coastal areas (Syvitski et al., 2005, 2022; Vörösmarty et al., 2003). However, the low sedimentary loads observed in some Mediterranean rivers are also related to deep socioeconomic changes in the wider catchment geographies conducive to decreases in sediment production (Dufour et al., 2017; Scorpio & Piégay, 2021). Moreover, the increasing extraction and consumption of sediment by human activities, most notably sand for construction, beach reposition and land conservation, and advanced industrial uses, implies a deep reconfiguration of sediment fluxes in which economic interests join natural processes as key driving forces (Syvitsky & Kettner 2011; Beiser, 2018). Both from the social sciences and from the natural sciences there is a growing recognition of the need of overcoming the nature-society divide and work towards more hybridized scientific approaches in the line of the planetary social science advocated by Clark and Szerszynski (2020) but also attentive to social and environmental justice (Lave et al., 2018).

Incorporating both perspectives helps to produce more nuanced explanations of the interplay between the material and the social. For example, in the Mediterranean, the increase in sedimentary territories found in the final stretches of rivers has been attributed to human induced erosion in the mountainous upper catchments since Roman times (Maselli & Trincardi, 2013). However, longer geological records reveal periods of relatively frequent large floods with abundant production and transportation of sediment as well (Cearreta et al., 2016). Likewise, decreasing sediment fluxes in rivers today could be attributed to declining rainfall but also to land use changes, for example afforestation processes following the collapse of traditional mountain economies that reduce erosion and the capacity for the mobilisation of sediment. These two scenarios are present in the case of the Ebro basin and delta, setting the scene for different interpretations regarding human and non-human factors explaining the fluctuations of sedimentary fluxes and the evolution of deltaic morphologies. At any rate, the interplay between material, social and political agencies in the different stages of the sediment cycle helps to understand why between 1950 and 2010 human activities at the global scale have simultaneously boosted river sedimentary fluxes by 215 percent and reduced the amount of sediment reaching the oceans by 49 percent, with reservoirs largely contributing to the latter figure by immobilizing sedimentary fluxes (Syvitski et al., 2005, 2022).

The convergence between the material turn in social sciences and the recognition of human agency in interfering with Earth cycles by natural scientists has profound social and political implications which, in the case of sediments, can be best unearthed by hybrid concepts such as "sedimentary justice" (Dawson, 2021a). Dawson conceives sedimentary justice as "a lens through which to excavate the layered politics of access, rights, and security of sediment" and mostly focuses on the spectacular expansion of sand extraction and trade (2021a). This notion connects to efforts towards the geologization of political ecology (Dawson, 2021b), in line with Clark and Yusoff's calls for a "politicisation of the geologic" and a "geologization of the political" (2017:17). While Dawson (2021a) does not relate sedimentary justice to the literature on water justice nor political ecology of water, there is ample space to do this in light of recent work that discusses water justice as historically rooted and contingent, while underlining its relational and multi-scalar character (Perreault et al., 2018). However, the literatures on water justice and political ecology of water have so far paid little attention to sediment.

In this regard, the lens of sedimentary justice can contribute to De Micheaux, Mukherjee and Kull's proposition of "a materially enriched hydrosocial cycle" (2018:645) that takes sediment into account, by analysing power relations embedded in water and sediment-related governance; scrutinizing how understandings of sediment as nuisance and resource change over time, as well as by interrogating scientific interpretations of river geomorphology and delta development and the role of human and non-human forces in these. In sum, the concept of sedimentary justice may provide a more encompassing approach to the complexity of fluvial systems that is somewhat constrained by the concept of water justice and its emphasis on the liquid component of rivers. Likewise, sedimentary justice would relate better to new developments in environmental justice in providing a wider field of theory and practice for incorporating the non-human world (Schlosberg, 2013).

While the notion of sedimentary justice (Dawson, 2021a) has not been drawn on widely, several recent studies explore the overlap between sediment politics and questions of justice. For instance, the Farakka Barrage Project in the lower Ganges has modified riverine sedimentation patterns and, among other impacts, this has changed the dynamics of formation and dissolution of river islands —known as *chars*. In consequence, the vulnerable *char* dwellers have been repeatedly forced to resettle, with a lack of responsiveness from the authorities (De Micheaux et al., 2018; Mukherjee & Lahiri-Dutt, 2021). In the lower Mississippi River, the local African American community has opposed a river diversion project aimed at directing sediment-rich flows to protect coastal areas on the grounds that it reinforces a history of racial inequalities connected to coastal engineering (Barra, 2021). In the Rhône River, fishers, environmentalists, and local communities have complained about dam flushing operations to restore sediment transport, due to their impact in spreading pollutants and affecting the local fauna (Guerrin et al., 2021). Last, but not least, the importance of restoring sediment transfer is one of the scientific arguments mobilised —and disputed— in the often-controversial projects for dam removal (Dufour et al., 2017).

