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30 Nature-Human-River Relationships at the Ebro River and its Delta (Spain)

Mariano, Mercè[1], Abella, Susanna[2], Araujo, Rafael[3], Ibisate, Askoa[4], Ollero, Alfredo[5]

[1] Terres de l'Ebre Environmental Policies Consortium, Amposta, Spain

[2] Platform in Defence of the Ebro (PDE), Tortosa, Spain

[3] Natural Sciences National Museum-CSIC, Madrid, Spain (*in memoriam*)

[4] Department of Geography, Prehistory and Archaeology, University of the Basque Country, UPV/EHU, Vitoria-Gasteiz, Spain

[5] Department of Geography and Territorial Planning, University of Zaragoza, Zaragoza, Spain

Summary

The Ebro is one of the largest river basins in Southern Europe, with an area of 85,000 km^2, a river length of 930 km, and a population of more than three million people. Since ancient times, it has not only been a resource, but also a channel for communication, commerce and the settlement of great civilizations along its course. The Ebro Basin has always been rich in cultural heritage and blessed with a diverse biology. It hosts a wide variety of endemic species, some of which are now endangered by human-induced threats. Spain is one of the most vulnerable countries in Europe concerning climate change. It also has a long history of human-water relationships, evident from Roman (after 197 BC) and Umayyad-Muslim (after 711 AD) influences; both cultures are famous for their water management technologies. The Ebro River waters, coming from the Pyrenees mountain range with which it flows almost in parallel southwards, have always been coveted. Over the centuries, land and water exploitation have progressively intensified, and the most recent transformations have resulted in the Ebro now being one of the most stressed rivers in the world.

A great number of large reservoirs produce a big amount of energy but have significantly changed the river's flow and sediment regimes. This regulation, combined with excessive water extraction for irrigation and drinking water in its thirsty surroundings, has been detrimental to almost all aspects of the river ecosystem. The highest impact is visible at the delta, which suffers from compaction, subsidence, and regression, today receiving less than 5% of the river's original sediment load. Despite being administered by one of the oldest hydrographic management organizations worldwide, the increasing overall water locations and subsequent environmental and social problems in the Ebro Basin area are a source of considerable on-going conflict and debate. This situation has given rise to one of the most powerful social movements in defense of the Ebro River.

Several initiatives are underway to reverse the detrimental losses of natural geodiversity and functionality, by maintaining flows that sustain ecological health, giving natural space back to the river and improving human flood defense systems. Nevertheless, much remains to be done, and ongoing challenges can only be effectively tackled through well-directed (and previously-lacking) institutional will, backed by broad public consensus. If not, what has taken countless centuries to create will be lost in less than one.

30.1 Introduction

Due to its size and position, the Ebro River has had strategic and commercial value since ancient times, giving its name – *Hiberus flumen* – to the Iberian Peninsula during the Roman period. Its 930 km length, tracing a predominantly West-East trajectory, makes it the second-longest river of the Peninsula (after the Tajo/Tejo River). It

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has also the second-largest basin area and discharge (after the Duero/Douro River). Both its basin and its course represent all of the climatic and altitudinal diversity of the Iberian Peninsula as a whole, and it is the quintessential Mediterranean river (Sabater et al. 2021). The Ebro River also possesses a high geodiversity, from its mountain streams and braided foothill courses, to the grand meandering channels of its wide floodplains. There is also a significant network of temporary and ephemeral courses. The Ebro Delta is one of the largest deltas in the Mediterranean Basin, with 320 km^2 of exposed surface area with a sediment volume greater than 28 km^3 (Guillén and Palanques 1992).

Throughout history, the Ebro River has been an axis for the communication and settlement of various civilizations. It crosses the landscapes of Cantabria, Basque Country, La Rioja, Navarra, Aragón and Catalonia, each with its own socio-cultural identity, which makes it difficult to talk about a single 'Ebro culture'.

The population of the basin is around 3.2 million inhabitants, with a density of 38 inhabitants per km^2, which is low compared to the Iberian Peninsula as a whole. Half of the population lives in the six largest cities: Zaragoza, Vitoria-Gasteiz, Pamplona, Logroño, Lleida and Huesca. The basin is managed as a hydrographic unit demarcated by the Ebro Basin Authority (CHE), a Spanish state organization that reports to the Ministry for Hydrological Transition and Demographic Challenge (MITERD). Territorially, this demarcation also includes the state of Andorra (445 km^2), some French territories (502 km^2, including the Val d'Aran, at the head of the Garonne Basin) and nine Autonomous Regions: Cantabria, Castilla-León, Euskadi, La Rioja, Navarra, Aragon, Catalonia, and small areas in Castilla-La Mancha and the Valencian Community (CHE 2018).

All over the basin, the tributaries and main river are highly regulated by the numerous reservoirs. Water and river use dates from antiquity. Agrarian use remains significant, while other uses are already lost, such as navigation and fishing. This has not only left their cultural imprints, but also environmental issues and unresolved conflicts. These manifest themselves in extreme events such as floods, particularly in the Middle Ebro, and in the current problems exacerbated by global change and the climate emergency, in the face of which the Delta is particularly vulnerable. In the following sections, we focus particularly on the most compromised reaches of the river, i.e., the middle reach and the delta.

30.2. Geophysical setting

30.2.1 Geography of the Ebro River

Occupying an area of just over 85,000 km^2 in the North-East, the Ebro Basin represents 17% of the surface of the Iberian Peninsula. It is triangular in shape, widening from its source in the Cantabrian Mountains to the Catalonian coastal mountain chain at the Mediterranean Coast (fig. 30.1). To the north, it is framed by the Basque Mountains and the Pyrenees. Its relief is characterized first by mountainous areas with peaks of over 3,000 m altitude, secondly by extensive foothills incised by the main Ebro tributaries, and finally, by an extensive flat and arid central depression. The scheme is similar in the south, closed by the Iberian Mountains. The continental Mediterranean climate dominates the basin, with considerable spatial variability in rainfall, from reaching 2,000 mm y^{-1} in some mountainous areas to figures below 350 mm y^{-1} in the Central Depression. The mean annual rainfall in the basin is about 622 mm y^{-1}, with strong seasonal and interannual variation. At its mouth, the average annual discharge of the Ebro River is 464 m^3 s^{-1}, with a standard deviation of 121 m^3 s^{-1} (CHE 2018). Climate change is having a great, recent impact on Spain (Vargas-Amelin and Pindado 2014).

The basin has an enormous geological diversity, with lithologies of all periods, complex morphological structures and a very variated geomorphology. The Ebro River flows from WNW to ESE, through the middle of the basin. It emanates in the Sierra de Peña Labra mountain range in Cantabria. Downstream the first large reservoir on the river (surface area of 6,253 ha), it flows through a succession of deep gorges and narrow valleys. After 210 km of its course, the river has entered the Ebro Depression and its meandering middle reaches. In upper and lower sectors of the Middle Ebro, valley and riverbed are cut into sandstone-dominated formations. In contrast, throughout the central Depression, it flows across a wider alluvial floodplain. The 150-km long Lower Ebro River starts from Mequinenza and Riba-Roja reservoirs and flows through various gorges. In Amposta the Ebro Delta begins. The channel widens and there are two large islands, Gracia and Buda, at the mouth.

30.2.2 Morphodynamics of the middle course of the Ebro

In the Middle Ebro, a free meandering channel of 350 km length develops between Logroño and La Zaida. Its floodplain has an average width of 3.2 km and a maximum width of 6 km. The active river channel has been highly dynamic throughout history. The channel form was predominantly meandering until 1900, as shown by the imprints left on the floodplain by course migration and oxbow lakes (Ollero 1992). Between 1880 and 1940, terracing and felling of forests in the mountainous areas of the basin released a large amount of sediments, transforming the Middle Ebro into a wandering course, with abundant gravel-bars and islands. However, from 1950, the river resumed a meandering form, due to the recovery of basin vegetation cover and increasing flow regulation (reservoirs). Between 1927 and 1957, there were 81 geomorphic plan form changes along this riverbed, with an area affected of almost 2,000 ha. Between 1957 and 1980, these dynamics were reduced to 39 changes, and less than 400 ha were affected (Ollero 2010). After 1980, only minor changes to river morphology were recorded, notably an increasingly restricted mobility of some gravel bars, due to their increasing vegetation cover; the average sinuosity index (i.e., the ratio of the curvilinear length (along the curve) and the Euclidean distance (straight line) between the end points of the curve) for the river has since remained 1.51, which is a relatively low value.

The open, low gradient floodplain of the middle Ebro naturally regulates flood events (Ollero 1990). For example, the highest recorded flood (31/12/1960) with 4,950 $m^3 s^{-1}$ measured at Castejón gauging station was reduced to 4,130 $m^3 s^{-1}$ at Zaragoza (02/01/1961) 100 km downstream. Floods occur generally in winter, during frontal rains in the Upper Ebro catchment and/or the western Pyrenees and are especially dangerous if the flood contributions of the Aragón and Ebro coincide. Bank overflows represent a serious risk for the local population, and to urban and agricultural land and infrastructure. Roads, irrigation systems, bridges and the flood defense system itself are the most flood-affected. In extreme cases, dykes have been actively breached to help prevent towns from flooding.

30.2.3 The Ebro Delta

The delta of the Ebro results from river sediment deposits originating mostly from the Pyrenees mountains. The volume of accumulated sediment is 65 km^3, with a mass of 149,000 million tons and a maximum thickness of 60 m. The delta coastline of around 52 km mainly comprises sandy beaches. Its continental shelf extends about 50 km offshore, then falling off to a depth of 100 m. The Ebro Delta currently comprises about 320 km^2 of emerged land and a submerged area of 1,845 km^2 (fig. 30.2).

The climate of the Lower Ebro and its mouth is sub-arid Mediterranean, with an annual average temperature of 17°C and with a mild thermal oscillation due to the coastal influence. Humidity is high all year round at 70–80%, and frosts are quite rare. These conditions favoring the cultivation of rice, for which the delta is well known. An ever-present factor in the deltaic landscape is the wind. In winter, dry strong northwesterly winds (known as the mistral) predominate, with gusts exceeding 100 $km\,h^{-1}$. In spring and/or autumn, there are easterly moist winds (levante) responsible for the storms that affect the coast. The east winds (or levantadas) are often associated with intense rains for two to three days. The rest of the time, the predominant winds are the southerly marinades, produced by the higher temperature of the land relative to the sea. The easterly storms have a direct effect on the coast, changing the coastline, particularly those points most vulnerable to regression and erosion. On the contrary, the "*marinades*" slightly reshape the landscape by mobilizing dune sands.

The delta is characterized by specific geomorphological features, highly important for its biodiversity. The most salient are the two lateral hook-shaped sandbars (with a total surface area of 82 km^2), the northwestern Fangar and southwestern Banya, which partially enclose the Fangar and Alfacs bays, respectively. Exceptional storms can breach the Banya sandbar (cf. chapter on the Senegal River, this volume). The lagoons have differing salinities, depending on whether freshwater inputs are directly from the river or via irrigated fields. Disconnected wetlands occupy 56 km^2. Also noteworthy are the dune fields at Punta del Fangar and Barra del Trabucador, the two most natural areas of the delta.

30.2.4 Hydrology and management of the flow and sediment regimes of the Ebro River

The Ebro River regime is variable from the Atlantic influence in the upper reach, the arrival of the Pyrenean tributaries with a snow-rainfall regime in the middle reach, to a more Mediterranean tributaries, coming from the Iberian Range, right margin in the lower reach. The upper and middle reach high waters and floods are in winter, whereas in the lower reach high waters are during winter and spring and floods in autumn in a natural flow regime, which is considerably altered due to the important reservoirs of the mainstem. Low water period is in the dry summer season.

The estimated annual discharge to the sea has decreased from 18,000 hm^3 (1940–1980) to 12,000 hm^3 in 1980–2015. In parallel to the reduction in flows in the natural regime, there has

Table 30.1 Main characteristics of the Ebro River

The Ebro River	
Basin size (km^2)	85,000 (of which 320 in the delta)
Channel length (km)	930 (of which 30 in the delta)
Average discharge ($m^3 s^{-1}$)	Miranda de Ebro (end of the Higher Ebro): 63 Castejón (Middle Ebro): 229 Zaragoza (Middle Ebro): 231 Tortosa (between Lower Ebro and Delta): 421
Hydrological pattern	High waters in winter (Higher and Middle Ebro) and winter-spring (Lower Ebro). Low flows in summer. Estimated annual sea discharge (1940–1980) of 18,000 hm^3. In 1980–2015, this flow has decreased to 12,000 hm^3.
Degree of naturalness	There are contradictory published statements about the degree of naturalness: – Official statements (CHE 2018) indicate that 16% of the waterbodies are highly modified, and that 31% of natural areas have no proposals to achieve good ecological status. – According to a revision of the river basin management plans by the European Commission (EC 2019), however 19% of the Ebro River is highly modified. If implemented, new management plans (CHE 2018) will increase the area under irrigation, further reducing flows (and connectivity to the floodplain), and increasing pollution. – About 25% of the delta is in a natural state, 65% is agricultural, and 10% urbanized.
Type of natural landscape	The Middle Ebro River is meandering, with a broad valley bottom and extensive floodplain. The predominant land use is agriculture. The Ebro Delta is a great plain, with some levees along the river banks. Reduced sediment supplies (dams upstream) have caused delta shrinking and marine transgressions. Predominant land use is salt-tolerant rice cultivation.
Impact types	The Ebro Basin has 125 dams of more than 1 hm^3 with a total reservoir capacity of 8,000 hm^3, regulating 60% of discharge and retaining 95% of sediments. The main issue related to the basin pollution is the diffuse contamination caused by intensive livestock and irrigation, which presents an almost irreversible character. There is also a problem with pesticides in the Gallego basin. Both animal and plant invasive species are abundant. Middle Ebro: Longitudinal dykes and breakwaters further alter natural channel dynamics and riparian forests. Delta: The greatest current impact is the reduction of sediments due to dams upriver. Two channels transformed the natural space into rice fields (25,000 ha). Despite this, there is a balanced relationship between natural areas (8,000 ha) and cultivated areas. Currently, the only contribution of sediment and 'flood' of the deltaic plain is associated with the cultivation of rice between April and September.
Biggest cities (population)	Middle Ebro: Zaragoza (674,997), Logroño (151,136) Delta: Tortosa (33,372), Amposta (20,738), Deltebre (11,482)
Urbanization	The Ebro basin has a relatively low urbanization in the Iberian Peninsula context. The main urbanization process occurred between 1960 and 1990 with a significant rural exodus in mountain areas.
Protected areas …	12 Ramsar wetlands occur in the basin with a total surface area of 62,579 ha. Middle Ebro: parts of the river are included in the Sotos de Alfaro Natural Reserve (La Rioja, since 2001), the Directed Natural Reserve of Sotos y Galachos del Ebro (Aragón) (since 1992) and some small protected riparian forests in Navarra

Table 30.1 (continued)

The Ebro River	
… Protected areas (ha)	Delta: Ramsar Area (7,736), Delta del Ebro Natural Park (7,802), Terres de l'Ebre Biosphere Reserve (367,729)
Predominant river basin land use	Agricultural food production, with cereal and forage crops supporting more than 30% of Spain's commercial meat production. The starch and sweetener industry, based on corn, and horticulture and fruits, and the associated canning industry, are also dominant. Mediterranean crops such as wine grapes, olives and almond are also common. Industries include metal, the manufacture of packaging material, paper and foodstuffs. Delta: rice growing, fishing and fish farming predominate
Renowned biodiversity elements	Middle Ebro River: Important habitats include the meandering main channel, riparian forests and galachos (oxbows, ancient meanders), and tertiary escarpment. Unionid mussel species in danger of extinction, such as *Pseudunio auricularius* (syn. *Margaritifera auricularia*) and *Unio mancus*, and fish species (e.g., *Salaria fluviatilis*, *Parachondrostoma miegii*, *Luciobarbus graellsii*). Delta: habitats of great environmental importance/value, such as bays, coastal oxbow lakes, river network, the Ebro Sea, the Fangar and Alfacs bays, coastal sandbars and dune beaches, ullals (freshwater upwellings), and salt flats. The enormous variety of aquatic habitats favors the coexistence of marine and freshwater species. 337 of the almost 600 bird species in Europe have been registered, notably > 60% of the world population of Audouin's gull, *Larus audouinii*. Among plants, e.g., *Limonastrium monopetalum* and *Zygopuillum album* are noteworthy.
Renowned cultural elements	Navigation along the Middle Ebro, with downriver wood transportation until the 1950s. The Imperial Canal (in Aragón) is a symbol of this stretch of the Ebro . In the Lower Ebro, traditional techniques such as making traditional fishing nets and construction of huts using reeds and mud, existed from the Middle Ages to the 20th century. In the Middle and Lower Ebro, the folkloric jota dance, of Arabic origin, spread upstream due to river trade. In the delta, characteristic elements are the hut architecture, rice culture, and the emblematic metallic Buda lighthouse (built in 1864), a mobile lighthouse that could be dismantled and re-erected. Since 2000, there is a strong social movement aimed at defense of the Ebro River and regaining a river identity (Platform in Defence of the Ebro).

been an increase in water consumption in the basin, decreasing the flow arriving to the mouth.

