TECHNICAL HANDBOOK

CONSERVATION AND RESTORATION OF RIPARIAN AREAS

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TECHNICAL HANDBOOK

CONSERVATION AND RESTORATION OF RIPARIAN AREAS

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Alder grove in the alluvial plain of the Segre River, La Cerdanya, Catalonia. Photo: Jordi Bas.

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Detail of flowers and fruits of alder (*Alnus glutinosa*). Photo: Jordi Bas.

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In recent years and in accordance with its remit, the Ministry of Climate Action, Food and Rural Agenda of the Government of Catalonia has drawn up strategic documents on the current state of conservation of Catalonia's biodiversity and natural heritage.

The world is facing a biodiversity crisis. Almost 60% of species populations have been lost worldwide. The "State of Nature in Catalonia 2020" report (similar to those presented by the United Nations, the European Commission and the world's most advanced countries) shows that Catalonia is far from immune to this crisis, although the degree of loss is lower, at 25%.

For decades, industrial expansion and population growth in Catalonia have entailed the exploitation of rivers and fluvial systems as a whole, especially in the most heavily populated areas. Human activities have led to the fragmentation of habitats, with the consequent degradation of riparian forests – in particular Mediterranean alder forests – and of the fish populations that inhabit our rivers.

Added to this is the fact that climate change has brought about new river dynamics involving an escalation of extreme weather events such as droughts and floods, along with rising water temperatures.

The LIFE ALNUS project has succeeded in generating knowledge, in contributing to the recovery of alder forests and other riparian forests, and in helping to raise awareness about the importance of riparian and alluvial plain vegetation, showing how it is impacted by the highly complex occupancy models generated by human activity.

The LIFE ALNUS project underlines the importance of shared governance, given the wide variety of socioeconomic interests that converge on fluvial areas. Accordingly, I would like to take this opportunity to call for the fostering of joint efforts by public bodies and other stakeholders directly involved in or with an interest in fluvial areas, in order to achieve the favourable state of conservation of our alder forests and, by extension, of our fluvial areas, as this ministry is doing within its remit.

Let us hope that, a few years from now, the contribution of the LIFE ALNUS project will prove to have been a key initiative in achieving this goal.

Finally, I would like to thank the Forest Science and Technology Centre of Catalonia, along with all the other project partners and contributors, for the work done by the LIFE ALNUS project towards enhancing and improving the conservation policies for alder forests in Catalonia, as well as promoting the other natural values of our river ecosystems.

Antoni Trasobares
Director
Forest Science and Technology Centre of Catalonia

The goal of the LIFE ALNUS project has been to restore the structure, functions and good governance of riparian ecosystems, bearing in mind that they are areas of human activity which in some cases are subjected to intensive public use. Accordingly, the restoration of these riparian forests has taken into account the different points of view of all the stakeholders involved in the ecosystem: public bodies, landowners, users, scientists, ecologists, etc. LIFE ALNUS has planned and intervened in the restoration of eco-fluvial dynamics, in accordance with European legislation (Water Framework Directive, Habitats Directive and Floods Directive). The ultimate goal is to enable the river ecosystem (the river and its banks) to recover its good ecological status, and to do so in a way that strikes a balance between the interests and goals of the various stakeholders in the area.

In previous studies, LIFE ALNUS has managed to achieve a better understanding of riparian forest conservation in a context of global change and - for the first time in Catalonia - at a basin scale. The project has taken into account the specific issues affecting the three project basins (Besòs, Upper Ter and Upper Segre): the disappearance of large forests, hydrological regulation and habitat recovery in degraded areas, among others. It has addressed the issue of restoring the good ecological status of banks at the river basin scale, adopting an optimised decision-making approach. It has drawn up conservation plans for the Besòs, Upper Ter and Upper Segre basins, encompassing 24 special areas of conservation (SACs) and 950 linear kilometres of fluvial areas (485 kilometres within the SACs and 465 kilometres along interconnecting water courses) in the three river basins of the project.

The conservation plans prioritise where it is most efficient to carry out ecological restoration actions, using spatial modelling tools such as systematic planning. The purpose of the project is to achieve the significant improvement of fluvial areas, adopting an active management approach that facilitates natural processes, enabling the habitat to reorganise itself once the key restoration actions have been carried out. In order to check the progress of the implemented actions, the project has set up a series of ecological monitoring stations that will be left in place permanently.

The project has achieved several significant results. For the first time, an agreement has been reached with a hydroelectric company to regulate flows and improve the state of conservation of the affected riparian areas. Another important action has been the extension of legal protection to cover an additional 970 hectares of river ecosystems not yet integrated in the Natura 2000 Network, especially stretches with alluvial alder forests, a habitat of priority community importance that has almost disappeared.

Another set of conservation actions has consisted of the restoration and ecological improvement of the habitat where it has degraded or fragmented. The actions have been carried out in the river stretches identified as priority areas in the conservation plans. The plans include the ecological improvement of alder forests through the application of silvicultural measures, the restoration of riparian forests that have become fragmented or that have disappeared, and the regulation of riparian uses across more than 255 hectares. Last of all, four pilot projects have been executed in an area covering 162 hectares, testing possible solutions for the most complex problems facing the habitat at the regional and Mediterranean scale.

The project has involved a significant amount of work in terms of dissemination and transference, such as environmental education activities for schools located close to the implementation areas. Another important action has been the drawing up of ten-item lists of recommendations, summarising the proposals made by the various sectors involved in the management and use of fluvial areas. The lists were produced by five discussion rooms set up to address five specific areas: forestry and livestock management, hydroelectric plants, municipal governance, agreements with rural landowners, and public use.

The Forest Science and Technology Centre of Catalonia (CTFC) is dedicated to the conservation of biodiversity, the sustainable management of natural systems, and territorial planning. It studies the biology and ecology of populations, habitats and threatened species, along with bioindicators or key indicators in the functioning of ecosystems in a context of global change, modelling the factors that determine the distribution of species.

The CTFC supports public bodies in the integration and analysis of biodiversity information, and in the creation of innovative planning tools to generate products that improve decision-making in the management of natural systems, including biodiversity conservation.

In the current context of global change, in which our country is extremely vulnerable, and in which we are witnessing increasingly frequent extreme weather phenomena, such as Storm Gloria, this may be a good time to rethink and judiciously reorient the restoration criteria of fluvial areas. For instance, the project has offered water managers a series of recommendations for the management of plant remains (and sediments) deposited by floods. Another key tool is this handbook, which brings together the experiences generated by the project. Special attention has been given to proposing measures aimed at striking a balance between the conservation and forest management of riparian areas.

The LIFE ALNUS project is committed to addressing a key challenge: to improve knowledge and conserve the riparian forests integrated in the river ecosystem. Given its status as a pilot project, it has transferred this knowledge to the public bodies responsible for managing fluvial areas, with the goal of making the maintenance and risk management of these areas compatible with the conservation of riparian forests and their restoration. The results can be easily transferred to and replicated in other basins, both in Catalonia and across the European Mediterranean region as a whole. This is our commitment.

Riparian forest in the Basses de Gallissà (Bellver de Cerdanya, river Segre) / Photo: Jordi Bas.

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INTRODUCTION. RESTORATION AND CONSERVATION OF ECOLOGICAL PROCESSES

1 / **INTRODUCTION.** RESTORATION AND CONSERVATION OF ECOLOGICAL PROCESSES

1.1. Restoration and conservation of ecological processes

Riparian vegetation has always been understood as a linear system that follows a watercourse. However, when the orography, hydraulic dynamics and land uses allow it, this vegetation stretches beyond the gallery forest (the corridor along the river or stream), filling the entire width of the alluvial floodplains. It is on the alluvial plains where riparian forests are at their most impressive and exuberant, where they can fully express their multiple ecological functions, their rich biodiversity and a special scenic beauty, making them one of the most highly prized environments.