As these cases suggest, the disruption of sedimentary fluxes caused by dams and the uses of sediment for river and coastal restoration offer a fertile avenue for studies of sedimentary justice. A case in point is the gradual but continuous deposition of sediments in reservoirs (Syvitski et al., 2022), known as reservoir silting or reservoir sedimentation. As a result of the accumulation of water in reservoirs, the substances suspended and dissolved in the turbid flows of rivers tend to settle to the bottom, slowly reducing its storage capacity (Schleiss et al., 2016). However, beyond the natural deposition of solids in reservoirs, the immobilization of sediments is favoured by specific uses of stored river flows. Sediment in flowing waters is considered an obstacle for hydropower plants, due to the abrasion it causes in hydraulic machinery such as turbines and their cooling circuits (Arora et al., 2022; Schleiss et al., 2016). Therefore, water uses for hydroelectric production favour the immobilization of sediment in reservoirs, upholding "clean" water and strengthening the land/water separation. The fact that the storage volume of reservoirs continues to be described as water despite the gradual reduction caused by sediments illustrates how "[t]he perspectives of dominant actors and available data often promote a view of river waters as a liquid resource only" (De Micheaux et al., 2018: 644). Most importantly, while sediment accumulates in river reservoirs, the resulting reduction of sedimentary fluxes downstream contributes to land subsidence and coastal erosion in deltas and other low lying coastal areas (Syvitski et al., 2009). Together with climate change this has multiplied what Dawson (2021a) calls "sedimentary insecurity" for humans and ecosystems present in these areas.

Finally, sedimentary justice acknowledges the importance of both sediment quantity and quality (Dawson, 2021a). Due to the long-time scales involved both in the alteration of sediment fluxes and the power relations embedded in them, this perspective requires a historical approach (Parrinello & Kondolf, 2021). Moreover, the immobilization of sediment in reservoirs can also fix toxic substances which remain a hazard decades after they were deposited, potentially reemerging in the future (SedNet, 2004; see also Guerrin et al., 2021). Last, but not least, a historical approach can also enlighten the changing perceptions of sediments from nuisances to resources as they evolve together with human societies becoming imbued with social and political matters

(Bridge, 2009; Guerrin et al., 2021). However, history needs to transcend the purely human past and embrace longer term, geological perspectives as well (Chakrabarti, 2019).

3. Dam building and the disruption of sedimentary fluxes

In 1955, the Instituto Nacional de Industria (National Institute of Industry) commissioned the construction of two large dams as part of the plan to expand hydropower in the Ebro basin. The construction of Mequinenza and Ribarroja reservoirs on the lower Ebro, with storage capacities of 1534 hm^3 and 207 hm^3 respectively, dwarfed in size the reservoir of Flix, completed in 1948 (11,4 hm^3). When they started operating in the late 1960s, Mequinenza and Ribarroja represented a major step of the hydraulic modernization project of the Francoist dictatorship (Swyngedouw, 2015). Built on the main stem of the river and with a large capacity, they became a barrier for sediments as soon as they were erected, reducing bedload sediment transport to the delta by 95% (Vericat & Batalla, 2006). At the time, however, engineers did not consider the potential impact of the interruption of sediment fluxes on delta sedimentation.[1] This has a parallel with the Po River in Italy, where the construction of Isola Serafini Dam did not trigger concerns about downstream impacts of the reduction of sedimentary fluxes when it was being built (Parrinello et al., 2021).