Floods have been reduced after the construction of dams, both in the mainstem and tributaries. However since the end of 20th century an increase trend of floods has been noticed, with longer duration and more complex hydrographs (Ollero et al. 2021, Tena et al. 2021).

The delta behaves hydrologically like an estuary, since the bottom of the riverbed, from Tortosa to the mouth, is below mean sea level. For this reason, in the absence of river discharge, seawater penetrates up the riverbed to the town of Amposta.

The last great flood in the Ebro Delta was in 1937. Then, the deltaic surface began to decline in response to the reduction of discharge (due to derivations and afforestation) and sediments (trapped in the upstream reservoirs, and reduced production due to afforestation). Nowadays floods rarely arrive the mouth due to the huge regulation capacity of Mequinenza and Riba-Roja reservoirs.

The current hydrological regime, while naturally variable, is strongly altered by tributary and mainstem dams. Much of the water of the Ebro is deviated by canals, for irrigation, agricultural irrigation is > 90% of consumptive use, and drinking water (fig. 30.3). In recent decades, strong changes have been experienced due to land use, increase of irrigation surface, and climate change. The Ebro basin has 125 dams of more than 1 hm^3 with a reservoir capacity of 8,000 hm^3. They regulate 60% of the flow and retain 95% of the sediments (Guillen and Palanques 1992, Vericat and Batalla 2005, Ibañez et

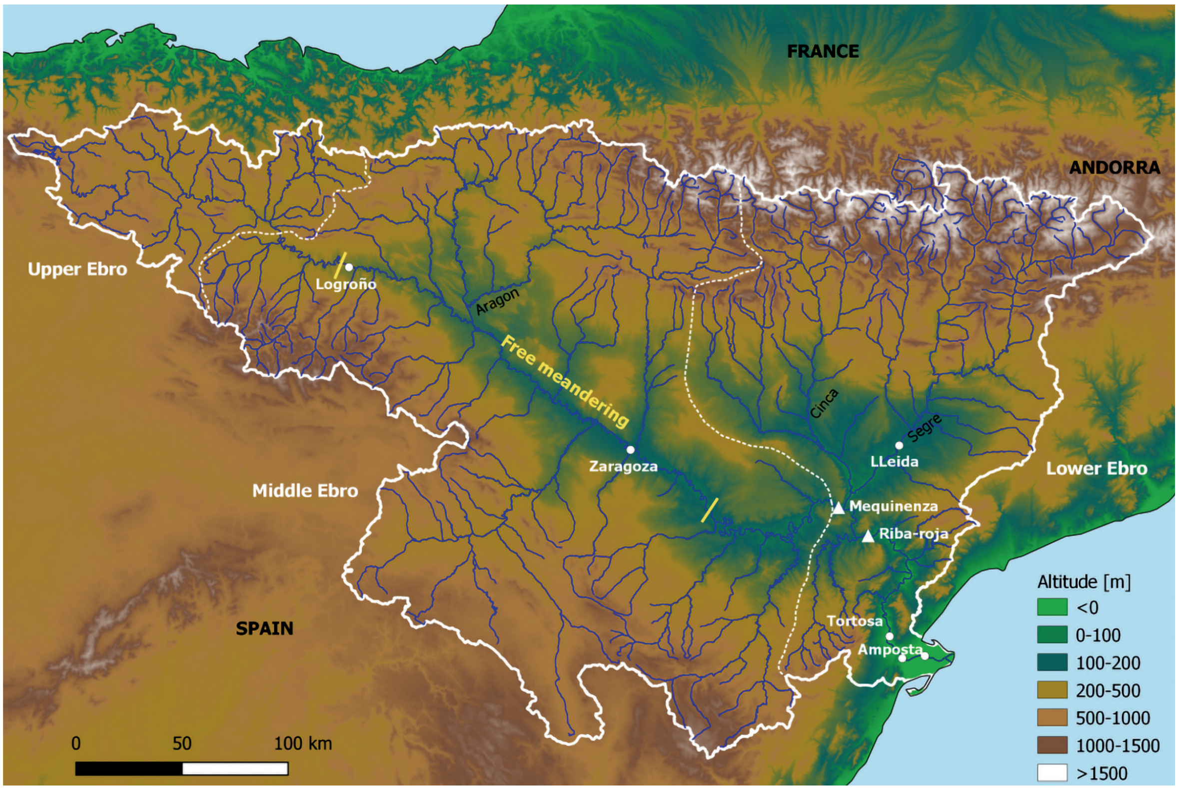


Fig. 30.1 Ebro Basin and its location in the western European context. Map: Rut Domènech

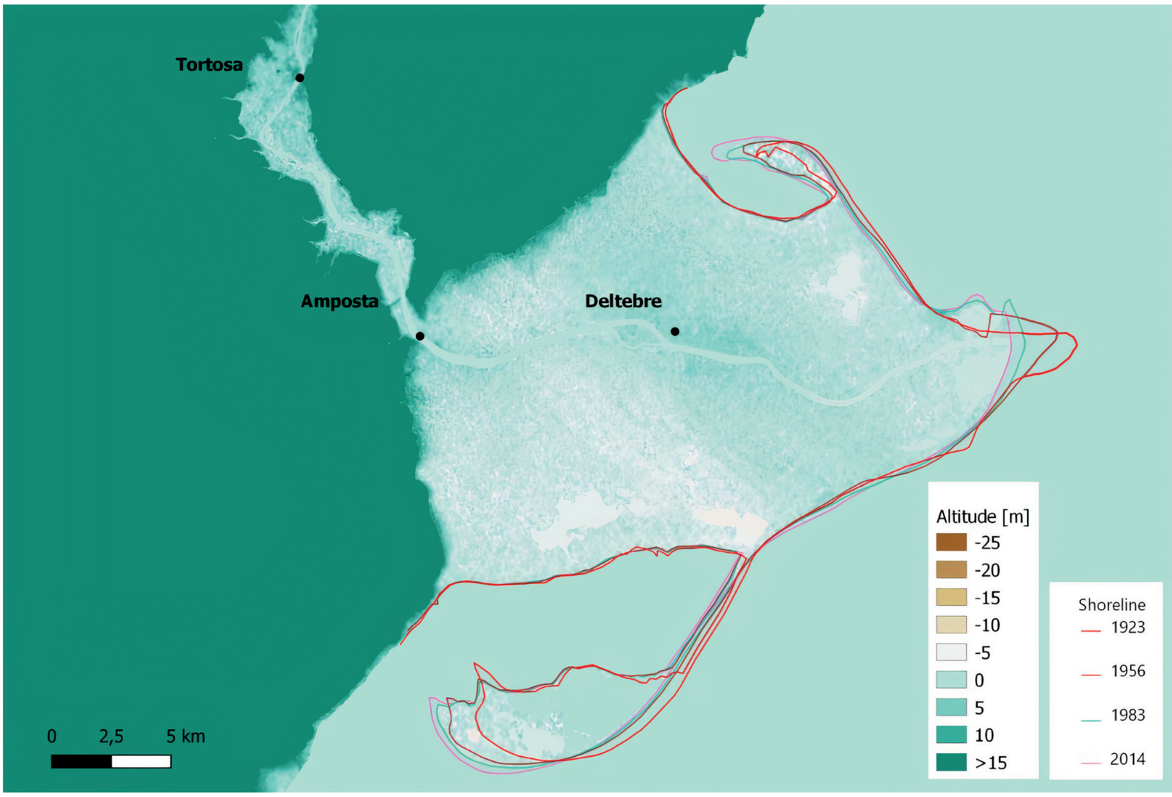


Fig. 30.2 Ebro Delta. Subsidence and recent regression from 1923 to 2014. Map: Rut Domènech

al. 2016), as compared with the late 19th century when the basin was not regulated (Gorria 1877). In the Pyrenean tributaries, it is common to divert water through hydroelectric jumps (pipes down the side of mountains) for electricity generation. Some of the main reservoirs located in the tributaries coming from the Pyrenees are mainly dedicated to irrigation, as well as to hydroelectricity. All of them impact on flow and sediment regime. Water diversions from Ebro River are mainly for irrigation, in the middle reach 71,5 $m^3 s^{-1}$ are diverted through three canals (Lodosa, Tauste and Imperial de Aragón) and other 48 $m^3 s^{-1}$ in the delta through two canals, one in each margin.

The most upstream water impounding is the Ebro Reservoir, of 541 hm^3, located at the headwaters of the Ebro River, in the Alto Campoó region, with an input average annual flow of 3 $m^3 s^{-1}$ (fig. 30.3), and a snow-rainfall hydrological regime of maximum discharge in July. Dam operation completely reverses the downstream flow regime, so that discharge maxima coincide with natural low water periods (summer), to meet the prioritized needs of irrigation in the middle basin. Further below in the Ebro canyons, due to the contributions by different tributaries (Oca, Nela and Jerea), average flow rises to 47 $m^3 s^{-1}$ in a nearly natural, rainfall-driven regime, with a maximum in February and minimum in September. The Ebro is again dammed in Sobrón, without any change in its regime, and 63 $m^3 s^{-1}$ average flow in Miranda de Ebro, few kilometers downstream (figs. 30.3, 30.4) after the confluence of Omecillo and Bayas. In Castejón, Ebro acquires its characteristics of a great river with its average flow rising to 229 $m^3 s^{-1}$ after the contributions of the Ega River, and particularly the Arga and Aragón River system, where it receives the first waters from the western Pyrenees and therefore increases the snow influence (Ollero 1990). The snow-rainfall regime has a maximum in February and a minimum that advances to August. In Zaragoza, the flow keeps at 231 $m^3 s^{-1}$, as there are no significant tributary contributions in this reach. Downstream and still in its middle reach, the river has no substantial change, despite the confluence of the Pyrenean Gállego River (12,4 $m^3 s^{-1}$) on the left bank, until arriving to the Mequinenza, Riba-Roja and Flix reservoirs, of 1530, 207 and 11 hm^3, respectively, which significantly regulate the Ebro River. In this reservoir system confluence the Cinca and Segre River system which drain the central and eastern Pyrenees. The annual average discharge has declined in the lower reach, from the 560 $m^3 s^{-1}$ pre-damming, to the current 327 $m^3 s^{-1}$ at Tortosa (Besne and Ibisate 2015). The interannual variations are lower in the upper section of the Ebro than in its middle and lower sections (Sánchez-Fabre 2018).

In addition to changes in annual average flows, dams have also influenced the flood regime. Generally, floods in the upper and middle Ebro occur in winter, due to Atlantic fronts and storms. In contrast, floods of the Lower Ebro have mostly their origin in the Cinca and Segre tributaries and occur in autumn, associated largely with Mediterranean storms and DANA episodes (high level isolated depression; is a high impact rainfall event occurring in the autumn in the Spanish Mediterranean coast). The large reservoirs on the Cinca and Segre and those of Mequinenza and Riba-Roja mitigate flooding in the Lower Ebro, modifying its hydrography, by anticipating the arrival of peak flows in the middle reach through preventive emptying to avoid bank overflows in the final course and the delta.