The Mediterranean region is home to a great diversity of riparian forests, from headwater alder forests to willow, poplar and alder forests on alluvial plains, where watercourses have more gentle slopes. Generally speaking, the riparian forests of headwaters in mountainous areas are quite well preserved, whereas these environments are highly degraded and fragmented in valleys and on plains, so much so that more than 80% of the riparian forests of Europe's alluvial plains are estimated to have been lost.

Alder, poplar and willow forests (*Alno-Padion, Alnion incanae, Salicion albae*) have been classified as Habitats of Community Importance (HCI) by the European Commission, and alder forests in particular have been given priority conservation status. The report on the status and trends of the habitat types regulated by the Habitats Directive for the 2013-2018 period classified the conservation status of alluvial alder forests and other related forests as "unfavourable-bad", therefore indicating the worsening of their status since the report for the 2007-2013 period, when it was classified as "unfavourable-inadequate". This means that 30 years after the enactment of the Habitats Directive and 20 years after the implementation of the Natura 2000 Network, the trend in the evolution of these environments continues to be negative. Meanwhile, the conservation and restoration of riparian forests is fully aligned with the Water Framework Directive, which aims to help achieve the good ecological status of the rivers of the European Union. The memory of what great riparian forests must have been like has been lost in the mists of time. We would probably have to go back to before the expansion of agriculture in the most populated valleys to imagine what they were like.

Despite its modest surface area, Catalonia is home to a great diversity of Mediterranean ecological systems, which include a wide variety of riparian forests. It should be highlighted that the Spanish section of the Natura 2000 Network contains 48% of the surface area of alder forests in the Mediterranean region, of which 15% are in Catalonia. This means that Spain bears a significant amount of responsibility for the conservation of this habitat in Mediterranean Europe.

The conservation and restoration of riparian forests poses a major scientific, social and political challenge for Europe which, to date, has only been addressed through one-off, local restoration projects. In other words, there has not yet been a European project with an integrated, cross-cutting approach to the conservation of alder forests and other riparian forests at a regional or national scale. This is the challenge facing the LIFE ALNUS project, co-funded by the LIFE Nature and Biodiversity Programme of the European Union. The goal of the LIFE ALNUS project is to make a significant and strategic contribution to the conservation, restoration and governance of alder forests and related riparian forests in Catalonia. The work area of the project encompasses the basins of the Besòs, Ter and Segre rivers, covering more than 1,000 linear kilometres. The three basins contain more than 50.5% of the geographical distribution of Catalonia's alder forests.

River and forest. Segre river in La Cerdanya county, Catalonia / Photo: Jordi Bas.

1. 2. Environmental issues affecting fluvial areas

The fluvial area or ecosystem (or riparian-fluvial ecosystem) comprises the river course and its area of influence: riverbeds, floodplains, ponds, lagoons and associated groundwater. These ecosystems are home to closely related aquatic and riparian habitats, and have been widely exploited for human benefit since ancient times. With the onset of the Industrial Revolution, they became the driving force of factories, harnessed to supply electricity and water to the agricultural and industrial sectors, along with the rapidly growing conurbations. As a consequence, the landscape today is affected both by natural factors (floods, droughts) and human ones (agricultural, industrial, urban and recreational activity). Despite the efforts made to preserve and improve them, the fluvial areas of plains and valleys that have been greatly impacted by human activity are far from being in good ecological condition. In fact, riparian forests covering extensive areas of alluvial plains have become practically extinct landscapes on the Iberian Peninsula. There are many reasons for their disappearance and the main ones are briefly outlined below:

Water pollution

Surface and groundwater pollution in inland areas comes largely from discharges of industrial, agricultural, livestock and domestic origin. Although the sanitation systems implemented in Catalonia and the rest of the European Union make it possible to regulate most or much of urban and industrial wastewater, there is still a significant amount of diffuse pollution, associated with agricultural and livestock activities, which gradually filters into surface and groundwater.

Fluvial areas have the ability to self-purify, to break down the organic matter that reaches them naturally; that is, the matter which forms part of the same ecological system (leaves, trunks, etc.). They can also absorb some of the organic and nutrient load that comes from human activities. However, self-purification depends on the intensity, the flow of each river course and the type of discharge. All too often, the assimilation capacity of the river and the riparian vegetation is exceeded. We were able to observe this phenomenon during the monitoring of biological indicators (aquatic macroinvertebrates and fish) carried out as part of the LIFE ALNUS project. For example, when an urban wastewater collector broke down for a few days in September 2020, the biological quality of a stretch of the Ter River in the Ripollès area, which had begun to recover with the application of an environmental flow regime, became simplified.

Water extraction and flow variation

In Mediterranean rivers, the density of uses for irrigation or for the production of electricity is particularly high. The agricultural sector, for example, uses around three quarters of the water consumed in Catalonia. The remaining water consumption is divided between livestock, industry and domestic use.

The extraction of water from rivers means that flows are lower than desired, creating a water deficit, an extraordinary contribution of nutrients and water stress on riparian vegetation. The lack of flows downstream from dams and locks hampers the survival and regeneration of the alder and other riparian woody species, whose roots must always be kept moist or soaked. Through the LIFE ALNUS project, the Catalan Water Agency has reached agreements with a hydroelectric company to implement environmental flows in two locks of the Ter River.

The transformation of fluvial areas

Thanks to their flat, extremely fertile land and their water resources, river valleys and plains have long been occupied and heavily exploited by humans. Floodplains have largely or mostly been used for agriculture, livestock farming, sediment extraction, urban development, infrastructure construction and intensive forestry. This degradation entails soil erosion and loss, along with increased pollution, given that plants retain the soil and at the same time act as pollutant filters. The transformation of alluvial plains has meant the reduction or loss of a unique, extremely rich biological heritage. Moreover, when they are turned into built-up areas, their enormous potential to supply local food is lost. The monitoring of biological indicators by the LIFE ALNUS project has provided valuable data to help us understand the distribution of bioindicator organisms in relation to the state of conservation of the riparian forest and the aquatic environment associated with the landscape matrix. River stretches with more extensive and complex riparian forests (with greater plant diversity and maturity) contain greater biodiversity, especially landscapes with an agroforestry mosaic or those dominated by zonal forests.

Invasive species

Invasive species are non-native, exotic or introduced species that become established in a territory which is not their native habitat and which they have entered due to human action. It is estimated that approximately 10-20% of the species that arrive in our territory have the ability to adapt to it. Among naturalised species, a further 10-20% have a great capacity for resistance and proliferation. Their adaptability allows them to propagate throughout natural environments, competing with and displacing native species, modifying ecosystems, and affecting the local economy and even human health.

Fluvial areas are the ecosystems in which invasive species – such as the red swamp crayfish (an aquatic species) and the American mink (a semi-aquatic species) – can spread most easily. The indigenous riparian vegetation competes with species that have a great capacity for propagation, such as species of the Robinia genus, trees-of-heaven, box elders and reeds. Previous studies by the LIFE ALNUS project have mapped and demonstrated the expansion of invasive plant species in all three project basins. The strategy for strengthening native riparian vegetation has consisted of identifying and acting in river stretches where invasive species were present but not dominant; that is, where it was easier to restore the area thanks to the existing native vegetation.