This is partly explained by the prevailing ideas about sediment excess in river waters, widely established by the mid-20th century. The incessant progradation of deltas was taken for granted. In the Ebro, writing in 1936, British geographer E.H.G. Dobby stated that the delta had progradated near 50 m in the 20th century. Dobby left a rich testimony of the Ebro delta landscape, with references to the uses of sediment in agriculture but also to the nuisances it caused. He observed how deposits by regular annual floods had reduced the effective heights of old houses' doors, estimating an increase of 50 cm along the riverbanks since 1900. Moreover, sediments silted irrigation canals, requiring regular cleaning (Dobby, 1936). The abundance of sediment hindered river navigation, as engineers working at the river basin authority (Confederación Hidrográfica del Ebro) highlighted immediately after the Spanish Civil War.[2] They argued that the solid matter transported by the Ebro was higher than in any other European river with a similar gradient and pointed at the "quick growth of the delta" as a proof of the abundance of sediment.

This situation changed when the impact of the dam construction started to be felt. In the late 1960s, Dutch geographer J.G.M. Kleinpenning pointed out that the delta was still growing, although at a much slower rate. Less sediment was reaching the river mouth, he argued, for two reasons: first, the barrier effect of large dams, and second, the ongoing reafforestation of the basin (Kleinpenning, 1969). In other words, most of the solid matter transported by the river was captured in the dams, but reafforestation was also reducing erosion and therefore decreasing the amount of sediment that ended up in rivers. Citing the work of local historians and geographers, Kleinpenning considered that the formation of the delta was "a recent phenomenon" in geological terms. According to this account, in the 6th century B.C. the city of Tortosa was still a port, while by the time of the Roman occupation the town of Amposta was still by the sea. Only in the 14th and 15th centuries, he argued, did the delta start growing rapidly, when the increasing rates of deforestation in the basin led to erosive processes that brought vast quantities of sediment to the Ebro tributaries, its main stem and, finally, to the delta plain (Bayerri, 1935; Deffontaines, 1951; Kleinpenning, 1969; Pena, 1964).

Kleinpenning's account summarises the conception of the delta as a relatively recent formation resulting from human activities in the river basin. However, around the same time, another researcher who was carrying out a PhD thesis on the geological origins of the delta came up with a different view. Unlike accounts that focused on the recent history of the delta's surface and emphasised the role of humans in the formation of the delta, geologist Andrés Maldonado adopted a longer time scale involving non-human forces. He argued that similarly to other large deltas, the deposits on the Ebro delta's base had their origins in the end of the last glacial period, when sea level rise submerged the "primitive delta plains" —as Maldonado referred to them. Using carbon-14 dating technology, Maldonado concluded that the basis of the delta started accumulating around 13.000 years before present (Maldonado, 1977; Solé Sabarís et al., 1965). Along with this new understanding on the delta's origins, Maldonado stated that the emergent part of the delta had been prograding significantly between the 17th and 19th centuries. In other words, the delta surface had changed significantly in the last five centuries, but its origins went back thousands of years (Maldonado, 1977).

During these very same years the claims that the Ebro delta had stopped growing reached the general public. Ramon Folch, a leading scientist at the Institució Catalana d'Història Natural (ICHN), observed that the delta had ceased its progradation of 10 m per year, which he attributed to construction of the reservoirs, and warned that the coastline had started to retreat (Folch, 1976). At the time, however, the Ebro delta faced more urgent threats than a decrease in the sediment load of the river. From large state-sponsored plans for agricultural drainage to urbanization projects for touristic uses and inter-basin water transfers, several development projects threatened the delta's ecological value and the highly diverse waterfowl population (Folch, 1976). It was the concerns over the ecological value of the delta's wetlands what eventually sparked the creation of a protected area in 1983, when the Catalan government approved the creation of the Ebro Delta Natural Park. This regional park ensured the protection of several wetlands of ecological value but left ample space for agriculture and human activities (Aguettaz-Vilchez, 2020). However, it did not influence river management, as the Catalan government had no legal power to regulate the Ebro River flows or to protect the delta's coast; both were and remain competences of the Spanish state, through the corresponding ministries and the river basin authority. The first proposals to mobilise the sediments trapped in the Ebro's reservoirs emerged during the following years, in the context of the scientific criticisms of large inter-basin water diversions sponsored by the state. Along with these, the arguments supporting the non-human origins of the delta gained new force.