30.3 Historical introduction

30.3.1 The Ebro River

Due to its refuge characteristics, being protected from European mainland by the Pyrenean Mountains to the North, the Iberian Peninsula was colonized about 800.000 years ago. The remains of the *Homo antecessor* were found in Atapuerca site. The peninsula also served as one of the last refuge of Neanderthals. During the last glacial maximum (30,000 BC), many early Europeans survived in the ice-free areas of future Spain, and later on (10th millennium BC) these Cro-Magnons (*H. sapiens*) migrated North and recolonized all of Western Europe. In the Bronze Age Iberia was colonized by the Celts, and later influenced by diverse Mediterranean cultures (Phoenicians, Greeks, Carthaginians, then Romans and lately Moors). The banks of the Middle Ebro were a privileged place for human settlement. The waters of the great river that crosses an extensive depression of extreme aridity were increasingly used for domestic water supply, irrigation, and transport. Although the river became an axis of settlement and communication in this flat landscape, its regular overflowing and flooding were feared. So, most Iberian native population centers were located at some distance from the river course, achieving the protection of the escarpments and first terraces (Ollero 1992). They even gave up cultivating the floodplain, where in the groves, which occupied vast areas, hunting was practiced, wood extracted and animals grazed, and were the object of commercial transactions between communities (Floristán 1951). After the Punic wars, in 218 BC, the Romans occupied Spain, bringing with them the Latin language, and later, Christianity, and water technologies, such as aqueducts, open irrigation channels, and wastewater canals. Under their rule, the Ebro Floodplain started to be widely used for the cultivation of vegetables and fruit trees, a

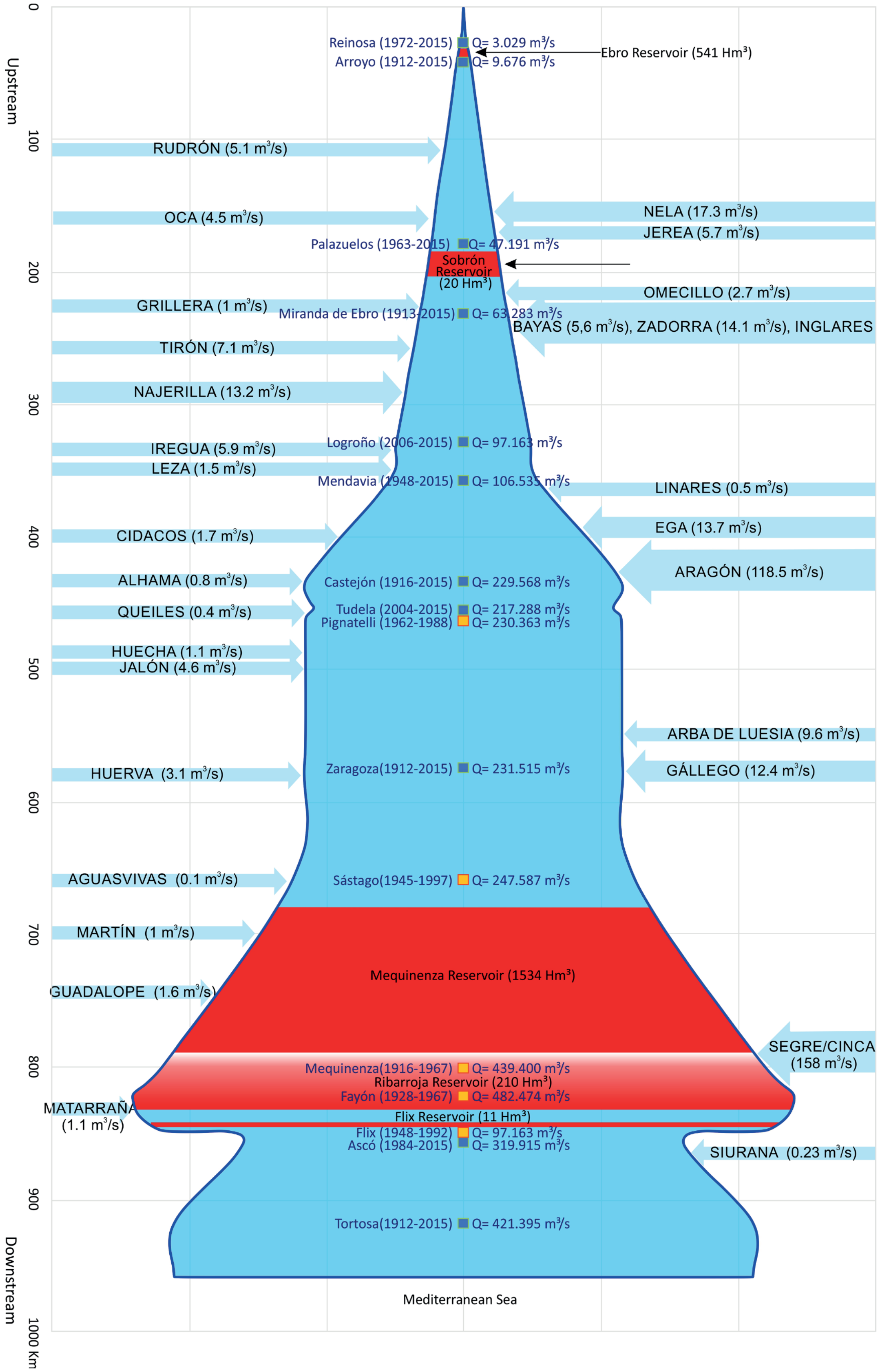


Fig. 30.3 Flow contributions of tributaries to the Ebro River, from the headwaters to the delta. Ebro mainstem dams and their storage capacities are shown in red. When discharge decreases in a downstream direction correspond with diversions of water. Squares in blue active gauging stations, squares in yellow out of service gauging stations. Graph: Mercè Mariano, based on Yearbook of Gauging Stations, Ministry of Ecological Transition, MITECO (2015)

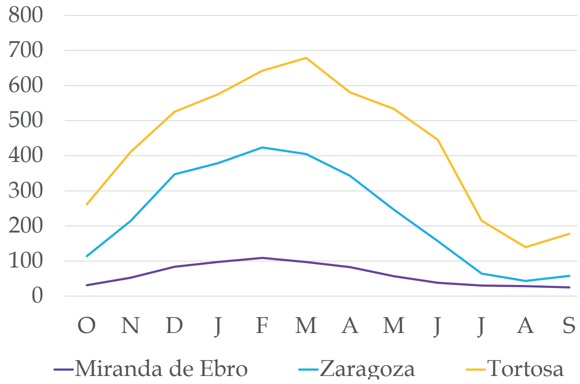


Fig. 30.4 Hydrological regime (mean monthly discharge in $m^3 s^{-1}$) of the Ebro River mainstem at Miranda de Ebro (*upper reach*), Zaragoza (*middle reach*) and Tortosa (*lower reach*), during the period 1913–2015. Graph: Mercè Mariano, based on Hydrological Statistics Yearbook, MITECO (2020)

means of subsistence fundamental to this day (Ariño 1990). The Roman rule lasted about 600 years, until the invasion by Germanic tribes, in 427 AD, mainly Visigoths (see chapter on the Rhine, this volume). It is thought that in the Roman *Caesaragusta* (today Zaragoza) the Ebro was artificially diverted so that it ran alongside the city, to form a defensive moat and also to maintain the usefulness of the only bridge of the city. The Ebro no longer left this manmade channel but returned to abandoned channels on the left bank when it flooded. The North African Muslims (the Moors) conquered Hispania during 711–719 and called the area they controlled '*Al-Andalus*'. While under reign of the Caliph of Cordoba (ca. 1000), the Upper Ebro still belonged to the kingdoms of Castile and Navarra. Coming from dry landscapes of Northern Africa, the Moors (or Umayyads) established sophisticated irrigation technologies and water administration schemes, and intensively used the Ebro Floodplain for cultivation. The reconquest (*reconquista*) of Spanish lands by Christian forces lasted about 780 years and ended with the fall of the Nasrid kingdom of Granada in 1492. Many of the Moorish water technologies were maintained until modern times. The Sindicatos de Riegos (irrigation co-operatives) and similar more archaic organizations, designed and built the network of drainage canals and ditches, from which extended a complicated hierarchy of water distribution points. Larger works were a state responsibility.

In the Middle Ebro, there are three large irrigation canals: Lodosa (right bank, completed in 1935, with a maximum capacity of 22 $m^3 s^{-1}$ and 127.5 km in length), Tauste (left bank, dating back to 1790 and able to convey discharges up to 10 $m^3 s^{-1}$) and Imperial of Aragón (completed in 1780, 30 $m^3 s^{-1}$, supplying 30,000 ha of agricultural land).

The navigability of the Ebro was a secular dream that became a reality in Roman and medieval times, when, for the entire valley, the river was the main trade route with the Mediterranean Coast. Apparently, the entire Middle Ebro was navigable, although with difficulties, with boats reported liable to reach Vareia (Logroño city now). These were generally small boats that carried consumer products, such as wine and olive oil. In many sections, they forced the deforestation of the riverbanks (as towpaths), since help with ropes was required to cope with the current and to bypass rapids. Also, in the 18th century, several meanders were bypassed to shorten routes. The historic need for Zaragoza to connect to a seaport ran into numerous problems, due to the multiplicity of weirs for irrigation and the complexity of some river reaches, particularly the confined meanders of Bajo Aragón. A partial solution was the transport of goods by roads for these sections, which greatly hindered the journey. Only the rafts, called "*navatas*" or "*rais*" (interlocking logs transport rafts used until the middle of the 20th century) were capable of completing the journey from the headwaters of the Pyrenean rivers down to Tortosa (Pallaruelo 1984, Guerrero 1992, Gil Olcina 2006).

Between the 17th and 19th centuries, there were various projects to enhance river navigation, with the development of canals as bypasses in the non-navigable reaches considered a solution. In fact, the Imperial Canal of Aragón was navigable, with freight and passenger traffic from Tudela to Zaragoza. Its planned extension to the sea had to be abandoned, due to the pervious limestone bedrock. The Company for the Canalization of the Ebro was even set up, but progressive development of road and rail communications made the old vision infeasible by 1916 (Pérez Sarrión 1975, see also chapter on the Loire River, this volume).

Numerous economic activities were based on the banks of the river, in addition to animal husbandry and agriculture, with the river current being used on many occasions as a driving force for rolling, grinding and threshing (Marcuello et al. 1986). The hydroelectric exploitation of the Middle Ebro dates back to 1895. Notably, the Ebro Hydrographic Confederation (Ebro Basin Authority), created in 1926, was the first body in the world engaged in territorial management based on water. The engineer Manuel Lorenzo Pardo was the author and architect of the proposal, supported by the Zaragoza Academy of Sciences, which led to the creation of the Confederations, dependent on the State, which currently continue to manage the peninsular basins. The initial purposes of the managing body of the Ebro Basin were the establishment of a plan for the general use of the waters, intervention in the natural system through the execution of works and installations, the imposition of an improvement fee to irrigation, and the management of regulated waters. Irrigation plans, hydroelectric production and river navigation were programmed.

In the middle of the 20th century, substantial changes occurred on the Ebro Floodplain that affected the river's functioning and precipitated current environmental problems. The foremost was the advance of agriculture, with part of the river corridor put under cultivation. This was justified by the difficult post-war economy and the absence of administrative obstacles, which led to the consolidation of private properties, which in many cases extended right up to the riverbank. The great flood of 1960–1961 did not reverse this use, but rather, consolidated it. With the declaration of a disaster zone, the banks were stabilized and the state paid for river defenses, establishing a continuous system of bulwarks on both banks completed in the 1980s, after the major floods of 1977 to 1981). Riparian forests were losing value and by the 1990s they were practically no longer used by livestock. At the same time, illegal housing developments had proliferated in the vicinity of Zaragoza and some farms had appeared, all of which considerably increased exposure to flood risk. The Ebro River has also changed its behavior, as a consequence of increasing water regulation and global change. Between 1950 and 1970, significant changes took place in the basin, with a clear impact on the main river: large reservoirs were built (see above). In addition, the traditional mountain agri-livestock economy was abandoned, and with it many villages and their farmlands. Forests recovered, moderating the run-off and reducing erosion. Consequently, the course of the Ebro became stabilized, the gravels not easily renewed and the vegetation, less disturbed by flooding, colonized them without difficulty, consolidating the vegetation on the banks of the riverbed. The river itself was no longer divided into arms between gravel outcrops but concentrated into a single wider course meandering between riparian forests.

All of these manmade changes to the river and its catchment caused notable difficulties for the ecological status of the Ebro. Furthermore, many ancient uses have been lost, and the River Culture (Wantzen et al. 2016) too, in the absence of clear initiatives to sustain it.

30.3.2 The Ebro Delta

Since historically the delta was highly saline, it went uncultivated for a long time. In its insalubrious marshes, mosquitoes transmitted illnesses such as malaria. Only after floods did salinity and nutrient levels become appropriate for temporary agricultural use. According to historical data, between 1700–1960 an average magnitude flood occurred every ten years (Bayerri 1935, Davy 1978). The threshold for inundation of the delta floodplain was 2,500 $m^3 s^{-1}$ and discharges of 10,000 $m^3 s^{-1}$ occurred for an average of three days. These floods temporarily allowed agriculture until the land became salinized again, with each low-water from June to October.

These conditions did not preclude products such as salt and fish from being exploited for many centuries. The first commercial activities are documented in the Population Charter of 1149 on the occasion of the reconquest of Tortosa (Fabregat 2009). They were based on a system of communal property and open access to natural resources by all inhabitants of the area, with the possibility of using them agriculturally (12th–14th centuries). The lands that were cultivated were temporarily privatized while they were exploited commercially, but then reverted to being communal .

Between the 14th and 18th centuries, driven by technological advances, the privatization of natural resources reoccurred. The first "industrial" salt flats were built in 1340 by means of precipitation beds. These expensive technologies required an investment and amortization time that led to the implementation of a concession regime. At the same time, the first exploitation of the inland lagoons caused fish catches to increase. These coastal lagoons are mostly fresh water lakes, but have a strong hydrological interaction with the sea. In order to increase their already-high fishing value, channels were dug to control the connections of the lagoons to the sea during certain periods of the year, taking advantage of the migratory movements of fish between the lakes and the sea and a medium rich in nutrients that increased fish production. In 1439, the first Fishermen's Association of Ribera appeared, which autonomously managed lagoons resources. In return, the fishermen agreed to sell their catches to local people at a regulated price.

Before the 18th century, the only nucleus of permanent habitation in the delta was Amposta, a small town located on the right bank of the Ebro. After the War of Succession (1701–1714), some residents of Tortosa who had been left homeless occupied the levees and founded the first stable settlements in the middle of the delta: La Cava, Jesús y María and Sant Jaume d'Enveja. The houses and the farm barns were built from naturally-occurring local reeds and mud, and thatched with brushwood. The population grew significantly from 358 inhabitants in 1719, to 8,362 inhabitants in 1825 (Fabregat 2002).

From the mid-18th to mid-19th centuries, the first attempt were made to irrigate the natural 'levees'. These levees naturally result from deposition of sediments on the river banks during high water. They have a lower salinity, allowing the cultivation of cereals and fruit trees. Irrigation was from dug-out wells. These were capped by waterwheels that, instead of capturing water from the excessively-salty water table, drew it indirectly from the Ebro River through channels of 200 m or more that joined its bottom with the river. In this way, fresh water was obtained for drinking and irrigation, although in limited quantities (Fabregat 2009).

Substantial changes in the Ebro Delta occurred from the middle of the 19th century onwards, with the construction of two canals parallel to the river. The Right Bank Canal was built by a multinational company (the Real Compañía de Canalización del Ebro (RCCE), to establish steamboat navigation between Zaragoza and the sea (see above). In 1859, two French engineers hired by the RCCE, Jean Baptiste Lenté and Jules Carvallo, determined that rice was the only viable crop, since it involved flooding of the fields and consequent salinity reduction. Delta del Ebro rice is a PDO (Protected Designation of Origin) product and all varieties (such as Tebre, Fonsa, Gleva and Montsianell) come from the *Oryza sativa* species. The construction of the canals and the expansion of the rice fields (1860–1960) generated a change in practically the entire delta landscape. The canals originated at the Xerta-Tivenys Weir, located 30 km upstream of the delta, allowing the water to be distributed by gravity alone. They branch out into countless secondary canals that convey fresh water (591 $hm^3 y^{-1}$) from the river to the delta plain. Despite the presence of the first dams, the water from the river still carried sufficient amounts of fine sediments for an elevation gain in the delta of an estimated 25–50 cm during the first half of the 20th century (Fabregat 2009).

The reduction of salinity in the soils and lakes had diverse consequences. The expansion of agriculture generated conflicts between farmers and fishermen, as lagoons were drained for cultivation and the reduced salinity caused a decline of (more expensive) saltwater fish species in favor of freshwater species (Reales 1906). The environmental changes also resulted in an increase in birdlife and the replacement of halophytes by freshwater plants. The shallow, long-term flooded rice fields enabled mosquitoes to proliferate, resulting in malaria epidemics. The Ebro Delta became an endemic area for this disease in Europe, until the use of insecticides changed this situation from the 1950s onwards. Reduction of flow and sedimentation by dams caused stopped the growth of the delta (see Marine transgression in the Ebro Delta, below).

The Ebro Delta produces 15% of Spain's rice. It is one of the crops that is subsidized by agricultural policies and with the most stable prices, which has favored the almost monoculture of rice in relation to other orchard crops.