Lack of ecological connectivity

The aforementioned environmental impacts fragment riparian habitats. Apart from the headwaters of mountain streams, the continuity of riparian forests has been lost in valleys and alluvial plains, often after centuries of human occupation of these areas. The presence of hydraulic facilities and the lack of flows hinder or prevent the movement and connectivity of wildlife populations. One affected species is the eel, which has already disappeared from inland Catalonia. However, all native fish populations have been affected and are in decline everywhere, among other reasons due to the severe difficulty they encounter in accessing their spawning or feeding sites. The extension of the Natura 2000 Network proposed by LIFE ALNUS provides greater legal protection for fluvial areas, thus facilitating their governance and restoration.

Effects of climate change

Mediterranean fluvial areas belong to a bioclimatic environment that is particularly exposed to and vulnerable to climate change. The ordinary flows of watercourses can suddenly fall and rise due to the progressive increase in temperature, the reduction in rainfall and the increasing recurrence of extraordinary episodes of drought and flooding. These suboptimal bioclimatic conditions are already showing an effect on riparian communities, particularly alder forests. The LIFE ALNUS project has been able to verify how the decline observed in alders at the head of basins is related to severe recurring droughts. It has also highlighted the effect of extraordinary flooding (storms Leslie and Gloria) on hydromorphological dynamics, on riparian forests and on fish and macroinvertebrate communities.

Insufficient legal protection and complex governance

Unfortunately, the best examples of alder forest in many cases do not enjoy proper legal protection. Despite the great effort made in deploying the Natura 2000 Network, few fluvial areas in Catalonia are protected by it. The LIFE ALNUS project has found that some of the best examples of alder forest on the alluvial plain (extremely sparse) are outside the area of protection of the Special Areas of Conservation (SACs), which is why one of the main actions proposed by the project is to extend this legal protection.

Meanwhile, fluvial areas bring together a wide range of socioeconomic interests that interact with each other, making fluvial areas perhaps the most complex natural systems of all in terms of governance. It is not surprising that there is often a lack of coordination between the sectors involved, between protection measures at the European, national and regional level, between the different administrative bodies, and between these bodies and citizens. Consequently, a review of the existing protection measures and governance models is clearly necessary.

Catalonia is probably one of the European biogeographical regions with the greatest potential for improving the conservation status of its habitat, but at the same time it faces some of the most difficult conservation challenges, due to its population density and its highly developed economic activity. Moreover, Catalonia forms part of the Mediterranean front where alder forests will have to adapt to more intense and recurring periods of drought as a result of climate change. This means that the experiences acquired through the LIFE ALNUS project and other similar ones will serve as valuable models for future action.

Hygophile grassland in an alder tree grove. Ardenya stream, basin of Besòs River, Serralada Litoral Natural Park. Photo: Jordi Camprodon.

1. 3. Functions of the riparian forest

Despite the substantial improvements made in river water quality, significant challenges remain to be met in the second decade of the 21st century: the facilitation of ecological flows, the minimisation of diffuse pollution, the deurbanization of alluvial plains, and the restoration of fluvial processes and riparian habitats. Raising public awareness is crucial in order to speed up the restoration of fluvial areas. Unfortunately, the riparian forest remains misunderstood. The notion persists that fluvial systems, and riparian vegetation in particular, constitute a major risk factor for human activity in the event of flooding. The standard technical argument is that in order to mitigate the risk of flooding, it is necessary to adapt the river, by means of hydraulic containment works and the reduction of living and/or dead vegetation. Meanwhile, certain customs persist, such as clearcutting to obtain wood and firewood from the riparian forest. These practices means that the forest is in a perpetual state of apparent youth, far removed from natural processes. Fortunately for the fluvial system, the extraction of sediments at the expense of the good ecological status of riparian forests is no longer allowed. A new paradigm for the governance of fluvial areas proposes shifting away from the domestication and intensive exploitation of rivers towards an ecosystem approach. Installing a rip-rap or earthen berm as a response to the flooding of fields, a campsite or an industrial estate means transferring the problem further downstream where no hydraulic corrective measures are in place. Removing fallen trees due to the risk of them blocking a bridge, or clearcutting an alder forest, means losing ecological functions and ecosystem services. If a bridge is supposedly at risk from the material carried by a flood, it is because this bridge is badly designed; well-designed bridges have survived for centuries.

The new approach entails reconstructing badly built bridges, implementing a design with arches and hydraulic safety mechanisms that allow drainage. An alder forest can be used for timber while maintaining a permanent canopy. The new paradigm involves deconstructing alluvial plains, taking into account flood return periods. As the Catalan saying goes, "*A la vora del riu no t'hi facis el niu*" ("Next to the river, you'd best not build your nest."). Considering these precedents and the challenges to be met, the key ecosystem functions provided by riparian forests – which end up defining the ecology of rivers – cannot be ignored.

Landscape value

The singular, extraordinary beauty of riparian vegetation is well known. It is a key component of the landscape, associated since ancient times with quiet contemplation, walks, gatherings around springs and fishing, along with all sorts of artistic expressions. The splendour of riparian vegetation has been exalted throughout the history of art. Riparian forests add great scenic and economic value to the area, offering plenty of potential for recreational and ecotourism activities.

Effects of riparian vegetation on floods

Riparian vegetation is an effective tool for managing river floods, since it helps to retain the flow of water and to reduce its speed. In the event of flooding, floodplains without built-up areas allow the flowing water – with all the materials it is carrying – to spread out, thus constituting nature's flood control solution.

The increased roughness of the land surface is the main element that controls the passage of floods. Trees and plant debris also help to concentrate flows, forming networks of canals and calmer water areas, facilitating water retention and the creation of new microhabitats. The sediment and organic remains transported by a flood increase soil fertility and protect infrastructure elements against flooding. During floods, the riparian forest reduces the speed of the water and retains sediments. However, if the river is canalised and its surroundings are turned into built-up areas, it flows faster and causes more damage when it overflows.

White willow catkins (*Salix alba*) on the banks of the Ter River in Osona county, Catalonia / Photo: Jordi Camprodon.

Shelter for animals and plants

Fluvial areas are among the most complex and biodiverse ecosystems on Earth. They are of strategic importance for the conservation of much of Europe's biodiversity. The aquatic environment, with all its special characteristics in respect of the terrestrial environment, is made up of its own forms of life. On the riverbanks, the flora is characterised by its diversity of species with different ecological features. Taken as a whole, the vegetation comprises a series of vertical strata that host the fauna typical of a forest, often specific to riparian habitats (for example, invertebrates associated with a specific plant species). At the same time, an extremely interesting interaction is established between the terrestrial and aquatic environments. The parts of the riparian forest that are submerged or in contact with the water (roots, stems, branches) offer shelter to fish, amphibians, aquatic invertebrates, birds and mammals, while the presence of winged insects associated with water attracts birds and insectivorous mammals from all around.

Pollution filter

Riparian forests act as "green filters" of pollution. They improve water quality and transparency, filtering suspended sediments and absorbing nutrients from human activities (industrial, agricultural and urban). They act as bioreactors to purify diffuse pollution and a certain proportion of wastewater.

Regulation of the degree of insolation and water temperature

The vegetation and the percentage of tree cover on the riverbank serve to regulate the temperature of the water and the degree of insolation on the riverbed. The more shade there is on the riverbed, the cooler the temperature of the river water and the riverbank, thus increasing the diversity of plants and animals in the ecosystem.

Ecological connectivity

The aquatic environment and the riparian forest are first-rate ecological connectors, a fast track for the movements of fauna and the dispersal of plant propagules. For example, bird migration takes place to a large extent following river courses and valleys. Fluvial areas make it possible to connect populations from different territories and basins, facilitating genetic exchange between populations.