4. Less water equals less sediment. Challenging interbasin water transfers

During the early 1990s, a state-sponsored draft for a National Hydrological Plan (NHP, Plan Hidrológico Nacional) envisaged that more than 1000 hm^3 per year should be diverted from the Ebro to Eastern and South-eastern Spain and to Barcelona (Swyngedouw, 2015). Scientists and environmentalists criticised these plans for their lack of attention to environmental impacts and a widespread social mobilisation against diversion projects formed in the Ebro River basin (Arrojo & Gracia, 2000; Ibáñez et al., 1999). A key claim of the local governments in the Ebro delta was that water transfers could worsen coastal regression, which they related to the lower fluxes of sediment connected to decreasing river water flows (La Vanguardia, 1985, 1990b).[3] Despite

[1] We have found no discussion on the impact of reservoirs in sedimentary fluxes in the projects of Mequinenza (1957) and Ribarroja (1958), nor in the "Plan de aprovechamiento del tramo del río Ebro entre Escatrón y Flix" (1956), all of them kept at the Archivo de la Confederación Hidrográfica del Ebro.

[2] See 'Referencia No6099. Informe sobre la navegación por el río Ebro' (1940, p. 181) authored by José Bravo Suárez and José Cruz-López Larrañaga; Ministerio de Obras Públicas and Confederación Hidrográfica del Ebro. Archivo de la Confederación Hidrográfica del Ebro.

[3] Letter from the Mayor of Sant Carles de la Ràpita to the Diputació de Tarragona, 5 December 1980. Arxius de la Diputació de Tarragona, box 991, 16B.

calls for calm by politicians who downplayed this possibility (La Vanguardia, 1990a), several storms affecting the Ebro delta in 1990 heightened these concerns. The southern bar of the delta (El Trabucador) broke in October 1990, leaving one of the delta's spits surrounded by water for months (La Vanguardia, 1990c). During the following years, several projects studied the best means to prevent the regression of the delta. The reports commissioned by the Irrigation Communities proposed building hard defenses and pumping sand artificially to protect the delta (La Vanguardia, 1992).[4]

As an alternative to this infrastructural approach, the idea of mobilising the sediment trapped in the large reservoirs of the lower Ebro started taking shape in scientific circles. In 1994, geologist Antoni Canicio and biologist Carles Ibáñez delivered a report to the Catalan administration in which they pointed at the scarcity of sediment in the lower Ebro River as the main cause of the delta's degradation. This was the result, they argued, of a hydrologic planning model that did not take into consideration that rivers carried solid matter, not only water. The drastic reduction of sediment reaching the delta after the construction of hydropower plants in the main stem of the river constituted "a severe aggression to the deltaic environment" (Canicio & Ibáñez, 1994, p. 80). To alter this process, they advised to establish a sediment management plan including measures to by-pass sediments immobilized in Mequinenza and Ribarroja reservoirs. Otherwise, they argued, the coastline would continue being eroded and the delta plain would keep sinking. This and other studies by the same authors emphasised the risks caused by the subsidence of the delta plain, which could be aggravated by sea level rise associated with climate change. Flushing sediments from the dams thus increasing solid matter reaching the delta was portrayed as a sustainable solution to counter this process which deserved to be studied in detail (Canicio & Ibáñez, 1994; Ibáñez et al., 1997; Ibáñez et al., 1996).

These arguments about the value of sediments and the causes of its scarcity in the river's mouth came accompanied with research that for the first time forcefully emphasised the non-human origins of the Ebro delta development. Following research discussing the early origins of world deltas and using radiocarbon dating techniques (Stanley & Warne, 1994), Canicio and Ibáñez (1999) built on the work of Maldonado (1977) and challenged authors (e.g. Guillén & Palanques, 1997) who portrayed the Ebro delta as the result of a quick development during the medieval period, mostly related to human intervention in the river basin (deforestation and agricultural development). Not only did they criticise the inattentive use of historical sources (Ibáñez et al., 1996) but also questioned interpretations of historical accounts that described the city of Tortosa as a seaport in Roman times (Bayerri, 1935; Serra Reventós, 1997), objecting to them for a lack of scientific basis. Instead, using carbon-14 techniques, they dated parts of the delta going back 5745 years before present (Canicio & Ibáñez, 1999). These analyses brought the Ebro delta case in line with other Holocene deltas that originated after the last sea level rise (Stanley & Warne, 1994).