In recent decades, sustainable tourism associated with the natural values of the delta, particularly its avifauna, has gained importance. This has been in tandem with the restoration of its rich culture based on local agricultural products, as well as the fisheries and marine crops that the area provides.

30.4 Key biodiversity elements

The Ebro Valley has a privileged position due to its being a climate refugium during the Ice Ages. This has resulted in a high degree of endemism and a rich biodiversity, supported by varying and temporally dynamic habitats along the river corridor. Recent developments, such as changes in hydromorphological dynamics, flow regulation and water withdrawal, and invasive species, have had strong detrimental ecological impacts.

30.4.1 Habitats of the Middle Ebro River and their biodiversity

The natural heritage of the Middle Ebro comprises habitats, species, and processes of great values such. Floods and related processes are central to habitat and species diversity, but they are feared by the people (Peño 2018).

The meandering channel displays a high geodiversity due to its dynamic sediment erosion, transport, and deposition. The freely meandering sections of the Ebro are the most important ones in the Iberian Peninsula and deserve social recognition and protection. They play an important role in bio-geophysical exchange processes between active channel and the floodplain. The highly diverse, and well oxygenated bottom sediments (including the hyporheos) are important fish reproduction sites and harbour a rich benthic community.

The riparian forests, include marsh and aquatic communities, reed beds, herbaceous sedge and meadow assemblages, shrub communities, as well as mature groves of trees, with the trilogy of *Populus nigra*, *P. alba*, and *Salix alba*, dominant, with small stands of *Ulmus* ssp. and *Fraxinus* ssp. On the outer riparian/floodplain fringes, brambles and meadows with an abundance of nitrophilic species dominate. In the border near the water flow and on the sediment bars, different species of *Salix* are being replaced by *Populus nigra* and particularly *Tamarix gallica* and *T. canariensis*, all of which have expanded in the last 40 years (Najes et al. 2019). The enormous aesthetic and bioclimatic values of the Ebro riparian forests are remarkable, providing a humid belt of atmospheric freshness in the midst of the arid Depression.

Since 1927, the area of floodplain covered by natural vegetation has shrunk, leaving only 40% of the riparian zone and 4.5% of the floodplain remaining. Many of the riparian forests, particularly that of Cantalobos downstream of Zaragoza, exhibit symptoms of drought related to a sinking water table as a result of over-abstraction. Others have reached maturity and now exhibit high tree mortality rates. The forests are subject to various, but intermittent initiatives for their protection (see table 30.1).

Another significant feature are the *galachos* or ancient cut-off meanders, for their dynamics and ephemeral nature. The most prominent, still preserving a surface sheet of water, are those of Boquiñeni, Juslibol, La Cartuja, La Alfranca and Osera (Najes et al. 2019, Peño 2019). Galachos that were disconnected from the river between 50 and 100 years ago generally lack surface water, or it is too shallow to be seen under the dense tapestry of helophytes (reeds and cattails). They are typically habitats with an exceptional faunal richness, particularly migrating birds.

Another unique, spectacular landscape element important to Ebro River dynamics is the remarkably continuous tertiary gypsum scarp that bounds long sections of the left bank of the floodplain, with 60 to 140 m elevation. It is an eroded escarpment, carved by the Ebro during the Quaternary, and moving northward due to recent tectonics. It evolves by mass landslides (Pellicer et al. 1984, Peña et al. 2021). In terms of biodiversity, they are outstanding due to their steppe flora, insect, reptile, and bird communities (see also chapter on the Dordogne, this volume).

Fig. 30.5 Live specimen of the Giant River Pearl mussel (in Spanish: ''*margaritona*'') *Pseudunio auricularius*. Photo: Rafael Araujo

The river mussels (also known as unionids or naiads) and migratory fish are among the most fascinating, diverse, and widespread elements of the instream fauna of the Ebro. Some of these species are mutually interdependent (see below). Not only are they ecologically valuable/important, but they also play an important role as food, and for festivities and many other leisure activities of the Ebro inhabitants (Marcuello 1996).

In the Ebro River system, there are four native naiads: *Pseudunio auricularius* (previously known as *Margaritifera auricularia*), *Unio mancus*, *Potomida littoralis* and *Anodonta anatina*. The first, known in Aragon as "*margaritona*", develops shells nearly 20 cm long (fig. 30.5). Present across Europe, it is currently listed as being in danger of extinction (Prié et al. 2017). The other species, excepting *A. anatina*, are also endangered under the IUCN Red list (Araujo et al. 2009).

We know that at the end of the 19th century, there were still huge populations of *margaritona* (*P. auricularius*) in the Ebro mainstem, from Burgos to Tarragona, although it seems the species did not inhabit the tributaries. The growing disappearance of this species, and the rest of the naiads, hinges on their reproductive strategy. Adult mussels release their minute larvae into the water which then becomes inhaled by fish. The larvae (or glochidia) then attach to the gills of the host fish (without harming it). After metamorphosis, the juvenile naiads fall to the river bottom to establish new colonies or enrich existing ones (Araujo et al. 2009). *Margaritona*, as all naiad species, can only survive if sufficiently large populations of the host fish exist. The host fish of this mussel are known to be sturgeon (*Acipenser sturio*) and lamprey (*Petromyzon marinus*) (Araujo and Ramos 2000, Soler et al. 2019), two species that have not been present in the waters of the Ebro for more than a century (Doadrio 2001). The absence of these migratory fish is due to fragmentation of river network and other human impacts.

A list of fish species native to the Ebro River system would have been quite long at the beginning of the 20th century, and would have included the following species, all of which are now extinct and/or endangered (scientific and local names):

Table 30.2 Protected areas and conservation sites in Ebro delta

Name /reference	Establishment date	Size	Conservation purpose	Conservation mechanism
Ebro Delta Natural Park (including Punta de la Banya Natural Reserve)	1983 1986	8,445 ha terrestrial 564 ha marine (in 1986 the protection area was extended)	Guarantee a rational use of the resources and to promote scientist and educational uses	Decree 357/1983 and Decree 332/1986 of the Catalan Government
Special Interest Zone	1984	1,200 ha	Conservation of halophile vegetation	European Council
Delta del Ebro SPAB [ES0000020] ZEPA	1987	40,341 ha (33,720 ha marine)	Special protection Area for Birds	European Directive on the Conservation of Birds (79/408/ EEC)
Ebro Delta IBA [ES 148]	1989	32,000 ha	Important Bird Areas	BirdLife Conservation (IBA)
Area of European Importance	1991	–	Conservation of aquatic vegetation	European Council
PEIN site	1992	12,378 ha terrestrial and 35,647 ha marine	Protection of natural sites	Catalan Government's Plan for Areas of Natural Interest
RAMSAR Site [593]	1993	7,736 ha	Wet areas with international importance, specially as an habitat for aquatic birds	Intergovernmental Ramsar Treaty
LIC [ES0000020]	2006	12,378 ha terrestrial and 35,647 ha marine	Protection of natural sites	Natura 2000 Network
Marine Platform, Delta del Ebro-Columbretes IBA	2009	≈ 30,000 ± 10,000 ha	Important Bird Areas	BirdLife Conservation (IBA)
Terres de l'Ebre Biosphere Reserve	2013	367,729 ha	Sustainable development	Programme MaB UNESCO
Marine Platform, Delta del Ebro-Columbretes ZEPA [ES0000512]	2014	9,017 km^2	Important Bird Areas	ZEPA Directive 2009/147/CE
IUCN category IV and V		V: 4,100 ha IV: 3,702 ha	Protection of landscapes and seascapes	IUCN

Salaria fluviatilis (pez fraile), *Parachondrostoma miegii* (madrilla), *Luciobarbus graellsii* (barbo), *Barbus haasii* (barbo), *Squalius cephalus* (escalo), *Squalius pyrenaicus* (escalo), *Achondrostoma arcasii*, *Phoxinus bigerrii*, *Aphanius iberus* (carpa de dientes española), *Valencia hispanica* (carpa de dientes Valencia), *Cobitis paludica* (colmilleja), *Alosa fallax* (saboga) and *Petromyzon marinus* (lamprea). In recent years, the fish fauna has undergone massive changes due to human-induced environmental changes, including invasions by exotic fish species (Clavero and García-Berthou 2006),

Fig. 30.6 Aerial view of the Ebro Delta. Map: Rut Domènech

which have outcompeted them (see sub-chapter 30.6). Species that were commonly fished in the Ebro, such as madrillas or barbels are rare today.

The fish require high quality water and coarse, clean spawning sediments, in which their eggs can develop. The assemblage of all mussel species help clean the egg-laying spots for them, by filtering the water and removing organic sediments. Water pollution and loss of dynamic habitats, due to human detrimental impacts on the river ecosystem, are thus resulting in a 'species meltdown effect' eliminating such interdependent species synchronously (Soler et al. 2019). In the Ebro, the invasive zebra mussel (*Dreissena polymorpha*) (Sanz-Ronda 2014) may have an additional, not well studied, negative effect on *P. auricularius* and other species.

30.4.2 The Ebro Delta and its biodiversity

The habitats and species of the Ebro Delta are highly dependent on the water and sediments that the river brings to it (fig. 30.6). Within a modest area of 320 km^2, the delta harbors a variety of natural ecosystems such as riverside forest, fluvial islands, bays, beaches, dunes, brackish waters, coastal lagoons, and *ullals* (places where underground freshwater emerges at the surface). It also includes rice fields as habitats which host a great diversity of wildlife (fish, birds and halophilic flora) and have a strategic role in bird migrations. Many of these deltaic habitats and species are scarce within Europe and the Mediterranean. Europe's Natura 2000 network includes the Ebro Delta as an area of international importance for eight plant and 69 vertebrate (mostly bird) species. A number of other protected areas/conservation sites have been established in the delta (table 30.2).

The fauna of the delta wetlands is distinguished by the spectacular presence of waterbirds both in breeding and overwintering seasons.

The nesting waterfowl population comprises more than 56,000 pairs, while the wintering population is about 200,000 individuals. Among the most notable species, the Audouin's Gull (*Larus audouinii*) is prominent, with 60–70% of the world population, five other species of larid seagulls (*Larus michahellis*, *L.s genei*, *L. ridibundus*, *L. fuscus* and *L.s melanocephalus*); nine species of ducks (*Anas platyrhynchos*, *A. strepera*, *A. clypeata*, *A. acuta*, *A. crecca*, *A. querquedula*, *Netta rufina*, *Tadorna tadorna* and *Aythya ferina*); nine species of herons (*Bubulcus ibis*, *Egretta garzetta*, *E. alba*, *Ardeola ralloides*, *Ixobrychus minutus*, *Ardea purpurea*, *A. cinerea*, *Nycticorax nycticorax* and *Botaurus stellaris*); five species of terns (*Sterna sandvicensis*, *S. nilotica*, *S. hirundo*, *S. bengalensis* and *S. albifrons*); and seven waders (*Himantopus himantopus*, *Charadrius alexandrinus*, *Recurvirostra avosetta*, *Tringa* *totanus*, *Charadrius dubius*, *Haematopus ostralegus* and *Vanellus vanellus*). Subsequent to the inclusion of the Ebro Delta in the Ramsar Convention List in 1993, the delta wetland was colonized by the common flamingo (*Phoenicopterus roseus*), with about 1,600 pairs, Common Morel (*Plegadis falcinellus*), Great Egret (*Egretta alba*), and Common swamphen (*Porphyrio porphyrio*). The abundance of waterfowl has traditionally generated great interest in hunting, particularly of ducks and coots.

The productive waters favours commercially valuable species of fish, mollusks and crustaceans, which has led to significant commercial and recreational fishing in the area. The coastal lagoons, bays and the coastal area close to the mouth of the delta are important areas for the reproduction and growth of fingerlings of several fish species valued for fishing and conservation. The great variety of Ebro Delta habitats allows many marine and limnetic fin and non-fin fish species to coexist, be they migratory, seasonal, seasonally-sedentary or sedentary. The site includes some species endemic in the western Mediterranean or within a restricted area, such as *Valencia hispanica*, *Lebias ibera* (both Iberian endemics), *Cobitis paludicola* and *Salaria fluviatilis* (which this is now most likely the main host species of *Pseudunio auricularius* mentioned above).

The most important geomorphological elements and their influence on the biotic richness of the delta will be described as follows.

Estuary: Downstream the town of Amposta, the final section of the Ebro. The native riverside forest is quite sparse (having been replaced by agricultural holdings), with the exception of the Gràcia, Buda and Sapiña islands. Towards the sea, common riparian plants (see above: Middle Ebro) become reduced to reeds, oleanders and tamarisk. These too have become reduced by agricultural use. In the last decade, however, narrow strips of riparian forest (5–10 m wide) have been protected by paths established parallel to the river. The brackish waters characteristic of the estuary gives rise to dense populations of phytoplankton and invertebrates that support a high fish biomass. Typical native fish species in the lower river and estuary, are eel, blackhead, friar fish (*Salaria fluviatilis*) and mullets (*Liza ramada*). As in other parts of the Ebro River system, native fish species often become outcompeted by invasives, as well as other stressors (see below: rice fields). Migratory species, such as the marine lamprey (*Petromyzon marinus*) and the twaite shad (*Alosa fallax*), are in decline and currently listed as threatened species. The European/Atlantic/common sturgeon (*Acipenser sturio*), went extinct about 50 years ago (Ludwig et al. 2011), as a result of a combination of overexploitation of the fishery (until the beginning of the 20th century), dams and other physical barriers to migration, and displacement by non-native species. A EU LIFE project currently aims to re-establish the sturgeon (Migratoebre 2019).

The Ebro Sea: The area of influence of the Ebro River covers a radius of about 100 km around its mouth, which extends between the fishing ports of Castellón and Tarragona. In the open sea, the marine renewal rate is higher compared to the bays and rich in nutrients provided by the fresh water of the river that make the area one of the foremost marine breeding areas in this part of the Mediterranean Sea. Phytoplankton constitutes the base of the marine productivity, as can be seen from the enormous catches of fish and shellfish. Ebro Sea constitutes one of the most productive in the western Mediterranean with an annual average of 8,048 tons (120 caught species) in the period 1990–2004 (Curcó and Vidal 2006). Likewise, it is a major feeding area for abundant seabirds (e.g., supporting 60% of the world population of Audouin's gull).

The Fangar and Alfacs bays: bays are enclosed by coastal sandbars (see fig. 30.7). Due to the inflows of river fresh water and nutrients, they have low salinities than the rest of the delta and surface layers of freshwater, providing excellent conditions for phytoplankton production and seagrass meadows, such as dwarf eelgrass (*Zostera noltii*), little Neptune grass (*Cymodocea nodosa*) and spiral ditch grass (*Ruppia cirrhosa*). The bays are used for semi-intensive aquaculture, particularly of mussels (*Mytilus galloprovincialis*), Japanese oyster (*Crassostrea gigas*), European fine clam (*Tapes decussatus*) and Japanese clam (*Tapes semidecussatus*) (parcsnaturals.gencat.cat 2021).