1. 4. Conservation goals and actions

The LIFE ALNUS project aims to transcend local experiences of habitat restoration. It addresses – for the first time at the Iberian scale – all the issues that affect fluvial areas at different scales: hydrographic region, river basins, SACs and priority action stretches. It does so by adopting a cross-cutting, integrated approach encompassing the planning, management, restoration and governance of river areas, including ecological monitoring of actions, applicable in the long term.

The main goal is to improve the conservation of alder forests* and related riparian forests at the regional and European scale, on the basis of their restoration and improvement in three river basins (Segre, Ter and Besòs). The experience acquired has enabled us to gain a deeper understanding of the issues and to make progress in overcoming the main challenges and difficulties involved in the conservation of riparian areas at the basin scale, from a technical-scientific, social and administrative perspective. The experience acquired through this project serves as a valuable example of what can be done. In terms of transference and replicability, its successes and failures will be useful for future projects in other basins, especially those of the Mediterranean region.

* According to the Habitats Directive, alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno Padion, Alnion incanae, Salicion albae*) [Code 91E0].

Strategic focus areas

All the actions included in the LIFE ALNUS project have been designed at the different scales governing fluvial ecosystems: the geographical scale (Catalonia); the functional or the basin unit scale (Besòs, Ter and Segre); and the river continuum scale (selection of stretches in which to intervene). Previous mapping studies have shown that the situation is more critical than expected: in the area of the three ALNUS basins, only 316 hectares of alder forests have been identified (184 ha in the Segre basin, 106 ha in the Ter basin and 26 ha in the Besòs basin). This figure is much lower than a bird's eye view of the river network suggests. In addition, 2043 hectares of riparian forest with the presence of alder and 432 hectares of riparian forests without alders were mapped.

This prior information includes the identification of impact elements, such as the presence of invasive plant species. "Habitat restoration and conservation plans" for each basin were drawn up on the basis of this prior information. The long-term goal of the plans is to restore the continuity of riparian habitats within the Natura 2000 Network. At the same time, the restoration of the fluvial-riparian continuum enables the interconnection of all the SACs of the territory. The strategy of the plan for each basin involves the selection and prioritisation of river stretches that are crucial for conservation and restoration within the river continuum as a whole. Statistical decision-making tools have been used for his purpose: multicriteria decision-making models and systematic planning models. Chapter 2 sets out how the previous studies and planning have been carried out.

The project was based on the premise that the best option for the restoration of fluvial areas is the recovery of natural dynamics; that is, enabling the river to regulate itself through the recovery of flows and the dynamics of sediments and the flooding regime. This passive restoration strategy can be implemented when the impact factors have disappeared or decreased significantly. However, this is not always possible, or not entirely possible. Therefore, the ultimate goal of the project is to implement active restoration actions that facilitate the recovery of natural processes. Accordingly, the fluvial system is improved trough the removal of earthen berms and barriers, the restoration of flows, planting, and eliminating invasive species. Meanwhile, the structure of the forest is improved through silvicultural work and planting, all with the goal of enabling the river to recover and organise itself naturally.

Improvement of the legal protection strategy for the habitat

The LIFE ALNUS project completes the Catalan strategy for the conservation of the habitat by strengthening the improvement and expansion of the protection of spaces in line with the Habitats Directive. The Natura 2000 Network protects the most important natural areas of the European Union, which contain habitats and species of flora and fauna of Community Importance, due to their precarious state of conservation. To this end, three complementary actions are established: (i) the improvement of the delimitation of existing SACs; (ii) the creation of new SACs; (iii) the improvement of the interconnection between SACs within each basin.

Improved legal protection must make it possible to prioritise and improve the conservation status of fluvial areas. Accordingly, the project has worked in close collaboration with the Directorate General for Environmental Policies and the Natural Environment (DGPA) of the Government of Catalonia, which is the body responsible for planning the Natura 2000 Network in Catalonia. The selection of areas has been based on previous studies (Chapter 2) and on the administrative procedures initiated by the DGPA, which include a participatory process involving all the relevant interest groups, administrative bodies and territorial/social agents. It is planned to extend the Natura 2000 Network to the fluvial areas of the Segre, Ter and Besòs basins by approximately 970 hectares (Chapter 9).

Restoration of the continuity and ecological quality of the habitat

Years of conservation policies and actions have not always fostered the generation of knowledge and the transfer of ecological processes. Nevertheless, the restoration of ecosystem functioning is increasingly taken into account and prioritised as a key holistic goal in order to achieve the good health of ecosystems, and in order to encourage their development and increase their ecological value over time.

In the case of riparian forests – like other forest habitats – it is important to highlight the importance of the continuity of habitats, through which internal ecological connectivity is enabled. Actions have been implemented to restore the riparian forest in stretches that are degraded but still retain optimal ecological potential; that is, stretches that are not affected by unique issues that are difficult to solve. These stretches have been established as priority areas in the conservation plans.

The actions have focused on i) the reconnection of the fluvial continuum (defragmentation of the habitat); ii) the reintroduction of the habitat in sub-basins and extensive stretches in which it has disappeared; iii) the improvement of the vegetation structure of the forest and its biodiversity through silvicultural work of various types (Chapter 3); (iv) the control of invasive exotic species (Chapter 4). The actions have been planned as experiences to demonstrate the forest management of the habitat and its associated biodiversity, in contrasting ecological and social contexts encompassing the identified issues. A transferable result consisted of technical guidelines for the sustainable forest management of the habitat (Chapter 3). In order to protect, improve and conserve riparian forests, it was necessary to reach so-called river stewardship agreements with various types of landowners: individuals, companies, public authorities, etc. Over the course of the project, agreements have been reached with 17 private landowners, two companies and three public landowners (Chapter 10) of the Ter and Besòs basins.

Pilot projects to demonstrate hydromorphological and flow restoration

With the goal of generating pilot experiences, within each river basin various stretches of river have been selected in each river basin that together represent the issues affecting Mediterranean riparian forests on alluvial plains, the complexity of which requires the implementation and testing of new, extremely complex technical approaches; that is, stretches characterised by deep incisions, a high degree of degradation or the strong regulation of the hydrological regime. The pilot projects consisted of: i) removal and reduction of barriers, and the restoration of the alder forest that had disappeared in the built-up stretch of the Congost River (Besòs basin) in the conurbation of Granollers (72 ha); ii) restoration of the hydromorphological dynamics of sediments and removal of barriers on two river islands of the middle course of the Ter River in the county of Osona (19.2 ha) (Chapter 6); iii) restoration of hydromorphological processes and of the alder forest on the alluvial plain of the Segre River, in Bellver de Cerdanya (4.5 ha) (Chapter 7); iv) recovery of flows in two hydroelectric power stations of the Ter, a highly regulated river in hydromorphological terms (Chapter 8).

Dissemination

The LIFE ALNUS project has raised awareness about the importance of fluvial areas among the population of the riparian area of the pilot basins through educational activities (schools), training activities (conferences) and dissemination activities (video, exhibition, publication of material). A process for the improvement of governance has been undertaken using an approach based on discussion rooms with different groups. These groups were established in order to discuss and reach a consensus that reconciles the environmental values, economic activities and social uses of fluvial areas (Chapter 10). The discussion rooms hosted managers of natural areas, forestry professionals, hydraulic engineers, owners of rural estates with riparian areas, local councillors, representatives of hydroelectric and extractive companies, naturalist, ecological and/or land stewardship associations, and groups that organise recreational river activities.