Despite the recommendations to consider sediment management policies, neither the Catalan government nor the river basin authority explored these possibilities at the time. After the victory of the conservative party in the 1996 Spanish elections, public discussion about the Ebro delta's future was increasingly marked by the re-emergence of water diversion plans from the Ebro as part of a new National Hydrological Plan (NHP). The conservative government announced the project in the year 2000, involving (again) the diversion of more than 1000 hm^3 per year from the Ebro to the South-eastern regions as well as to Barcelona (Swyngedouw, 2015). In response, the so-called Platform in Defence of the Ebro (PDE) was launched, bringing together social movements, non-governmental organisations, and scientists critical of the NHP. Among the organisations forming the PDE there were several groups that had been active in the Ebro River basin throughout the 1990s and before, when they rejected inter-basin water transfers and large hydraulic works, focusing instead on managing water demands and promoting efficiency, desalination, and reutilisation policies (Tàbara & Ilhan, 2008). Several relevant scientists critical of the NHP —such as Carles Ibáñez, Narcís Prat or Pedro Arrojo— participated actively in the PDE.

From the preservation of wetlands and the life of birds to the protection of local livelihoods and the fate of river sediments, the PDE mobilised a diverse set of human and non-human concerns in its criticism of the NHP (Swyngedouw, 2015). The idea that further water diversions from the Ebro would endanger the river delta was one of the central claims. Diminishing water flows would have negative effects on the delta's hydrology and ecology, worsening problems of eutrophication and salinization. It is in connection with these arguments that the decrease of sedimentary fluxes was brought to the fore. One of the most prominent scientists critical of the plan, Pedro Arrojo, argued that further water transfers would also reduce the already scarce sedimentary fluxes and worsen both delta subsidence and coastal erosion processes. Citing the research of Carles Ibáñez and other scientists (Ibáñez et al., 1997, 1999), Arrojo pointed out that larger river flows and regulated floods were needed to maintain the ecological value of the delta and called to consider "new techniques of sediment management" (Arrojo & Gracia, 2000, p. 12). In contrast to this vision, the state-sponsored studies of the NHP impacts regarded the effects of the massive water transfers projected for sediment transport as "practically negligible" and therefore did not include any compensatory action (Centro de Estudios Hidrográficos, 2000, p. 54).

Despite the significant social opposition to the NHP in the Ebro basin, the Spanish conservative party approved the plan in 2001. In this context, since one third of the funds required for it depended on the EU contribution, the PDE focused their efforts on convincing European authorities about the negative environmental and socioeconomic impacts of the plan (Tàbara & Ilhan, 2008). To do so, they put upfront the endangerment of the delta ecosystems and the importance of taking sediments into account when calculating the minimal river flows required to sustain their mobilisation (Ibáñez & Prat, 2003; Arrojo Agudo, 2003). Coinciding with these efforts, several storms affecting the Catalan coast brought again under the spotlight the degradation of the Ebro delta (La Vanguardia, 2002a).

The symbol of the Platform in Defence of the Ebro River —a knotted pipe— and the blue colour of their iconic t-shirts make evident the focus on water in the opposition to inter-basin transfers during the 1990s and early 2000s. However, the scarcity of sediments was implicit in the movement demands for larger river flows and explicit in the arguments about the value of sediments to compensate for the delta's subsidence. In fact, in 2002 the PDE already protested the immobilization of sediments in reservoirs by removing a symbolic quantity of sediments from Mequinenza and pouring them in the delta (La Vanguardia, 2002b). During the first decades of the 21st century, as the impacts of climate change became increasingly manifest, the claim for more sediment reaching the delta became the foundation of a campaign launched by several organisations in the lower Ebro River.

5. Campaigning for more sediments

In early 2004, the Directorate-General for the Environment of the European Commission advised against the EU funding of the Ebro water diversion. Their report —leaked to the press— included some of the arguments advanced by the PDE, pointing to the ecological impact that the reduced river flows could have in the delta as one of the reasons against funding the project (La Vanguardia, 2004a, 2004b; Tàbara & Ilhan, 2008). Without the EU support, the fate of the NHP was sealed, and the unexpected socialist victory at the 2004 Spanish elections

[4] Comunidad General de Regantes del Canal de la Derecha del Ebro, and Iberinsa. 1992. '0479A Estudio de la Regresión del Delta del Ebro y Propuesta de Alternativas de Actuación'. Archivo de la Oficina de Planificación Hidrológica (CHE).

confirmed its demise. One of the first measures taken by the new government was to cancel water diversions and propose the building of desalination plants instead (Swyngedouw, 2015).