Coastal lagoons and inland lakes: As a consequence of rice cultivation, the connectivity to the sea and the salinity of these shallow (0.40–1.00 m)

Fig. 30.7 Fangar bay, arrowhead and sandbar. Photo: Mariano Cebolla, with permission

brackish lakes is decreasing. They remain highly productive, however, harboring fish species such as flathead grey mullet, seabass, sea bream, eels, sole and carp, as well as dense concentrations of birds, such as Eurasian coot (*Fulica atra*) and various duck species. Freshwater turtles (*Emys orbicularis* and *Mauremys leprosa*) occur here. Hunting and fishing still follow century-old traditions, for example, the distribution of designated communal/collective hunting points and the collaboration among fishermen of the Cofradía de Sant Pere (Sant Carles de la Ràpita). Their scenic views and rich fauna make the lagoons one of the most visited environments by tourists.

Alfacs and Fangar arrowhead sandbar and dune beaches: Extensive sandy beaches and the largest dune landscape in Catalonia are found within the delta (fig. 30.7). Near the sea, the dunes are mobile, while further inland they are more stable and partially vegetated with psammophilic (moving sand-tolerant) species (e.g., beach tares, burs and sea lilies). These species are adapted to the harsh living conditions, such as high permeability of the soil and a high solar radiation index 30. Behind these dunes, there exists a splendid plant community with flowers of extraordinary beauty in spring and summer, such as cat's claw and purslane. The dune fauna is quite varied, with the presence of some large beetles, and reptiles, such as red-tailed (*Acanthodactylus erythrurus*), and long-tailed lizards (*Psammodromus algirus*). The beaches and dunes are also breeding and resting sites for terns, seagulls and waders. Even the endangered marine loggerhead turtles (*Caretta caretta*) breed here.

Salty and brackish flats: Located in the area behind the dunes are flats, with clay-silty soils, that are often flooded and, therefore, quite saline (fig. 30.8). The halophilic plants that grow in this environment have two adaptation strategies: either they accumulate salts and water in their tissues, such as species of Salicornia, or actively excrete salt, such as Limonium. Along with frog grass (*Sarcocornia fruticosa*), purslane (*Portulaca oleracea*) and white bean-caper (*Zygophyllum album*), together these plants represent one of the most threatened vegetation groups in Europe, contributing to the recognition of the Ebro Delta as a conservation site of international importance. The sosares (salty areas) are also the breeding place for rare birds such as the golden plover, the sea partridge and the small tern (*Sterna hirundo*), and feeding grounds for waders and other seabirds. The salt flats are the wetland habitat of a diversity of microorganisms, such as small worms and crustaceans, which feed species as valuable as the common flamingo (*Phoenicopterus roseus*), the pied avocet (*Recurvirostra avosetta*), the white jar (*Tadorna tadorna*) and the red-billed gull (*Larus genei*). The salt flats have been used as salines for centuries. Currently, the only commercially-productive salt works in the Delta is La Trinitat, at the tip of La Banya, with an annual production of 80,000 tons (Infosa 2021).

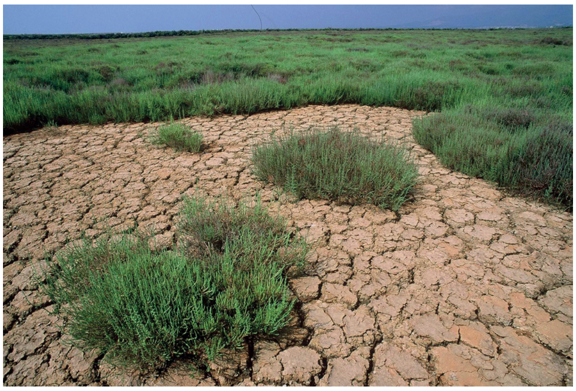


Fig. 30.8 Sosares, salty zones in the coastal wetlands of the Ebro Delta. Photo: Mariano Cebolla, with permission

Fig. 30.9 Irrigation channel in rice fields. Photo: Mariano Cebolla, with permission

Fig. 30.10 Rice irrigation system. Photo: Mercè Mariano

Ullals: The ullals are crystal-clear freshwater ponds with a constant temperature of 17–18°C throughout the year. They originate by upwelling

Table 30.3 Key elements of biodiversity in the Middle and Lower Ebro

Key element	Link to the natural flow regime	Ecosystem services	Human use and threats
Meandering riverbed	Erosion and sedimentation patterns, and diverse river morphology, depend on flood regime	Cleaning of the bed sediments (spawning and incubation areas for fish), biogeochemical processes, exchange between main channel and floodplain	Reduction of hydromorphological dynamics, reduced water for the environment, and barriers to connectivity, due to dam construction and operation
Riparian forests (*Populus nigra*, *P. alba*, *Salix alba*)	Succession/recruitment cycle according to the frequency of major flood events	Living and dead wood are important habitats and biologically active surfaces. Forests buffer flow events and absorb nutrients	Loss of high conservation value groves with loss of traditional agro-livestock use since the 1990s and flood regulation, aesthetic value for recreation threatened by dikes and dams
Galachos – cut-off river meanders	Final successional stage of meanders. Stagnant water with high water table	Excellent habitat for a complex plant community and a rich fauna, such as migratory birds	Some galachos / reed beds are spoilt by illegal rubble dumping
Pseudunio auricularius and other naiads (*Unio mancus*)	Mussels depend on migratory fish (as dispersal agents for their larvae) and longitudinal connectivity of the river	Filtering purifies water and sediments in spawning sites, benthic-pelagic coupling (foodweb effects)	Previously used for mother-of-pearl cutlery industry in Sástago (18th century). Severely threatened by excessive river flow regulation, invasion by non-autochthonous zebra mussel and disappearance of main host fish
Migratory fish (*Alosa fallax*, *Petromyzon marinus*)	Habitat choice and life cycles influenced by hydrological pattern and timing of flow events	Importance for the food web, host fish for naiads, ecosystem engineers (*P. marinus*)	Fisheries. Threatened by damming and invasive fish species, e.g. giant catfish (*Silurus glanis*)
The Ebro Delta and Sea, bays of Fangar and dels Alfacs, and coastal lagoons	Contributions by the Ebro River (freshwater, nutrients, sediment, biotic exchanges) create an extremely productive fresh-/saltwater interface in the coastal zone	Important feeding area for fish and seabirds, harboring many rare species	Highly productive fisheries, threatened by reduced sediment loads and freshwater inflows. Semi-intensive mollusk aquaculture, tourism
Arrowhead sandbars: Punta del Fangar and Punta de la Banya and dune beaches	The sediments transported become redistributed along the coast, forming a mobile, dynamic landscape	The diverse psammophilic vegetation helps retain the sand and create dunes, forming habitats for other species. Dune beaches are breeding sites for Caretta caretta turtles	The most extensive dune beaches in Catalonia; center of attraction for tourists

Table 30.3 (continued)

Key element	Link to the natural flow regime	Ecosystem services	Human use and threats
Ullals	Upwellings of ground water seeping from mountain ranges	Peatland microhabitats for specific flora and a fauna, including Iberian Peninsula endemics	Impacted by surrounding agriculture. The Ullals de Baltasar were restored in 2010, and interpretative itineraries were created
Saline and brackish zones	Located behind the back dunes, under direct marine influence	Harbor special plant species such as *Salicornia fruticosa*, *Zygophyllum album* and key feeding habitats for waders (e.g., flamingos)	Salt production through evaporation, with a production of 50,000 $t\,y^{-1}$, tourism
Rice fields	Artificial flooding with river water, with nutrients and sediments creates productive paddies. They are drained seasonally for harvesting	An exemplary man-made ecosystem that combines agricultural production with the conservation of biodiversity (mostly birds)	Important rice production, use for tourism. Threatened by climate change (sea level rise) and reduced sediment supply from the catchment

of groundwater originating from rainfall in the Sierra de El Montsià and Els Ports coastal mountain ranges, located 50 km away. They appear in peaty areas within the delta (and elsewhere – see above) on the boundary between the deltaic plain and the surrounding landscape. They range between 2.5 and 6.0 m in depth, and 5 to 55 m in diameter. In terms of their flora and fauna, these small wetlands differ notably from the rest of the delta plain. They provide microhabitats for the white water lily (*Nymphaea alba*), pondweed (*Potamogeton* sp.) and the carnivorous bladderwort (*Utricularia* sp.) as well as several fish species. These include the river blenny (*Salaria fluviatilis*), and two killifish species, the fartet (*Lebias ibera*) and the samaruc (*Hispanic valencia*), which are Iberian endemics and in danger of extinction. The higher fertility of the peatlands surrounding the ullals has conditioned their use for agriculture, which makes their conservation difficult.

Rice fields: The high salinities in most of the delta mean that rice is the only agricultural crop possible and even so, the fields need to be flooded by irrigation with fresh water to keep the salinity under control (figs. 30.9, 30.10). After artificial flood irrigation, the rice is sown in spring and harvested six months later. After the harvest, the rice fields are plowed over and flooded again, making them a strategic refuge for birds. The European Union, in its agricultural policies, recognizes the environmental role of the rice cultivation cycle during autumn and winter and provides agri-environmental grants to farmers. This crop is essential to preserve the ornithological importance of this wetland, as well as providing a livelihood for the local population. The current production of rice exceeds 120,000 tons per year, making the Ebro Delta the third-largest producing area within the European Union (Day et al. 2006).

The rice fields also act as a temporary, diverse aquatic ecosystem, but one that harbors many exotic species, including the highly invasive red swamp crayfish (*Procambarus clarkii*). Exotic fish species such as stone moroko (*Pseudorasbora parva*), common carp (*Cyprinus carpio*), dojo loach (*Misgurnus anguillicaudatus*) and eastern mosquitofish (*Gambusia holbrooki*) make up more than 95% in the local rice fields (Clavero et al. 2015). When the paddies are drained, the inorganic nutrients and organic matter in their waters helps improve the productivity of the surrounding bays.

30.5 Key elements of cultural diversity

The physiographic features of the Ebro Valley have strongly influenced its cultural development (see above: history). It connects the cultural landscapes of the Atlantic with those of the Mediterranean. Moreover, its function as a humid ecological corridor in a very dry region has led to the evolution of specific cultural forms over time.

30.5.1 Cultural heritage of the Middle Ebro

Navigation of the Middle Ebro was, as already mentioned, a commercial activity that, while it generated revenues and new projects, also negatively impacted the riverbed and banks. The commercial transport of wood along the riverway, which supplied sawmills for the construction of furniture and boats, lasted until the 1950s when it became outcompeted by the railway. To these transport ways should be added other more modest, household uses of riverine goods, including deadwood for heating, livestock grazing in the groves, medicinal plants, reeds as wind barriers in the fields, quarrying gravel from the riverbed and banks for construction, and fishing for barbels and eels, as a major source of nutrition for the local population. The rich traditional riparian orchards near population centers had even greater value. Although primarily established for subsistence, the agricultural products also had commercial value in nearby cities. The genetic variety of heritage crops was extremely high, but many of these varieties have since been lost, replaced by subsidized crops such as corn and alfalfa.

The Canal Imperial of Aragon: This canal was built by the Aragonese engineer, Ramón de Pignatelli, in the 18th century, under the mandate of King Carlos III of Spain (fig. 30.11). However, its history dates back to the time of Carlos I, in what was known as the Imperial Acequia (Conde de Sástago 1796, González Rodrigo 1984). The imperial canal takes its waters from the Ebro River in El Bocal de Tudela (Navarra). It runs for more than 100 km, to the town of Fuentes de Ebro (Zaragoza), following one of the old river terraces of the Ebro. Its initial purposes were the transportation of goods by navigation (abandoned at the beginning of 20th century) and irrigation of the landscape it traversed (Fernández Marco 1961, Pérez Sarrión 1975). Currently, the canal supplies water for irrigating about 25,000 ha of field crops, in 26 municipalities, and for municipal and industrial purposes for the city of Zaragoza. Its constant current flow rate is 30 $m^3 s^{-1}$. The bottom sediments of the canal were until 2013 among the last refuges of rare mussels (Araujo and Ramos 2000), especially the Giant River Pearl Mussel (*Pseudunio auricularius* with the most abundant and diverse populations in the entire Iberian Peninsula). However, successive canal reinforcement works finally extinguished this population in 2019. The measures taken to limit seepage, by lining the Imperial Canal with concrete, and by establishing locks only focused on its function as a hydraulic structure, whereas historic, geographical, environmental and artistic values were not taken into consideration.

The manufacture of mother-of-pearl at Sástago: The city of Sástago (community of Zaragoza) lies in the middle of a large meander bend of the Ebro River. In the 18th century (and possibly earlier) specialized blacksmiths used the mother-of-pearl (nacre) of the formerly abundant margaritona mussels (*P. auricularius*) to make knife handles, which were renowned throughout Aragon (Monesma 1993, Álvarez-Halcón 1998, 2001). This activity was maintained from generation to generation of blacksmith's guild members, mainly of the Liso family. It is known that at the end of the 19th century, a single fisherman could harvest 500 kg of mussels in a single day in the river reach near Sástago. This is equivalent to some 1,300–4,000 individuals. By 1915, mussel catches decreased dramatically, in large part due to overharvesting, with fishermen requiring one and a half months to harvest 50 kg (Haas 1916, 1917). In the last 20 years, only one (!) living specimen of the species has been found. The ecosystem of the Sástago meanders has not only suffered the decline of the river mussels, and along with them, several other elements of biodiversity, but also of course, with them, the abandonment of the Sástago cutlery tradition.

30.5.2 Cultural heritage of the Lower Ebro

Following the course of the river, it is also worth highlighting the emblematic fortifications that testify to the strategic enclave of the Lower Ebro and delta as a gateway to the Mediterranean Sea.

Fig. 30.11 The canal bridge of the Canal Imperial crossing the Jalón River. Photo: Rafael Araujo

Fig. 30.12 Miravet Castle. Photo: Jaume Boldú, Consell Comarcal de la Ribera d'Ebre archive, with permission

Miravet Castle and Xerta Weir: An example is the medieval Castle of Miravet (fig. 30.12), an exemplar of the architecture of the Order of the Templars in Europe. Another built infrastructure for the use of the water resources of the Ebro River and a testament to the Catalan industrial heritage of the Renaissance is the Xerta Weir (fig. 30.13), linked to which is also a disused flour factory and mill. The weir is a 310 m diagonal semi-circular weir/partial diversion where the water flows evenly over the crest. It is believed to have been built in Islamic times and restored in the 12th century, but the works did not finish until 1411. Later, in the 19th century, it was reconditioned to redirect the water to the Ebro Right and Left Bank Canals for rice irrigation.

Navigation and boat crossings: Concerning the navigability of the Lower Ebro, has given rise to a rich heritage in terms of traditional boats and boat crossings, as well as lost arts and crafts, such as boatmen and towmen. In recent decades, efforts were made to promote river tourism and increase navigation and recover the popular culture and old trades with festive events. (i.e. River festival in Flix with traditional punt boat races, or to recover old techniques: rice planting or harvesting festivals in various towns of the Delta). Among the non-material cultural elements related to river navigation, the boatman's trade is worth mentioning, dating back to the 12th century. For centuries, the only crossing place in the estuary final stretch of the Ebro Delta was the *Paso de las barcas* (the boat crossing) in Tortosa. The construction of the first bridges condemned the ferries to their disappearance (more than 300 boat crossings were counted along the Ebro River). In 2020, only three ferries remain: in Miravet and Flix, and one recently restored, in Garcia.