Monitoring and transfer

Using hydromorphological indicators and biological indicators (aquatic macroinvertebrates, fish, flora and vegetation, birds and mammals) (Chapter 8), several aquatic and riparian indicators have been monitored. Through an initial extensive sampling process, the biological monitoring has made it possible to establish the association between bioindicators and the complexity of the riparian forest structure and matrix landscape. The second goal of monitoring has been to evaluate – in the short and long term – the response of the hydromorphological and biological indicators to the habitat improvement and restoration actions. Finally, the results and conclusions, derived both from the previous studies and from the monitoring of bioindicators, have provided basic information to be integrated in the planning of the actions of the LIFE ALNUS project, and in subsequent adaptive management plans to enable its replicability in other river basins.

This handbook aims to provide an overview of the status of riparian areas and the actions undertaken within the framework of the LIFE ALNUS project (www.alnus.eu), with the goal of contributing to the conservation of alder forests and similar riparian forests within the Natura 2000 Network in Catalonia. This project hopes to have made a decisive contribution to the conservation, restoration, governance and dissemination of the natural values of riparian forests. Meanwhile, by raising awareness about the importance of alder forests as a key habitat, the project – and by extension this handbook – aims to contribute to the promotion and protection of the natural and cultural heritage of the fluvial areas of the Mediterranean region.

The editors

The Segre River in La Cerdanya is one of the best examples in Catalonia of a watercourse free of great artificial impediments / Photo: Jordi Bas

Alluvial plain of the Ter River, in its middle course. Space where restoration actions have been carried out in the LIFE ALNUS and that will be incorporated into the Natura 2000 Network / Photo: Jordi Bas.

2 /

META-ECOSYSTEMS AND META-RESTORATION: : THE LIFE ALNUS PROJECT, AN EXPERIENCE IN THE DIAGNOSIS AND RESTORATION OF FLUVIO-ALLUVIAL SYSTEMS AT A REGIONAL SCALE

2 / **META-ECOSYSTEMS AND META-RESTORATION:** THE LIFE ALNUS PROJECT, AN EXPERIENCE IN THE DIAGNOSIS AND RESTORATION OF FLUVIO-ALLUVIAL SYSTEMS AT A REGIONAL SCALE

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2. 1. Introduction to a biological crisis: the Mediterranean "fluvio-riparian meta-ecosystem" and its alluvial forests

2.1.1. Ecological and biological importance of the "fluvio-riparian meta-ecosystem"

Non-fluvial ecosystems are spatially expressed as typically distinct patches in the landscape. From both a structural and functional perspective, they can be conceived as pieces, subunits or constituent *organs* of a complex *organism*; that is, the entire ecological and biological mosaic of a particular biome. Their main functions are relatively specific and distinct, and they are often shared with other ecosystems. While their biocenoses support only a fraction of the total continental biodiversity, they usually do so in conjunction with other similar ecological landscapes (most organisms depend on more than one ecosystem).

Meanwhile, *fluvial ecosystems* follow a different organisational and functional logic: they constitute the structural basis for the interconnection or functional assembly of the remaining ecosystems; that is, the territorial ecological mosaic. Moreover, they perform essential functions in the support and evolution of the ecosystems involved in the ecological matrix of each territory, and in that of the biome in general. In other words, they are not merely another *organ*, but rather the *system* through which much of the physical (material), metabolic and energy regulation and reorganisation of the biome is concentrated and takes place (Schlesinger & Bernhardt, 2013). Therefore, they perform, on an exclusive basis, the most essential regulatory functions in a given ecological system and biome (Hynes, 1975; Hornung & Reynolds, 1995; Giller & Malmqvist, 1998; Sabo & Hagen, 2012; Allan et al., 2021).

By way of example, the fluvial network is the territorial area where the large-scale reorganisation of matter take place within each drainage basin, and where the regulation (dissipation and transformation) of the *potential energy* derived from that process occurs. The fluvial collectors network assumes and accommodates the functions of collecting, transporting, and rearranging or reorganizing all the eroded continental lithological material within each basin, the integration and evacuation of the superficial flow generated by the terrestrial phase of circulation of the water cycle, and the redistribution between ecosystems of primary production (organic matter and nutrients), or else the export of part of said production to the coastal and marine environment. In the tiny area occupied by the fluvial network, with the participation of slope processes, we see the progressive integration and concentration of colluvial and mass wasting deposits. Periodically, the pulses provoked by extreme meteorological phenomena, causes a massive mobilization of these deposits leading to an spatial *hyper-concentration* of extremely energetic dynamics (only comparable to those of a tectonic and volcanic nature) that are capable of intervening in the deconstruction and new creation of entire landscapes and ecosystems at different time scales.

Consequently, all energy regulation and continental geomorphological shaping processes depend upon this skeletal area that determines the control of the physical base (topographical and lithological) on which the ecological matrix of each basin is built, along with the sedimentological and hydrological conditions of all the ecosystems that it interconnects and drains. It is therefore a *networked system* (*integrated and continuous*) in which the huge transfers of matter and energy processes take place that are necessary to build the physical base of the new ecosystems of valley corridors and bottoms, and of the sea coast, at the expense of the lithological erosion and persistent reshaping of high-altitude ecosystems (typical of tectonic positive reliefs) (Allan et al., 2021).

Another equally important function of matter and energy cycles developed by these ecosystems is the spatial regulation and reorganization (inside each basin) of the dissolved components and inorganic particulates, and of the organic matter (biomass) produced by its biotic cover. The waterscape is a key system that enables the spatial redistribution of inorganic components, organic matter and nutrients within the biological mosaic of each drainage basin, thus playing an essential role in the transfer and regulation of these components between the different fluvial and non-fluvial ecosystems (through transfer, retention or evacuation flows), but also along the aquatic and riparian corridor, and between the terrestrial and marine environment (evacuation) (Thorp & Delong, 1994; Baxter et al. 2005; Marczak et al., 2007; Sabo & Hagen 2012; Schlesinger & Bernhardt, 2013; Marleau et al., 2020).

The fluvial network is also the most crucial landscape structure in terms of enabling biological and genetic transfer between all the levels of ecological organisation (habitats, ecosystems, biome), thus constituting one of the main underpinning mechanisms of ecological resilience and plasticity at the meso- and macro-territorial scale. Moreover, the continental water network and its associated ecosystems shape the principal areas and connections (with a bidirectional influence) between the surface and subterranean hydrological and biological landscape; that is, between terrestrial ecosystems and subterranean ecosystems, and between these and the marine environment.

In short, the fluvio-riparian ecosystem (FRE) constitutes the most complex, multifunctional and essential ecological system of a biome. The organic functioning of the biome's ecosystem mosaic as a whole depends upon it, and vice versa. It can be understood as the circulatory system that enables ecohydrogeological reorganisation within each basin. It is a dendritic, quasi-fractal and trans-ecosystem structure; that is, it can influence and connect every single square centimetre of a given territory, underpinning ecological interactions and interdependencies at each landscape scale (Tockner et al., 2002). Its functional logic corresponds to a system involving the progressive integration and subordinate interconnection (primarily directional, but not exclusively so) (Schulz R, 2015) of the multiple compartments and levels of organisation (basins, sub-basins, slopes, fluvial network) (Thorp et al., 2008).