However, the interest among scientists involved in the PDE in the mobilisation of sediments and the possibility of using part of the funding already promised by the EU led to the first studies that examined the feasibility of sediment transfers from reservoirs to the delta. In 2004, at the request of the Catalan Water Authority and the *Fundación por la Nueva Cultura del Agua*, engineer Juan Pedro Martín-Vide prepared an economic, technical, and environmental assessment on the sources of sediment in the lower Ebro and the available techniques to transport it to the delta. Martín-Vide concluded that flushing sediments from the Ribarroja reservoir was the least costly measure to restore sedimentary fluxes to the lower Ebro and alleviate the delta's subsidence. Even if Martín-Vide considered that the benefits of restoring sediment supply to the delta would be apparent only after decades, he believed that these policies could avoid much more costly interventions in the future (Martín-Vide, 2004).

Less than two months after Martín-Vide delivered his report in 2004, a major scandal involving pollutants immobilized in the sediments of Flix reservoir —located downstream of Ribarroja— hit the news (La Vanguardia, 2004b). According to a scientific study requested by the Catalan government —and again leaked to the press—, near 700.000 tonnes of sediments contaminated with organochlorides, mercury, heavy metals and radioactive isotopes filled the reservoir. The pollution was the result of the activity of the electrochemical industry located in Flix, established in 1897. While initially the pollutants were washed away periodically by seasonal floods, once the reservoir was completed in 1948, they started accumulating in its bottom, mixing with sediments (Pujadas i Garriga, 2015). According to Martín-Vide this news seriously hindered public debates about sediment transfer.[5] The long and convoluted cleaning process that followed —today at its final stages, with costs larger than 200 million euros— was covered almost completely with public funds, as the courts ruled that the company could not be charged with the historical liability of the pollution load (Pujadas i Garriga, 2015).

Martín-Vide's team went on to complete a detailed proposal for flushing sediment from Ribarroja (Roca & Martín-Vide, 2005). However, such scheme required drawing down the reservoir periodically —therefore disrupting hydropower production— and was received coldly by the private company managing the dam. The river basin authority was also sceptical about the feasibility of releasing sediment, claiming, among other reasons, that the nuclear power plant located downstream of the dam should be taken offline every time that sediments were flushed from Ribarroja.[6] To this day, both the concerns with sediment quality in Mequinenza and Ribarroja and the nuclear power plant downstream Ribarroja remain among the main cautions invoked by the river basin authority and the Spanish ministry in relation to the restoration of sedimentary fluxes (Centro de Estudios de Puertos y Costas, 2021).

Parallel to these developments, local youth organisations of the delta announced a "Day for Sediments" in 2008. Starting at a youth camp for the preservation of the southern delta's sand bar, this meeting became a yearly event involving scientists studying the delta, like Antoni Canicio or Carles Ibáñez. On several occasions from 2008 to 2015, the organisers of the "Day for Sediments" called for management policies that would restore sedimentary transport to the delta to balance both subsidence and coastal retreat. Finally, in February 2015 they launched the Campaign for Sediments ("Campanya pels Sediments") with the support of the PDE, green non-governmental organisations and ornithological associations, together with scientists and local population (Bertomeu, 2010; Ebre.net, 2015; Segarra, 2018, 2020; Tinet.cat, 2008).[7]

From its onset, the Campaign has made sediments visible in performative ways —pouring sands and gravel in front of official buildings during protests or carrying them during demonstrations. At a march in Barcelona against the water policies of the Spanish government, the members of the Campaign for Sediments carried a wheelbarrow full of sand and silt, showing a sign that read the names of the main dams of the Ebro River, along with the sentence "sediments are here". The centrality of sediment is illustrated by the Campaign's t-shirts, coloured brown —in contrast to the distinctive blue of the PDE protests— as well as the depiction of the Ebro's large reservoirs on maps as patches of mud.[8] The Campaign's mottos and banners at protests encapsulate the idea that water transfers aggravate sediment scarcity ("We want sediments, no to water transfers") and that both river flows and sediment fluxes are key for the delta's future ("The Ebro without flows = the end of the delta").[9] Overall, rather than arguing for dam removal, the Campaign defends the feasibility of sediment transfers and management policies, referring to international experiences and to scientific literature that supports its application to the Ebro River (see, among other, Rovira & Ibáñez, 2007 or Kondolf et al., 2014, both cited in Segarra, 2020).