Traditional punt boats: The Lower Ebro between Ascó and Amposta is now navigable and recreational activities using traditional punt boats, such as the *llagut* (Catalan), *muleta* or *pontona* have been restored. The recovery of the recreational and sports use of the Ebro continues its history of the transportation of goods and people that was common until the 1970s.

As already mentioned in the history section, the Ebro Delta was uninhabited until the middle of the 19th century. With the construction of irrigation canals and land reclamation for rice cultivation, the first settlers came from the neighboring areas of Amposta and Tortosa, their cultural features being common to the rest of the Ebro Basin.

Among all the rich cultural heritage associated with the Ebro Delta, we can distinguish between

Fig. 30.13 Xerta weir. Photo: EliziR, Wikimedia Commons, CC BY-SA 3.0

Fig. 30.14 Amposta suspension bridge. Photo: Mariano Cebolla, with permission

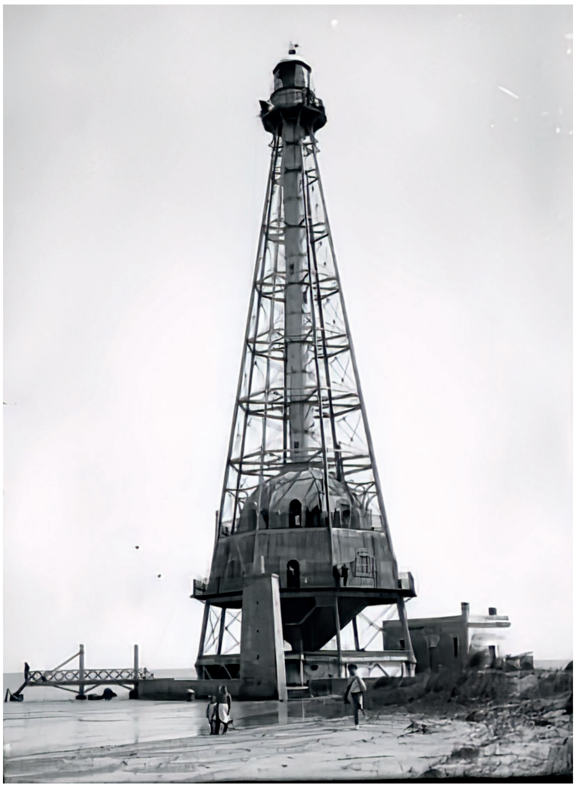


Fig. 30.15 Buda Lighthouse. Source: Ramon Borrell, Baix Ebre county archive, with permission

the material elements (typical buildings, architectural elements, etc.), the handicrafts, and the intangible elements of identity (forms of social organization and relations). Parts of this section were derived from the documents and information archived in the inventory of Terres de l'Ebre intangible heritage (IPCITE 2017).

Amposta suspension bridge and *Lo passador bridge*: Following the course of the lower stretch of the Ebro River and entering the estuary, we come across viaducts and bridges built from 1868 onwards, among them the Amposta suspension bridge (1915, the second bridge of this type in the world, fig. 30.14) and the Sant Jaume d'Enveja bridge (2010). This design was chosen due to the depth of the river channel and lack of stability of the land. The bridge notably improved the exchange between the towns of the Ebro Delta, since it was the first permanent crossing point within the delta from 25 km to its mouth. It was only in 2010 that the "Lo Pasador" road bridge further downstream connected the cities of Sant Jaume d'Enveja and Deltebre, previously only connected by barges (motorized since 1859). Lo Pasador ('the ferry man') is the most significant modern architectural element in the delta and, at 12 m high, it is one of its highest topographic points.

Buda lighthouse: Among the most unique architectural elements of the Ebro Delta are the Buda Lighthouse (1864, fig. 30.15). Today, it lies at the bottom of the Ebro Sea, more than 3 km off the coast, and represents one of the main testimonies of the delta's recent regression.

When the Buda Lighthouse was built as one of the first lighthouses on the delta coast the Ebro River still contributed so much sediment that the delta and adjoining coast were rapidly advancing . Therefore, a metallic lighthouse was built that could be dismantled and moved as the delta grew. The Buda Lighthouse was active until Christmas Day 1961, when it collapsed during by a storm, as its pillars already had been corroded and foundations laid bare due to the reduction in river sediment inputs. .

Delta farm barns: The rich ecosystems of the Ebro Delta have influenced the development of traditional techniques and crafts, based on the use of its natural resources, most of which t have remained unaltered for centuries. For example, the delta farm barns (fig. 30.16) represent an architectural element and symbol of identity that is in perfect balance with the surrounding landscape. They are built with materials typical of the area, with a wooden structure and vegetal roof, and vertical walls made with reeds and mud. These constructions have been documented since the Middle Ages, but had their maximum

Fig. 30.16 Typical delta barn or "barraca del delta". Photo: Mercè Mariano

Fig. 30.17 Fishing gears in lagoons: Rall. Photo: Mariano Cebolla, with permission

Fig. 30.18 Fishing gears in lagoons: Tresmall. Photo: Mariano Cebolla, with permission

expansion between the end of the 19th century and the beginning of the 20th century. Thereafter the barns were abandoned for decades, before the recovery of their construction trade in the 1990s as they became highly appreciated from sociocultural and landscape points of view.

Traditional methods and gears: for traditional fishing in fresh and brackish waters such as cast nets locally called rall (fig. 30.17), beach seines or tresmall (fig. 30.18), and fyke or *gànguil* and *bussó gears*/techniques have been documented from the 17th century onwards, some of which remain in use today (IPICITE 2017).

Traditional cooperatives and guilds: Likewise, the ongoing need to find ways to distribute the resources of the Ebro between farmers and fishers have led to centuries-old organizations remaining fully operational even today. Regarding the distribution of irrigation water for rice growing, there are two co-operatives associated with the main left and right bank irrigation canals: the Canal de la Derecha (right canal) del Ebro (1860) and the Canal Izquierdo (left canal) del Ebro (1912). In the township of Bot, in the Terra Alta region (a high plain), there is the Canaletes River irrigation cooperative, for the irrigation from this tributary of the Ebro of 25 ha, with statutes dating from 1895. For the organization of fishing in the lagoons, the (1383) *Cofradia* or *gremi de Sant Pere* (1383) exists, an entity of certified fishermen of medieval roots (they managed fishing from Mequineza to the mouth) with its statutes practically unaltered since 1828.

30.5.3 Emergence of social-environmental movements in defense of the Ebro River

During the 20th century, 125 reservoirs (each one larger than 1 hm^3, one $hm^3 = 10^6$ m^3) were built in the Ebro Basin, enabling the regulation of 8,000 hm^3 of water per year to irrigate nearly one million ha of cropland and generate about 9,000 GWh of energy (CHE 2018). Next to each reservoir, there are countless personal stories of places that have perished, drowned by the waters. The construction of the Ebro reservoirs displaced an estimated 15,000 people from the rural world to the urban environment (Marcos et al. 2019).

In the 1990s, in the midst of the construction of the last two great dams on the Ebro, the Itoitz and Rialb reservoirs, and when the construction of four new dams, Biscarruands, Mularroya, Lechago and Santa Liestra and the enlargement of Yesa Reservoir were imminent, local opposition groups appeared at the towns of the tributaries of the Ebro (Bergua 2003) appealing "*For the dignity of the mountain*". At the same time, in the Lower Ebro, periodic threats of water transfers to Valencia and/or Barcelona that would further deplete the waters of the Ebro, together with the change in social perception about the environmental importance of the Ebro Delta, gave rise to an anti-water-transfer social movement, called the *Coordinadora Antitransvasaments* (Pont 2004).

Initially, all of these social movements were local and composed of diverse people, usually without specific knowledge on the subject. They had in common the defense of the territory in which they lived when confronted with large projects decided upon and approved by faceless centers of power, far removed from the territories where they would be implemented. The projects were conceived without any sort of consensus, nor taking into account the people at risk of being compromised economically, environmentally and socially in the territory in question (Pont et al. 2002). During the 1990s, social movements went from being local to joined together to create the institution COAGRET (the Coordinator of People Compromised by Large Reservoirs and Water Transfers) with a common claim that "*rivers and water are not the property of irrigation unions or hydroelectric lobbies, but a common good, a patrimony of everyone, already quite degraded, progressively more scarce and precious*" (COAGRET 2000). At the same time, aware that social demand required the countering of technical arguments, the New Culture of Water Foundation (FNCA) was created, a movement of academics and experts in the field of water management.

In September 2000, the presentation of the National Hydrological Plan (Hidrological Spanish Plan 2000) and the proposed transfer from the Lower Ebro to the south to the basins of Júcar (Valencia and Alicante, 450 $hm^3 y^{-1}$), Segura (Murcia, 315 $hm^3 y^{-1}$) and Almeria (190 $hm^3 y^{-1}$) and north to Barcelona (195 $hm^3 y^{-1}$) was the trigger for the

Table 30.4 Key cultural elements in the Middle and Lower Ebro

Key element	Link with the natural flow regime	Ecosystem services	Threats to the cultural element
Traditional arts and crafts linked to subsistence horticulture and the use of riverside forests in the middle section and the Lower Ebro	Navigation along the river itself until the 1960s. Use of the resources provided by the river. Family farms linked to the flow regime of the river (e.g., floods served to fertilize the soil)	Mosaic landscape and sustainable use of natural resources. Conservation and maintenance of the elements for the use of water resources linked to traditional agriculture	Modification of land use. Unsustainable agriculture and livestock, urban and/or industrial waste discharges, flood defenses and regulation works (dams and reservoirs, weirs, etc.)

Table 30.4 (continued)

The Imperial Canal of Aragon (18th century)	Water diverted at El Bocal de Tudela and conveyed 100 km to Fuentes de Ebro. Supplies water to the city of Zaragoza	Patrimonial and artistic element representative of the age of the Enlightenment. Also a refuge for freshwater mollusks	Single-purpose management of the canal for irrigation, neglecting the conservation of biodiversity, and architectural and other heritage elements.
Mother of pearl craftsmanship in Sástago	Use of abundant mussels to produce cutlery handles, common in the 19th-century throughout the Middle and Lower Ebro	Mussels improve the environmental quality of the river by filtering water. Traditional craftsmanship	Breakdown of the mussel populations and the craftsmanship due to human impacts.
Miravet Castle (9th–12th centuries) and Xerta Weir (10th–15th centuries)	Architectural monuments of the Templar architecture and the industrial heritage of the Renaissance, respectively	Heritage assets that testify to the strategic nature/position of the Lower Ebro	Not threatened. Tourist and cultural use of Miravet Castle. The weir serves for energy generation and tourism, and a fish ladder is planned
Navigation on the Ebro (Punt boats: llagut, muleta or pontona)	Traditional boat architecture for specific purposes	Function changed from fluvial transport to leisure activities, bringing the local population closer to the river	Mostly replaced by modern boats, some traditional boats are restored for tourism
Amposta Suspension Bridge (1915) and Bridge "lo Pasador" (2010)	Iconic architectural monuments of great social importance	Connects communities on both sides of the river, strengthens their identity and use by tourism	Not threatened
Buda Lighthouse (1864)	The metal lighthouse could be disassembled and moved as the coast advanced, in use for more than 100 years	Indicator of delta progradation and subsequent shrinking. Today, sunk to a depth of 20 m and shifted about 3 km from the current coastline	Does not exist any more
Delta farm barns	Sustainable constructions with local materials such as reeds and mud	Architectural, landscape and identity elements of the delta	Many barns have been abandoned, but since the 1990s, this type of traditional construction has become more valued again
Traditional co-operatives and guilds	Irrigation co-operatives dating back to the late 19th century and the Sant Pere fishermen's guild (medieval origin) played a fundamental role in the bays	Organized shared use of common goods (water and fish), avoiding misuse of resources and mediating in conflicts. Strengthening of local social structures	Partly superimposed by modern administration, but gaining importance as an example of how to manage resources in a public, transparent and fair way, taking into account the needs of all stakeholders, as well as the preservation of the natural environment
Social movements in defense of the Ebro river. Slogan: "The river is life, no to the transfer"	The approval of the National Hydrological Plan in 2000, precipitated an unprecedented, massive citizen mobilization	Social movement for an ecologically-sustainable flowrate that would allow the survival of the delta, home to 50,000 people. Vindication of a new water culture	Change in social perceptions of the importance of the Ebro Delta. Emergence of a new social, collective identity linked to the Ebro River

Cartuja's Galacho. Photo: Alfredo Ollero

The Imperial Canal of Aragon (Bocal). Photo: Rafael Araujo

Coastal lagoons (La Tancada). Photo: Mariano Cebolla, with permission

Traditional rice planting festival. Photo: Mariano Cebolla, with permission

Tip of La Banya. Trinitat Salt flats. Photo: Mariano Cebolla, with permission

Anti inter-basin water transfer demonstrations. Photo: Platform in Defence of Ebro (PDE), with permission

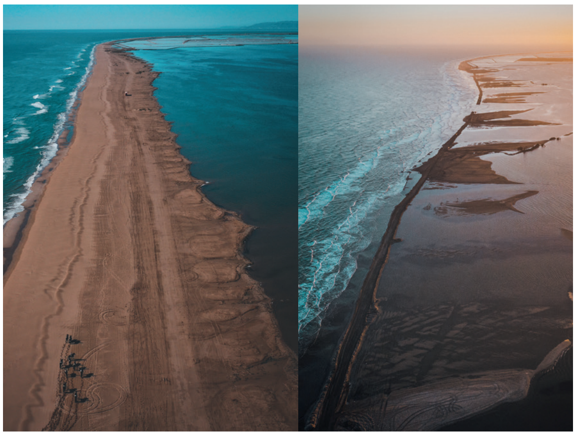
Fig. 30.19 Left column: iconic examples of biological diversity, right column: iconic examples of cultural diversity

Flood in the middle Ebro Section. Photo: Pilar Cabrero, with permission

Decontamination work of sludge contaminated by the Ercros industry in Flix. Photo: Josep L. Sellart, with permission

Apple Snail (*Pomacea sp.*), invasive species. Photo: Jpatokal, Wikimedia Commons, CC BY-SA 4.0

Control campaign of the black fly (*Simuliidae*) population. Pouring BTI, a biological larvicide, in the river. Photo: Montse Masià, with permission



The Gloria storm (2019) caused great damage in the Ebro Delta, including flooding of 3,000 ha of rice fields and destruction of mussel pans, and retreat of the coastline, destruction of Trabucador beach (*left*: before, *right*: after the storm). Photos: Èric Barberà, with permission

Sediment injection pilot test (IRTA, LIFE Admiclim 2019). Photo: IRTA, Life Ebro-Admiclim (http://www.lifeebroadmiclim.eu/es/), with permission

Fig. 30.19 (continued) Left column: iconic examples of threats, right column: iconic examples of sustainable management emergence of an unprecedented citizen mobilization throughout the Ebro basin, with continuous mobilizations and massive demonstrations from 2000 to 2004 in Zaragoza, Barcelona, Madrid, Mallorca, Valencia and Brussels, with the slogan "*Lo Riu És Vida*" ("the river is life") and symbolized with an iconic image 'the knot' (fig. 30.20).