As such, it can be argued that *fluvio-riparian ecosystems* (FREs) go beyond the established concept of *ecosystem* (Schlesinger & Bernhardt, 2013); they are systems that play an important role in ecological regulation at every level of the overall ecosystem matrix of the three elements that govern the web of life (matter, energy and information) at different spatiotemporal scales (Marleau et al., 2020). In this respect, they must be situated within the *meta-ecosystems* concept (Gounand et al., 2017; Cid et al., 2021), which in turn is based on emerging concepts such as the *Watershed-Continuum Model* (WCM) (Stevens L. et al., 2020; Stevens L. et al. 2022), according to which FREs are complex, open and trans-territorial systems that connect the arborescent network of aquatic, riparian and alluvial habitats, including all its elements and water bodies (wetlands of fluvial origin, canals, hyporheic zones, springs, groundwater, valley bottom fogs, etc.), to the hydrographic domains of the slopes and their ecosystems, and which may be conceived in reality as an *eco-hydro-geomorphological continuum* that encompasses the entire basin, bringing together physical, biological and sociocultural processes through dynamics thattake place at every spatiotemporal scale (Tockner et al., 2002; Allan et al., 2021; Jacquet et al., 2022; Stevens et al., 2022).

Beyond this meta-ecosystem function as an orographic and geomorphological regulator of the landscape, and as a spatial organiser of the ecological processes of each basin, the FRE constitutes in itself the most complex, heterogeneous and biodiverse ecological mosaic of the continental biomes. Spatiotemporally speaking, it is also the most dynamic-plastic one. Indeed, freshwater aquatic systems contain the highest level of biodiversity known in continental environments (Dudgeon et al., 2006; Maes, 2010; Tierno de Figueroa et al., 2013; Hitt et al., 2015; UICN, 2022). The conservation of a disproportionately high percentage of global biodiversity (10% of known organisms) depends upon their small surface area (they occupy a mere 1% of the Earth's surface) (WWF 2020); the percentage of species directly dependent on these ecosystems rises to more than a third (>33%) when it comes to the biological group of vertebrates (42% of fish, 70% of amphibians, 5% of reptiles, 9% of birds and 6% of mammals (Maes, 2010).

This extremely high intrinsic biodiversity is due to multiple factors (Gregory et al., 1991; Naiman & Décamps, 1997; Naiman et al., 2005; Stanford et al, 2005; Wohl, 2016): (i) they are typically highly productive systems, (ii) they are constituted by an exceptionally heterogeneous and dynamic (changing) mosaic of habitats, from a spatiotemporal perspective, (iii) they transit through, and merge, the altitudinal succession of ecological landscapes; (iv) they interconnect and interact ecologically (and thus evolutionarily) with the biocenoses of all the ecosystems that compose the ecological mosaic of each basin across the *watershed continuum*, connecting them to the marine environment; (v) they are in turn an ecological ecotone (lateral, vertical and longitudinal) hosting and integrating aquatic, semi-aquatic and terrestrial environments and communities; (vi) and they are the main orographic and hydrological connector of any landscape, bringing different types of fluvial biocenoses into contact with each other along the fluvial axis (longitudinally), and all of these with those of the subterranean and marine ecosystems (e.g. transitional fluvio-marine habitats and communities, diadromous fish communities, stygobiont, crenobionts, etc.).

In short, the intrinsic biological importance of the fluvio-riparian meta-ecosystem is enormous: in addition to all the biodiversity that is *directly* dependent on the ecological mosaic contained in the fluvio-riparian corridor, the functions it performs in the integrated ecological functioning of the basin are essential, which means that the overall biological fabric of the basin also *indirectly* depends on it.

In this sense, we might say that the fluvio-riparian meta-ecosystem performs a protective or "umbrella" function: it is undoubtedly the most strategic and irreplaceable ecosystem in the conservation of continental biodiversity.

Finally, it is worth highlighting the important functions and resources that *fluvial areas* provide for our species. They are probably the most topographically friendly landscapes, as well as the most productive, while at the same time offering the best scenario for direct access to water. In addition to the spatial resource it offers as a friendly, habitable, productive landscape (agronomy, forestry, fish farming) and the access it provides to the most essential element (water), the FRE performs functions and provides ecosystem services that are irreplaceable: it is the only space capable of channelling and evacuating eroded material on the inland environment; it participates in the filtering and recycling of nutrients and in the reorganisation of organic and mineral compounds, and in the control of greenhouse gases (CO2, methane) and climate regulation; it cushions flood pulses; and it is a major cultural and tourism resource. For all of these reasons, it is considered key to the adaptation and survival of our society (Naiman et al., 2005; Elosegui & Sabater, 2009; Riis et al., 2020; Havrdová et al., 2022), so much so that water distribution have even guided and can explain, to a surprising extent, hominid evolution (Cuthbert & Ashley, 2014) and the current configuration of the occupation of the territory and the structure of our current landscapes.

In conclusion, fluvial ecosystems are the ecological compartment that brings together the greatest biological and ecological wealth, that performs the greatest number of functions in the maintenance of the overall ecological mosaic, that offers the greatest number of natural resources and ecosystem services, and that has had the greatest influence on the evolution of our species.

2.1.2. The conservation problems of alder forests and other Mediterranean alluvial ecosystems

Despite the huge, irreplaceable ecological and biological importance of fluvio-riparian ecosystems, they have constituted (together with the coastal environment) the area most coveted by humans. As a consequence, they have been voraciously occupied and exploited, which has led them to be considered the most severely punished ecosystem in the current scenario of ecological crisis of the Anthropocene: the largest proportion of known extinct or endangered species pertain to freshwater ecosystems (Costelo, 2015), and they are currently experiencing the greatest biodiversity decline of all ecosystems (Ricciardi & Rasmussen, 1999; Sala et al., 2000). It should be noted that this loss of biodiversity is particularly concentrated in all the planetary domains of the Mediterranean biome, one of the main biodiversity hotspots (Myers et al., 2000) where the fragility of waterscapes is at its highest. Moreover, within this biome, the transformation of the fluvial ecosystem has been most precocious, incisive and persistent in the circum-Mediterranean drainage basins, beginning with the hominid settlement of the Neolithic revolution and the subsequent cultural explosion of the first civilisations (especially from the Chalcolithic onwards), of the great empires, and of the ancient, mediaeval and modern cultures. In this process, the fluvial network has acted as a channel for cultural and technological propagation and exchange, as well as for the establishment and development of these cultures.

However, a closer examination of the grave situation facing the European and global FRE shows, that the elements of it which are under the greatest pressure and which are experiencing the most worrying biological crisis, are alluvial depositional systems. This degradation of aquatic and riparian ecosystems, and the associated loss of biodiversity, is particularly concentrated in the middle and lower reaches of river basins; that is, in the most markedly alluvial ecosystems.

There are several reasons for this. On the one hand, compared to mountain streams and headwater torrents, fluvial terraces and alluvial plains are, topographically speaking, friendlier, more accessible and more amenable to transformation, as well as being the most resource-rich territorial domains; in short, the ones that are most coveted and suitable for exploitation. As a result, the large alluvial plains and valley bottoms have become the landscapes that have been most severely punished and transformed over the centuries by anthropic action. They are also the most naturally scarce landscapes, given that the inverse dendritic nature of the hydrological network means that the number of subrogated upstream courses (upper reaches) increases exponentially with respect to the major -but scarce- river axes. Finally, the structural and functional logic of these ecosystems (the hierarchical integration of processes and dynamics) means that all the pressures inflicted at any point in the basin or its fluvial ecosystem (whether geomorphological, hydrological or chemical) are progressively transferred and concentrated along the hydrological network (Hornung & Reynolds, 1995; Poff et al., 1997; Yates & Bailey, 2006).

The severity of the selective occupation that alluvial systems have endured is such that it is estimated that more than 50% of the world's depositional plains and plateaus have been lost in recent decades, with this figure rising to more than 80% in Europe and North America (Davidson & Finlayson, 2018).