Together with the mobilisation of sediments trapped in reservoirs, to address the "sedimentary insecurity" (Dawson, 2021a) produced in the delta, the Campaign for Sediments has argued for an increase of Ebro water flows to guarantee the river's capacity for sediment transport and to sustain estuarine ecosystems. Setting river environmental flows —an obligation under European legislation— is a prerogative of the river basin authority, which in 2014 set this value for the Ebro at 3370 hm^3/year, less than half the value demanded by the authorities of the Catalan government and environmental organisations. The river basin authority considered that the modification of environmental flows caused by hydroelectrical activity did not affect the functioning of the Ebro (Zografos, 2017). In this regard, the Campaign for Sediments has been particularly active in denouncing corporate hydropower interests for prioritising the production of electricity at the expense of sediment management needed to ensure the delta's future (Segarra, 2020).

The non-human origins of the Ebro delta play an important role in the Campaign's politicisation of sediment scarcity. In the account of the Campaign for Sediments, it is not only the origin of the *current* delta in the Holocene that is underlined, but the action of the sediment carried by the river during the last few millions of years (Segarra, 2020, p. 32). The present-day delta is presented as originated in the Holocene, approximately 6000 years before present, but the continued action of sediment fluxes and the existence of "other deltas" millions of years into the past is emphasised, echoing the accounts of Carles Ibáñez and other authors (Ibáñez et al., 1999, p. 37). Hand in hand with this portrayal of the delta comes a fierce critique of the "myths" that depict the delta's origin as a product of the deforestation of the Ebro River basin since the Roman, Medieval or the early Modern period. While it is conceded that deforestation increased the sedimentary transport during the last centuries, Segarra draws on research indicating that the main processes shaping the delta's morphology have been transport of sediments eroded from the river basin for thousands of years. In other words, according to the spokesperson of the Campaign for Sediments, the delta is not "man-made", and the arguments that sustain such origins "are interested in legitimizing the current management of reservoirs and downplaying the importance of the Ebro delta" (Segarra, 2020, p. 42).

Finally, the Campaign's political mobilisation of history and geology

[5] Interview with Juan Pedro Martín-Vide, 8 March 2022.
[6] Interview with Juan Pedro Martín-Vide, 8 March 2022.
[7] Interview with Josep Juan Segarra, spokesperson of the Campanya pels Sediments, 18 October 2021.
[8] Campanya pels Sediments, Facebook account, 17 September 2016. Retrieved on 21 September 2021.
[9] Campanya pels Sediments, Facebook account, 5 June 2016. Retrieved on 21 September 2021.

also engages with the role of sediment in the deltaic culture. The portrayal of the sediments immobilized in reservoirs as a resource develops hand in hand with the appreciation of past knowledge and uses of sediment in the delta. "When turbid waters were flowing, my father used to tell me: 'this is gold'", remembers one of the Campaign's activists, underlining the role that river flows had in the past to fertilise rice fields (Josep Bertomeu in Segarra, 2018, min 1, sec 18). The historical practice of *colmateo* —the redistribution of sediment carried by the irrigation canals in the rice fields— is mobilised as an example of a traditional culture that kept the delta's subsidence at bay before the large dams were built on the Ebro and cut off the sediment supply (Rovira & Ibáñez, 2007; Segarra, 2020). While the Campaign conceptualises sediment as a blessing, it also acknowledges the need to study the quality of sediments deposited in Ribarroja and Mequinenza to ensure that they are not polluted. However, it accuses the river basin authority of using this argument to postpone discussions about sediment mobilisation and portray it as dangerous and expensive (Segarra, 2020).

Overall, the proposals of the Campaign for Sediments to mobilise the sediment trapped in reservoirs and to increase river environmental flows come in contrast with the policies implemented by the Spanish environment ministry, which has focused on intervening in the coastline. During the last years, the state has started buying out (or expropriating) land in the delta coastline in order to transform it into natural buffers that absorb the effects of sea-storms, de facto applying a strategy of climate change adaptation (Reuters, 2021; Zografos, 2017). More recently, state authorities have agreed on the mobilisation of vast quantities of sand deposits submerged in the delta as a temporary solution to reinforce the coastline. But these also come at high costs and uncertainties regarding safe futures (Catalunya Diari, 2021; Segarra, 2020).