The emergence of this social movement was not accidental but was the result of efforts to raise public awareness of the environmental value of the territory, from the Pyrenees to the Delta, together with the close collaboration of the scientific community promoting the New Water Culture, which questioned the outdated models of hydrological planning based on water supply, for new sustainable planning from a social, environmental and economic point of view, both in the territories affected by reservoirs and water transfers and in the territories receiving water transfers. The New Water Culture and citizen mobilizations demand compliance with the EU framework directives on habitats, birds and water as key elements in water planning (Council Directive 92/43/EEC; Council Directive 79/409/EEC, Directive 2009/147/EC; Directive 2000/60/EC)

Once the proposal for the Ebro water transfer was canceled in 2004 (Law 11/2005), citizen mobilization around the repeal of the water transfer focused its objective on the modification of hydrological planning and the implementation of ecological flows as a key element to achieve the good ecological status of the Ebro and the survival of the Delta. In the Pyrenees, it focuses against the construction of the Mularroya and Biscarrues dams and the enlargement of the Yesa reservoir.

There are several examples of how intensive human impacts have resulted in a synchronous degradation of biological and cultural diversity in recent years, but also, of how environmental and social consciousness have raised a new culture of resistance against further impacts to the Ebro River system. The social movements for the Ebro, by defending the river's rights to flow, and acknowledging that its water is not 'lost' when discharged into the sea are tackling globally important, socio-ecological issues.

Fig. 30.20 Mass mobilizations of Platform in defense of Ebro (PDE) with the knot symbol. Photo: PDE, with permission

30.6 Challenges and threats

Against the backdrop of climate change, Mediterranean rivers may serve as important case studies for all of Europe and worldwide. Climate scenarios and data clearly indicate a migration of the heating and irregular precipitation effects of a changing climate to the European North. This is accelerating existing changes by direct human impacts such as the construction of dams and hard flood defenses, and water abstraction, all of which have the potential to act synergistically as multiple stressors. Therefore, the analysis of socio-environmental problems such as sharing limited water resources in the Mediterranean deserves special attention.

30.6.1 Effects of global change on fluvial dynamics in the Upper and Middle Ebro

The hydrogeomorphological functioning of the rivers of the Ebro Basin has undergone notable changes since 1950, resulting from marked reductions in discharge, floods, riverside spaces, and sediment delivery. The causes of all this are climate change, which includes the evolution of temperatures and rainfall, as well as substantial changes in land use and vegetation cover throughout the basin, to which has to be added the overarching effect of the numerous dams (Ollero et al. 2015). The situation has been studied in detail in the Pyrenean Mountains (Beguería et al. 2003, Batalla et al. 2004, 2014, Ibisate 2005), and it presents notable similarities with other Mediterranean areas. The reduction of discharge in all rivers of the Ebro Basin since 1950 (Beguería et al. 2003) has intensified since 1980 (López Moreno et al. 2011), both due to the reduction in rainfall (Del Río et al. 2011) as, above all, evapotranspiration has increased, induced by higher temperatures (Lorenzo et al. 2012). The frequency and intensity of floods have become lower in response to the increase in native forest cover in mountain areas (García Ruiz et al. 2011, 2015). The Ebro Basin has one of the highest densities of dams in relation to available water resources worldwide (Milano et al. 2013).

This abundance of reservoirs and the consumptive use of water for irrigation have changed the seasonality of flow regimes and altered flooding and low flow frequencies (Frutos et al. 2004, Sánchez Fabre and Ollero 2010, Lobera et al. 2015). Sediment transport has also been altered by water infrastructure (including sediment trapping in reservoirs) and over-abstraction (Batalla et al.

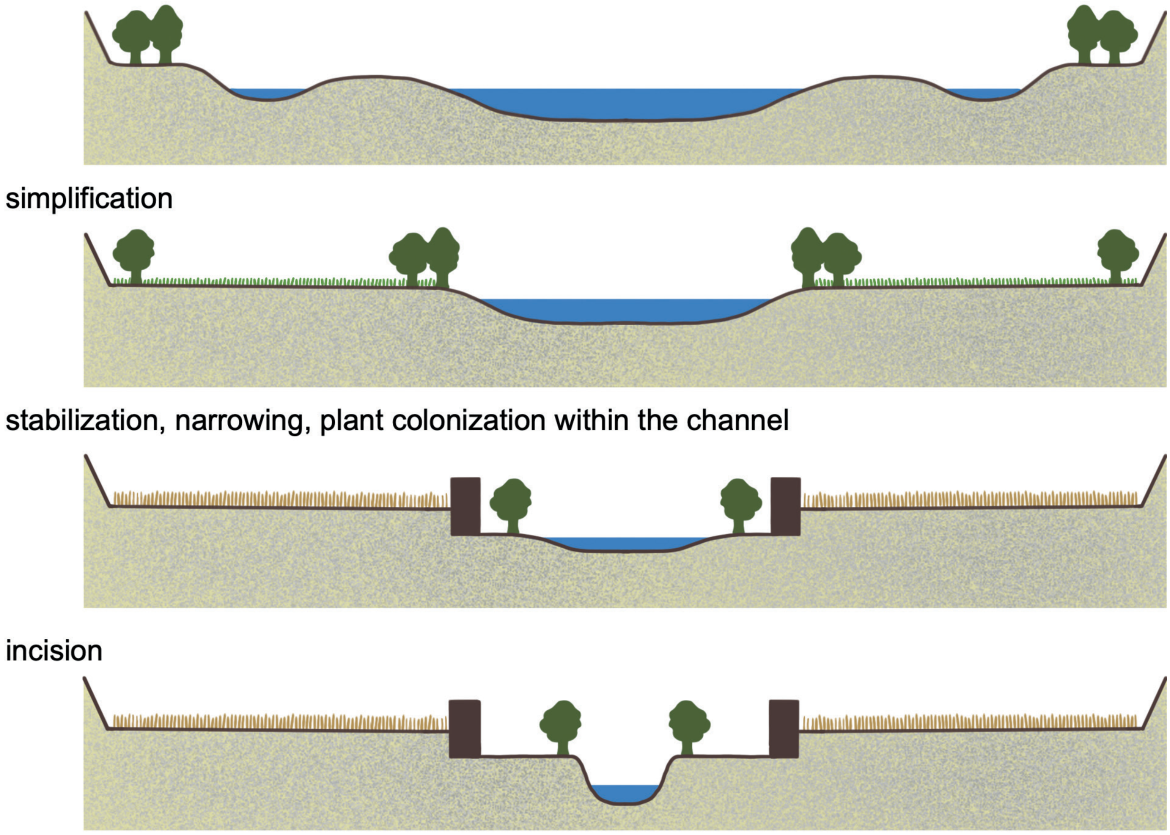


Fig. 30.21 Sequence of the changes in the middle Ebro since the middle of the 20th century. Graph: Alfredo Ollero

2004, Day et al. 2006, Liquete et al. 2009, Batalla and Vericat 2011). Flood defense works (dyke construction and bank erosion control, below) ended up completely deactivating trajectory changes, such that the Middle Ebro has become a stabilized meandering river, constrained between flood defenses (Ollero 2010).

As a result of combined impacts, the previously highly diverse morphology of the river (Ollero et al. 2004) has become simplified and the connectivity to floodplains was reduced or entirely obliterated (Ollero et al. 2015, Llena et al. 2016). The sizes of tributary alluvial fans have lowered, and the rivers have become entrenched (Gómez Villar and García Ruiz 2000). The impact is especially pronounced in the piedmont zone (Beguería et al. 2006, Gómez Villar et al. 2014). Braided and meandering stream channels have been superseded by single-thread, sinuous channel forms (Ollero et al. 2016). Once vegetative colonization of the channel is complete (e.g, in the Iberian Jalón and Huerva Rivers), the dynamic/mobile channel bars (highly important habitats) disappears.

The sequence of the geomorphological processes driven by global change evidenced in the Ebro since the middle of the 20th century (fig. 30.21) is strikingly similar to that of other river basins (see, e.g., chapter on Loire, this volume), namely: i) simplification (reduction of branching and morphologies), ii) stabilization and reduction of lateral dynamics, iii) plant colonization within the channel, iv) narrowing of the channel and v) incision of the riverbed (by up to 2 m). This tendency is very well documented for the Ebro (Ollero 2010, Cabezas et al. 2009, Magdaleno and Fernández Yuste 2011, Magdaleno et al. 2012, Ollero et al. 2015, 2018, Najes et al. 2019) and a slow-down has yet to be observed.

In addition to these basin impacts, there are a number of local impacts on the riverbed due to the intensive utilization of river spaces and resources (Ollero et al. 2018, Ibisate et al. 2011, Serrano-Notivoli et al. 2017, Sánchez Fabre and Ollero 2010). All these act to accelerate the processes described above, and provoke a downstream accumulation of environmental problems.

Smaller dams are built for small and medium-sized hydropower generation or more frequently as water storage dams for local irrigation to mini-power generation plants (Ibisate et al. 2013). Gravel quarrying was frequent and widespread in numerous rivers in the basin, used in the construction industry and to increase the drainage capacity after floods. This has particularly compromised the gravel sections of the Pyrenean river courses (Martín Vide et al. 2010, and see chapters on the Loire and Dordogne Rivers, this volume).

Former floodplain space became occupied by agriculture after diking in the 1960–1980s, so that in 2012 only 14.3% of this remained in a natural state in the Middle Ebro, 9.3% in the lower Aragon tributary 18.8% in the lower Gállego River and 19.3% in the lower reaches of the Cinca (Ollero et al. 2015). In the Middle Ebro, 100% of the active banks are now defended. An extreme example is the cutting of the natural meanders and total channeling of the last 13 km of the Arga River (Acín et al. 2011). The situation of the floodplain forests is worrying, evidenced by losses of biodiversity and complexity, drought symptoms, and high tree mortality (Najes et al. 2019).

As a consequence of these impacts, the hydro-morphological state of the Ebro River system is deficient (Mora et al. 2012). The loss of geomorphological heritage and ecohydrological diversity in river channels constitutes a deterioration in the ecological status according to the European Water Directive (2000/60/CE). The most degraded systems are the river floodplains and mountain streams, due to flow regime alteration and river fragmentation. The ecosystems in the best condition are the headwater reaches of the Iberian rivers and the Pyrenean rivers within protected areas.

30.6.2 Flood defense – a social conflict

The proximity of the Ebro River floodplains to the Pyrenees results in frequent, high-velocity flood events, while the growing, intensive use of the floodplain for agriculture and urban settlements increases exposure to flood risk. In response to the great floods of 1959, 1960 and 1966, major flood defenses were built between 1980 and 1985. However, these are insufficient to control floods. Even small floods today can cause significant economic damage, and conflicts between affected people and other stakeholders (Ollero 2020). In addition, the perception of risk is inadequate, since structural measures and periods without large floods together generate a false sense of safety (Sánchez Fabre et al. 2018). This has made floods a chronic social problem in the Middle Ebro River. Flood management is a complex issue and the key problem is spatial planning.

30.6.3 The water conflict

The Lodosa canal diverts 25% of the 106 $m^3 s^{-1}$ of Ebro discharge at that point, the Tauste and Fontellas canals divert 19.5% of it near Tudela (CHE 2019). These canals are dedicated to agriculture irrigation. The volume of water dedicated to urban uses (urban water supply, street cleaning, garden irrigation, or connected industrial uses) was 309 $hm^3 y^{-1}$ in 2014. This quantity has progressively decreased since 2000 when it was 391 $hm^3 y^{-1}$, due to the improvement of the network, progressive rates, not treated water uses (CHE 2019).

The reduction of flows and sediments arriving at the lower sections, due to the reservoirs and water diversions, has a direct affection on the survival of the delta, its land uses, the fisheries, its ecological values and fluvial and coast dynamics. This has led to a conflict among different stakeholders on the basin, farmers and people from the delta, who see the risk of disappearance of their way of life in a territory with high ecological and cultural values.

30.6.4 Invasive species and the blackfly plague

In the past decades, the Ebro Basin has been overrun by exotic species, many of which have deleterious effects on the already-impoverished wildlife communities. Habitat change and increasing temperatures favor this trend (see Biodiversity). For example, in 1974, large wels catfish (*Silurus glanis*) was released in the Ebro River as a sought-after gamefish (as reported in the media) and has since spread system-wide (including reservoirs). This species has a highly efficient hunting behavior, predating on large (reproductive) migratory fish and even terrestrial birds (see chapters on the Loire and Dordogne, this volume). It has practically wiped out several native species, hence its local nickname, 'The Ebro Monster'.

Among the non-native invertebrates (Oscoz et al. 2010), the most prominent cases are the invading bivalves *Corbicula fluminea*, which appeared in the delta at the end of the 20th century (López and Altaba 1997) and now covers the entire basin, and *Dreissena polymorpha*, the zebra mussel which has had millions of Euros spent on its eradication (Araujo et al. 2010, Durán et al. 2010). In 2009, for the first time in Europe, an invasion of the aquatic apple snail (*Pomacea insularum*, fig. 30.19), a large tropical pest species, was detected (López et al. 2010). This invasion is causing enormous ecological and economic problems, severely affecting the rice fields of the Ebro Delta, where it appears on a massive scale. Large sums have had to be invested for its control (Pérez-Gallego et al. 2019). Other invasive species in the delta with abundant populations are the American crayfish (*Procambarus clarkii*) and in recent years, and with serious effects on the local freshwater fauna, and the marine blue crab (*Callinectes sapidus*).

Not only exotic species have profited by human-induced environmental changes. Like previously other European rivers (see, e.g., chapters on Loire and Rhine, this volume), the Ebro currently receives irrigation returns and treated waste water with elevated concentrations of dissolved nutrients and organic particles. These nutrients increase the productivity of microalgae and bacteria, which are consumed by filter-feeders, such as blackfly (Simuliidae) larvae. Their adults suck blood from mammals, especially humans and cattle. In tropical countries, blackflies may transfer water-borne diseases such as river blindness. The blackfly plague in the stretch of the Ebro from Tortosa to Zaragoza is currently wreaking havoc on the inhabitants and farmers of the area and public resources are being invested in controlling the population. The reduction of flows due to damming results in the deposition of sediments, which has changed the turbidity of the river. The transparency and nutrient concentration of the water favor the growth of submerged macrophytes (*Potamogeton pectinatus*, *Myriophyllum spicatum* and *Ceratophyllum demersum*). Macrophyte leaves create the ideal habitat for black fly larvae and the entire invertebrate community has also changed (Ibáñez and Peñuelas 2019).

30.6.5 Marine transgression in the Ebro Delta

The Ebro Delta, one of the foremost wetlands in the western Mediterranean is in serious danger of disappearing altogether. The Ebro Delta was originally classified as an intermediate domain influenced by river and maritime dynamics (Galloway 1975). Currently, the fluvial sediment input is greatly reduced, the delta is becoming mainly marine, wave-dominated and large parts of it are about to vanish (Molinet 2007).