Meanwhile, for the purpose of analysing the impact of the transformation of the alluvial landscape on the loss of biodiversity, it should be borne in mind that, although the aquatic environment and the riparian environment are seen as two spatial and ecological areas that can be managed on the basis of partially separable strategies and policies, the truth is that they are intimately linked and interdependent, to such an extent that the conservation of one is acutely dependent on the conservation of the other. Just as riparian forests depend on the water system that sustains them, the conservation of aquatic biocenoses is not possible without the protective and regulating umbrella of riparian forests. Therefore, both strictly aquatic biodiversity and riparian biodiversity depend on alluvial forests.

To sum up, we might say that the forests of large depositional systems (fluvial terrace and alluvial terrace systems) are not only an indispensable element for maintaining the ecological functions of the biological mosaic of the basin but also an essential part of the *fluvial meta-ecosystem* to which they belong. They are forest formations that protect and regulate the habitats and aquatic communities within them, and in themselves constitute a lush ecological structure that contains biocenoses composed of species which, whether exclusive (their own) or ecotonic (shared with neighbouring habitats and ecosystems), are highly complex, dynamic and extremely rich from a biological perspective. Under natural conditions, alluvial riparian systems are considered the most diverse, dynamic and complex ecosystem mosaic of the terrestrial portion of our planet (Erős et al., 2019). In this sense, it is worth considering that, given that fluvio-riparian ecosystems link and interweave a multitude of aquatic, semi-aquatic and terrestrial environments, the spatial corridors formed by their banks constitute three-dimensional ecotonic domains of such breadth and ecological complexity that more than 60% of the planet's biological species inhabit them in one way or another (Elosegui & Sabater, 2009).

The erosion of all this biological biodiversity in the fluvio-riparian ecosystem is not likely to be homogeneous. Since its ecology and its biocenoses undergo a succession along the fluvial continuum, and also along its transverse dimension (Vannote, 1980; Ward, 1989), the biological communities that are representative of the large depositional forests of valley bottoms and alluvial plains, and, in particular, the characteristics of the outermost and most mature forest formations (and all the associated habitats) are today an impoverished fluvial biological system that can be considered threatened with extinction, including on the Iberian Peninsula (Berastegui et al. , 2015).

Alluvial plains and forests have been described as "lifelines of the landscape" that provide globally important ecosystem services and that are "disproportionately" deserving of urgent attention as key ecosystems (Erős, 2019; Riis et al., 2020). Few unspoiled elements remain in what has been identified as one of the most threatened ecosystems on the planet and one that has lost most of its natural functions (Tocker et al., 2008; Brown et al., 2018; Havrdová et al., 2022).

In the specific case of temperate Europe and part of its Mediterranean region, both the great arborescent galleries that once flanked mountain rivers and most of the forests on the wide alluvial plains were alder forests: alluvial forests composed of *Alnus glutinosa* and other accompanying forest species.

Despite having been the main forests of the Central European and Atlantic fluvial landscape, and, to a large extent, part of the Mediterranean region, the evolution of recent centuries has meant that the alluvial forests of *Alnus glutinosa* are now in a critical state. The alder groves forming large forests or woodlands of a more alluvial nature have been progressively eliminated throughout Europe. Their existence is now made impossible by agricultural occupation and anthropic urban development. There is a consensus that they have become an ecologically homogenised, biologically impoverished, residual, fractal or discontinuous landscape, of which only fragments remain, mainly in damp or wet environments (riverbank forests) (Havrdová et al., 2022). Their precarious state of conservation has led them to be included as a *natural habitat types of community importance whose conservation requires the designation of special areas of conservation,* in *Annex I* of *Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora* (*The Habitats Directive*), in the category of Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion*, *Alnion incanae*, *Salicion albae*) [Code 91E0*]".

Despite being an endangered habitat that has enjoyed the highest level of protection in the framework of European policies since 1992, the implementation reports drawn up by the EU in application of article 17 of the Habitats Directive reveal an alarming state of conservation that does not appear to have improved in the successive six-year periods analysed (CEC, 2022). In short, given the huge proportion of global biodiversity that depends directly or indirectly on riparian corridors and on their alluvial alder forests, their ecological degradation largely explains Europe's current biological crisis.

2.1.3. Iberian alluvial alder forests and their conservation in Catalonia

According to the studies carried out in the framework of the *LIFE ALNUS* project, the territory of Spain encompasses 48.2% of the geographical distribution range of the 91E0* habitat, and 56.3% of its actual surface area in the European Mediterranean biogeographical region. Meanwhile, Catalonia is home to 26.1% of the surface area of alder forests in the Spanish Mediterranean biogeographical region, which represents 14.7% of the total surface area of the Mediterranean habitat in the whole of Europe. Therefore, Spain bears the greatest burden of responsibility for the conservation of the habitat (and of all habitat-dependent biodiversity) in Mediterranean Europe (MN Consultants, 2019).

However, the evolution of the habitat appears to continue to follow an unfavourable trend: while the first habitat monitoring report for the whole of the European Mediterranean biogeographical region for the period 2007-2012 reported an

[1] Dado que la *Directiva 92/43/CEE* define como un "hábitat" a los bosques riparios y selvas aluviales de los ecosistemas fluvio-riparios deposicionales, en el presente trabajo aceptamos y empleamos el término *Hábitat 91E0** como sinónimo de bosque aluvial dominado o codominado por *Alnus glutinosa.*

"unfavourable-inadequate" status (category U1), the assessment for the period 2013-2018 downgraded this status to the worst possible category, "unfavourable-bad" (U2) (CEC, 2022). In the specific case of the geographical context of Spain, the surface area occupied by the habitat within its area of distribution (Spanish Mediterranean region) has been classified as "unfavourable-bad" (U2) (Calleja, 2009). Meanwhile, as expected, the assessment of the "Future prospects" for Spanish Mediterranean alder forests is "unfavourable-inadequate" (U1) for mountain areas, but obtains the worst possible assessment ("unfavourable-bad", U2) for middle and lowland water courses, which is attributed to the direct destruction of alluvial depositional areas by agroforestry and town planning activities (Calleja, 2009).

The conservation of the alder forests of Catalonia is also crucial, not only due to the quantitative importance of the surface area that they cover in the region but also due to the wide variety of ecological forms of habitat that they contain (MN Consultants, 2020). Catalonia has been identified as the region with the greatest diversity of environments in the territory of the European Union as it stands, being considered a "small sampler" of the ecological mosaic of Western Europe (EU28).

In fact, alder forests constitute the dominant riparian forests in approximately one third of the Catalan territory (Figure 1), which means that they are of crucial importance as an "umbrella" habitat on which the future of a large percentage of the region's biological wealth depends.