6. Conclusions

Through the lens of sedimentary justice (Dawson, 2021a), this paper has examined the politics of sediment scarcity in the lower Ebro River and traced the emergence of the social demand for more sediment to counter delta subsidence, sea level rise and coastal erosion. These gradual processes of degradation seemed a distant risk in the 1970s, when development projects began to directly threaten the delta's ecological value. However, throughout the 1990s and 2000s, the social mobilisation against water diversion schemes and the impacts of climate change in the delta brought renewed attention to the immobilization of sediment in reservoirs and the resulting "sedimentary insecurity" (Dawson, 2021a) produced in the lower Ebro River.

As a sediment-centric perspective (Parrinello & Kondolf, 2021), the lens of sedimentary justice can address the insufficient attention given to sediment in political ecology and water justice studies and contribute to a "materially enriched hydrosocial cycle" (De Micheaux et al., 2018:645). The perspective of sedimentary justice opens new avenues to incorporate the non-human world, enriching the literature on environmental and water justice (Boelens et al., 2018; Schlosberg, 2013). In particular, the historical perspective allows for visibilising the agency of the non-human world in the politicisation of sediment scarcity. We highlight the relevance of sedimentary justice for the Ebro River case in the following points.

First, key to claims of sedimentary justice, activists and scientists defending the restoration of sedimentary fluxes portray the sediments immobilized in reservoirs as a valuable resource. A sedimentary justice perspective may involve maximizing the resource dimension of sediments and minimizing its hazardous potential for humans and non-humans. However, the restoration of sedimentary fluxes does not come without its own problems: sediment flushing from dams can create nuisances and be contested by local and environmentalist organisations as well (see for instance Guerrin et al., 2021).

Second and along these lines, the pollution of the sediments immobilized in the reservoir of Flix shows how not only quantity, but sediment quality relates to questions of justice (Dawson, 2021a). In addition, the long-lasting impact of the Flix scandal illustrates powerfully the capacity of sediments to "erupt into and disrupt human politics" (Bremner, 2020, p. 1). The materiality of sediment —unlike that of water— can easily transcend history and bring the pollutants from the past to the present long after the activities that produced them ceased. In Flix, from the perspective of sedimentary justice, not only the costs caused by private industry have been shifted to the public, but the possibilities of building alternative futures mobilising sediments for coastal restoration have been compromised. The pollution of Flix has contributed to concerns about the quality of the sediments in Mequinenza and Ribarroja dams and the potential dangers of mobilising these sediments (Centro de Estudios de Puertos y Costas, 2021).

Third, a sedimentary justice lens makes visible the power relations embedded in the separation between water and sediments taking place in reservoirs. Building on scientific research and international practices of sediment management, the Campaign envisions an alternative management of reservoirs that makes it possible to transfer immobilized sediments and facilitates sediment transport by increasing river environmental flows. But this proposal disrupts hydropower interests, as it involves a different use for the water stored in reservoirs than the production of electricity (and of economic benefit). The production of electricity favours the accumulation of water and the use of "clean" H20 in turbines, therefore contributing to the deposition of sediment. On this basis, the Campaign for Sediments argues that the production of sedimentary scarcity and insecurity in the delta is part and parcel of a specific way of managing reservoirs that prioritises the interests of hydropower corporations.

Fourth, the non-human forces shaping the origins and development of the delta are key in the arguments of the activists and scientists that demand the restoration of sedimentary fluxes. In arguing for the non-human origins of the delta, the Campaign mobilises the geological past in claims for sedimentary justice, highlighting the importance of sedimentary fluxes without human intervention and hence pointing at the building of reservoirs and the immobilization of sediment as the geological scale turning point that marked the production of "sedimentary insecurity" (Dawson, 2021a) in the delta (Campanya pels Sediments, 2020; Segarra, 2020).

Finally, as shown by the *Gloria* storm, the impact of extreme climatological events during the last decades has made more visible the human vulnerability associated to sedimentary insecurity. While perhaps ephemeral in the media, the storms of 1990 and 2002 urged public debate, research and policy proposals about the delta's future. What remains to be seen is if the devastation caused by *Gloria* will mark a turning point in the politics of sedimentary management in the Ebro River basin and the protection of the delta. As the degradation of deltaic environments around the world worsens, the Campaign for Sediments may be one of the first examples of social mobilisation politicising sediment scarcity and demanding more sediment for the preservation of deltaic environments, their population, and livelihoods. But it may not be the last.

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