Early studies of sediment inputs to the delta had estimated solid flow inputs of 30 $Mt\,y^{-1}$ (Gorria 1877). Later studies estimate the pre-dam sedimentary contributions at around 20 $Mt\,y^{-1}$ (Ibañez, et al. 1995, Life Ebro Admiclim 2019). The most recent studies estimate present-day contributions at 0.1–20 $Mt\,y^{-1}$ (Rovira et al. 2015) with 87% of these sediments in the form of suspended, highly mobile silts and clays (most of which become flushed to the sea) and the remainder as sand (Batalla and Vericat 2011). The amount of sediment that reaches the Ebro Delta has decreased drastically over the last century, nowadays, less than 1% of suspended load is transferred compared to pre-dams construction (Guillen et al. 1992). Average data of the subsidence (surface lowering) of the deltaic plane (1–3 $mm\,y^{-1}$), regression of the coastline (22 $m\,y^{-1}$, with a cumulative setback of more than 1,500 m in 30 years) and sea level rise (4.5 $mm\,y^{-1}$, with an estimated rise in sea level of 15 cm by 2050) spotlight that the Ebro would need to contribute between 1.5–3.5 $Mt\,y^{-1}$ of sediment to enable the physical survival of its Delta on the medium and long term (Sánchez-Arcilla et al. 1997, Somoza et al. 1998, OCCC 2008, Garriga et al. 2010, Pandrez-Aragüés and Pipia 2015).

Since 2000, following the opposition movement to the Ebro water transfer, the local population and the different productive sectors have become well aware of the changes taking place in the delta, and have made a historic demand for action, both in the Delta and in the upstream section of the river. In 2005, the PIPDE (acronym for the Integrated Protection Plan for the Ebro Delta) was drawn up, which included different measures to improve the environmental quality of the delta's water bodies and to protect the most unprotected areas (PIPDE 2005). This plan has never been fully developed.

In 2018, with the problems of regression and subsidence becoming more and more pronounced, the local municipalities and the irrigation co-operatives joined together in the Delta Consensus Board and drew up a basic document 'El Pla Delta' (Taula de Consens del Delta 2020). The presentation of this document coincides with the devastating storm, Gloria, in January 2020, which caused millions of euros in damage, but brought the extreme fragility of the Delta into the media spotlight.

In February 2021, the Ministry for Ecological Transition and the Demographic Challenge (MITECO), the competent body for the management of the coast and the river, presented the 'Plan for the protection of the Ebro Delta' (MITECO 2021). This document marks the starting point for an adaptation to sea level rise, although it is not yet the definitive document for the protection of the delta. It addresses for the first time the problem of subsidence resulting from the lack of sediment over the last 60 years and proposes coastal protection and adaptation measures, including the mobilization of sand at the most affected points to recover the width of beaches and a dune system that allows for natural protection, following the experiences of the Wadden Sea in the Netherlands.

30.7 Management suggestions

30.7.1 Give room to the river

For a long time, scientists have proposed floodplain restoration, fluvial territory, or room for the river (Ollero 2007), which would alleviate most of the flood problems in the Middle Ebro. A new flood defense system using nature-based solu-

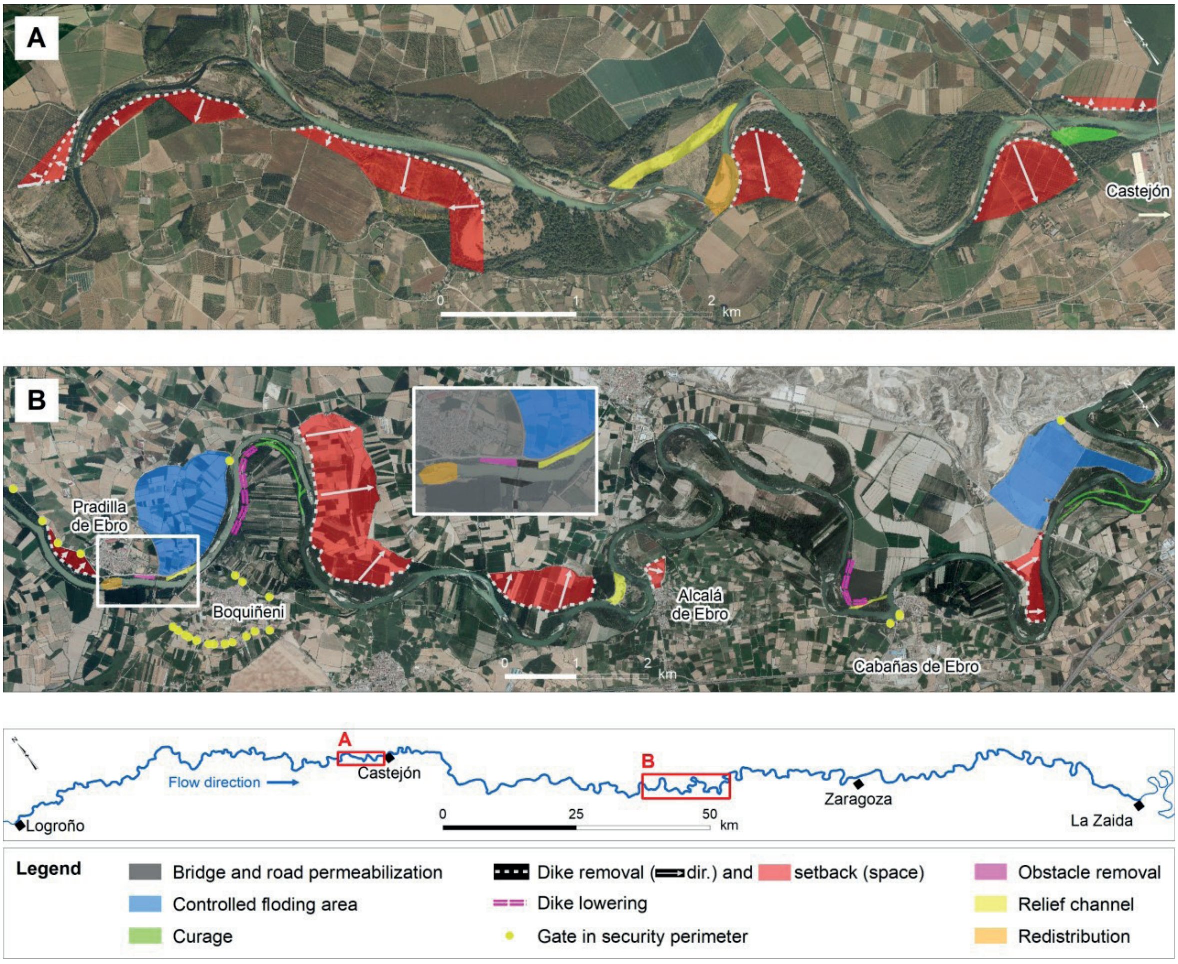


Fig. 30.22 Some actions implemented in the middle Ebro in the context of Ebro Resilience Strategy. Maps: Ollero et al. (2021), with permission

tions is urgently needed. Adaptive spatial planning needs to be addressed efficiently to reduce the risk of exposure of people and of assets. This transformation would not be possible without education about the risks and benefits of flooding. We consider essential to increase participation, training and outreach initiatives for the administration and local people. Ultimately, management would become more effective and less costly if it was inspired by adaptation to the specific risk landscape and natural dynamics of the Ebro River, providing a valuable example for other Mediterranean and European rivers. Current initiatives by the hydrological administration (Ministry and Basin Authority) seem to integrate these ideas, but clearly defined objectives and specific measures are lacking. The Ebro Resilience Strategy (fig. 30.22) stands out in this way, a new action plan in which it is encouraged to give more room to the river and the flood stream through areas of controlled flooding, removing dikes and the curage technique, by which terrestrialized flood channels become cleaned out and remobilized (fig. 30.23) (Horacio et al. 2019, García et al. 2021).

Fig. 30.23 An example of *curage* technique in a riparian forest near Zaragoza. Photo: Alfredo Ollero

30.7.2 Recover natural flow dynamics of the Ebro River system

New social pressure has induced a reflection on how to achieve sustainable development that improves the quality and diversity of agricultural products, without further water abstraction or damage to the environment. In the case of the Ebro, this would mean rethinking the management of dams and water abstraction/irrigation schemes, to recover, as far as possible, the connectivity of the river and its natural ecohydrological and morphological dynamics.

The presence of the Mequinenza Reservoir (fig. 30.24), dedicated to irrigation and electricity purposes, greatly complicates a proposal for realistic river system regeneration measures, unless dismantling of it was seriously considered, which will be hardly possible in the near future. This drastic measure, in addition to being the basis for a possible future plan for a new more rationally-dimensioned agriculture, would considerably contribute to eliminating the presence of exotic species: Chinese clam (*Sinanodonta woodiana*), zebra mussel (*Dreissena polymorpha*), asian clam (*Corbicula fluminea*), and giant catfish (*Silurus glanis*). It would also mean the disappearance of barriers for native fish, so that sturgeons, shad, and lampreys could regain their migratory routes and build back their populations. The recovery of the river banks would also mean an improvement for hunting, fishing and traditional and leisure navigation, while the release of previously trapped sediments would greatly benefit the Ebro Delta.

The water uses for some other hydropower plants could also be reconsidered, such as Sástago I, to regenerate the area of inserted structural meanders and recover the 'public hydraulic domain' throughout the area. This legal delineation of the river in the Spanish law comprises the space of the river frequently flooded 10 year-return period. In this way, three types of habitat would appear to improve the development of biodiversity in this area: the low-velocity zones behind the weirs, the wide gravel beaches, and the floodplain zones.

A recent study has shown that about 10% of the estimated one million dams and weirs in Europe are obsolete (Belletti et al. 2020), especially in Spain and in the Ebro catchment. Particularly those associated with canals and mills could be removed or improved passages for fish and sediments. Old buildings associated with dams or weirs could be used as centers for environmental education. It would be interesting to involve the Department of Culture in a project to recover the old Ebro water wheels as an historic example of traditional irrigation. The Aragonese Imperial Canal (see above) could be restored in accordance to its historical, artistic and environmental values, and turn into an attractive popular element, used for recreational, touristic and educational purposes. For example, passages, in which the groves alternate with exemplary irrigated crops (experimental and educational) and rehabilitation of historical hydraulic structure, could be used as demonstration sites of a 'reversible and prudent' intervention approach on heritage, and connect to the educational function of water museums (see chapter on Venice, this volume).

Fig. 30.24 Mequinenza dam and reservoir. Photo: Rafael Araujo

30.7.3 Collaboration between NGOs resulting in joint management proposals

The social movements of the territory, led by the Platform in defense of the Ebro (PDE), Campaign for sediments, Save the Delta and SEO Birdlife, together with the Delta Consensus Board propose the need to protect the delta from two parallel and complementary fields of action: (1) the management of the river upstream of the Delta with the recovery of ecological flows and the transit of sediments from the Ribaroja and Mequinenza reservoirs in the Ebro Hydrologic Plan 2021–2027, and (2) the management of the coast, especially in the most vulnerable points such as La Marquesa, Illa de Buda and El Trabucador. Coastal management includes actions to reinforce the balance of the beaches and dune systems by means of sand contributions and protection of the wetlands as a buffer zone in the event of storms.

At this point, there is a territorial debate between those who consider the provision of sand as the only permanent solution and those who consider it to be a temporary solution to gain time while the dynamics of sediment supply in the delta is recovering. There are numerous studies, including a pilot test of sediment addition in the final part of the Ebro and in the canal network, actions carried out in the context of EU LIFE project EBRO ADMICLIM (IRTA 2019), as well as projects elsewhere in the world (Gaeuman 2014, Loire et al. 2021), which could provide viable solutions to this debate.

30.7.4 Identify contradictions to resolve water conflicts

Social movements call for more transparent, democratic and participatory instruments in the management of water resources in the Ebro basin, and denounce the contradictions by the administrations that continue with the same policies of expansion of reservoirs, irrigation and transfers that have generated the situation of vulnerability in the Delta. As an example, while showing the images of Storm Gloria (23/01/2020) and the entry of the sea of 4 km into the Delta in the evening news, the Spanish government approved the transfer of water from the Ebro to Santander and the Catalan government approved the extension of the transfer to Tarragona.

Thus, in the short term, there does not appear to be a concerted effort to manage the demand for water from the Ebro River in a way that ensures an ecological-sustainable level of water use and addresses the critical demand for protection of the Ebro Delta. The pattern is a classic one of territorial confrontation and the prevalence of private and undeclared interests. Demagoguery and partisan struggle do a disservice to the return of environmental quality to the Ebro River basin, from a systemic and comprehensive point of view. Clear statements that consider the integrity of the entire river system are needed.

30.7.5 Managing for adaptation to global change: increasing resilience

Global climate change effects in the Ebro Delta include temperature increase (+ 0.7ºC to 1.4ºC, between 2021–2050), spatial and temporal irregularities in rainfall, changes in land use (including expansion of new irrigated crops), sea level rise, and the negative effects on fishing catches and aquaculture, amongst others. Resilience could be achieved if the demands on water resources were rationalized and optimized, and the use forms adapted to the available water (including the demand to maintain ecosystem functions and biodiversity). Acknowledging these facts by the society, guidance actions must be developed, and the different sectors trained, creating permanent structures for the participation of all social, economic, public and private agents, defining the impacts and transform them into opportunities, agreeing and developing action plans, and seeking financing for the highest priority actions (such as promoting a more efficient use of water, with precision agriculture techniques, crop monitoring, humidity sensors, etc.). Recently, within the framework of the LIFE CLINOMICS (DiBA 2021), adaptive plans have been developed by sectors, participation structures, as well as two pilot actions of this plan in Terres de l'Ebre. One of them was a drought observatory. This tool is being carried out with a climate research center in collaboration with an agrarian training school to put some humidity sensors into agricultural areas of the Terra Alta to correlate soil moisture data with satellite images in a continuous way with a great quality (resolution 1x1 km scale) to allow farmers to access these data. The second pilot action has been the feasibility study for an autochthonous Oyster Hatchery with a local aquaculture school and mollusk producers in the delta. Currently, due to the high temperatures, all the naturally reproduced oysters are dying in the bay and every year, and the producers have to buy oyster larvae in France at high costs.

30.8 Conclusions

The Ebro Basin is suffering the results of relatively recent and largely uncontrolled human pressures that have led to a significant loss of natural functioning and of geo-, bio-, and cultural diversity, with a pessimistic, high-risk, and possibly irremediable prognosis for its future.

Processes derived from dwindling flow rates are generalized throughout the Ebro Basin. The negative effects of river regulation are even more acutely apparent at the delta as the sediment deficit is the root cause of substantial coastline erosion in a landscape already close to sea level. The future effects of global and local climate variations will only exacerbate the situation.

Water flow rates have been overvalued historically, causing over-optimistic expectations for water use and extraction, exacerbating over-exploitation of the resource. What is clear is that, during the 20th century, the mean annual discharge has decreased by almost one-third and the sediment transport has almost completely ceased. Currently, river flows are already below levels estimated to be ecologically sustainable.

Despite efforts to mitigate or reverse these processes, they remain serious problems, which are difficult to solve. Finding, financing and following through the correct path for river restoration in all its dimensions constitutes the overriding challenge for the future. This involves many individuals and organizations, and can only be addressed if there was consensus to achieve a participatory and transparent process. The previous, strictly utilitarian and economic considerations need to incorporate environmental, ethical and social aspects to achieve a unity of purpose and action. Policy, science, planning and implementation need to be integrated, to provide structural solutions for repair and future management that are based on natural dynamics and proven methodologies, supported by an appropriate legislation.

Not to act is already a decision – it means sanctioning the disappearance of a unique and protected space such Ebro Delta, vital to all of us and home to more than 50,000 people who do not want to be Europe's first climate refugees.

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