The regional monitoring report on the 91E0* habitat for Catalonia (locally defined as "Alder forests and related riparian forests of the Alno-Padion") assesses its conservation status as "unfavourable-inadequate" (U1) for the Mediterranean biogeographical region, while its status is declared as "unknown" for the Alpine biogeographical region. (CTFC, 2020). However, as we highlight below in this paper, the diagnosis obtained for the

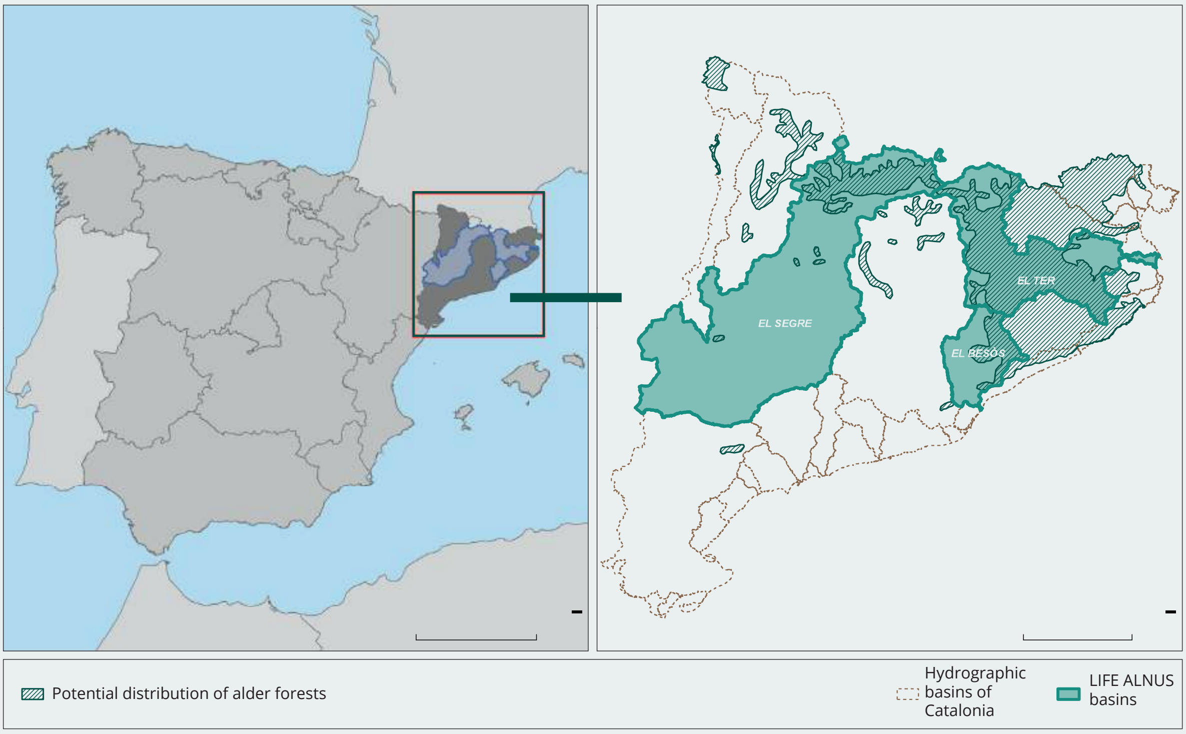
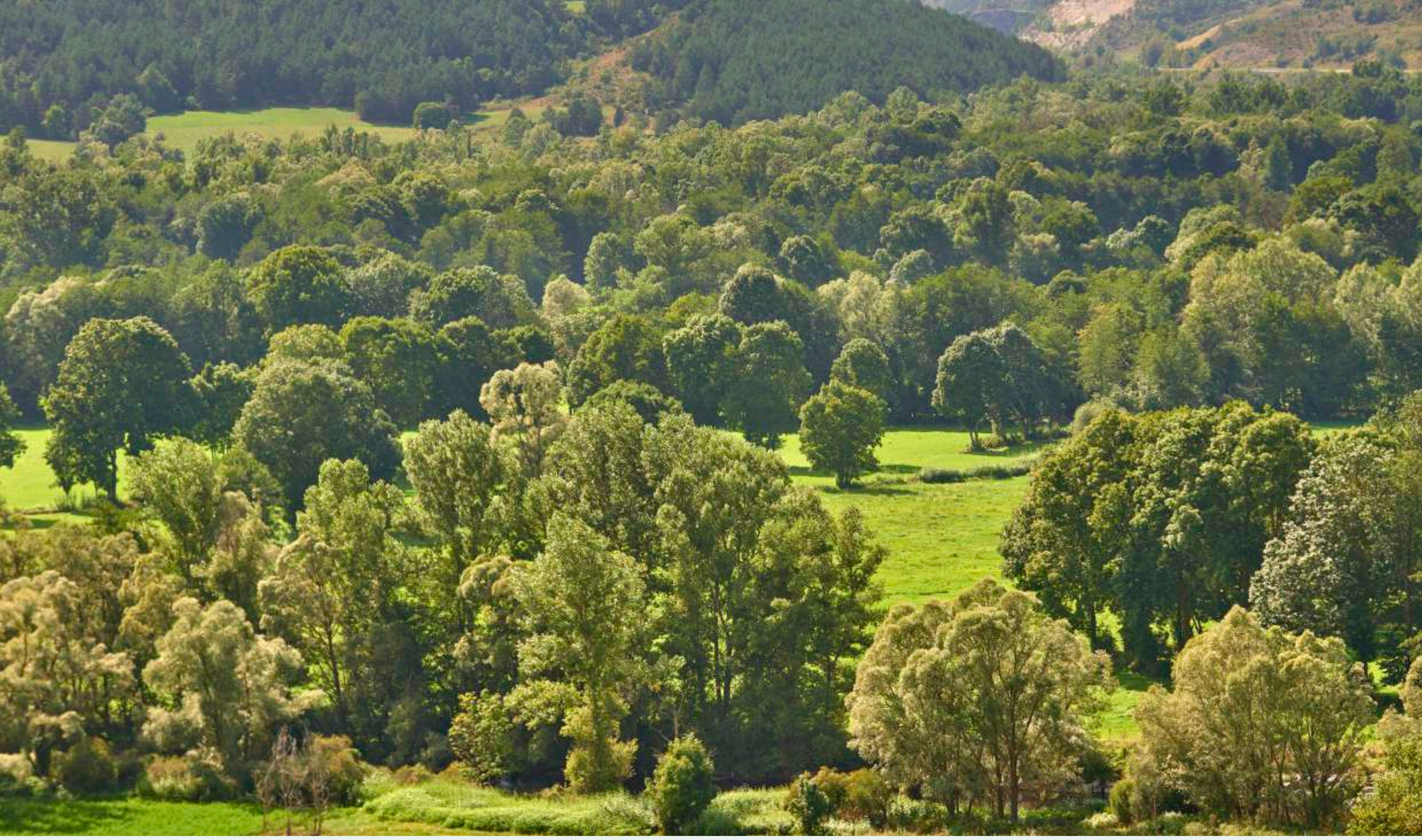


Figure 1 /

Geographical distribution area of alder forests in Catalonia, with identification of the pilot basins of the LIFE ALNUS project (Besòs, Ter, upper Segre). Source: MN Conservation Science Consultants, 2019.



Mosaic landscape of the floodplain of the Segre River. La Cerdanya. Photo: Jordi Bas.

habitat in the framework of the *LIFE ALNUS* project would appear to indicate that the situation is even more unfavourable (MN Consultants, 2019).

In the specific case of Catalonia, the price to be paid in terms of loss of aquatic and riparian biodiversity as a consequence of the degradation and loss of its FRE has not been estimated, let alone the loss of its alluvial forests. However, recent studies indicate that epicontinental aquatic ecosystems (river corridors and wetlands) only occupy 3% of the continental surface area of Catalonia and more than 34% of the region's protected or vulnerable habitats, while 30% of the taxa classified as endangered depend directly on them (31.6% flora, 30.3% vertebrates, 26.9% invertebrates) (MN Consultants, 2022). This is a very high proportion considering that these endangered species list also include marine species.

The same study analyses the spatial distribution of endangered taxa in the water network of the *River Basin District of Catalonia*, finding that the vestiges of the large coastal alluvial ecosystems are those with the highest concentration of endangered taxa, which confirms that ecological impoverishment and biodiversity loss is generally concentrated in depositional sections, especially in valley bottoms and coastal plains.

The biological crisis of Catalonia's aquatic systems is also reflected in the region's *Living Planet Index*, contained in the first report on the *State of Nature in Catalonia* (Brotons et al., 2020). According to this report, referring to the period 2002-2019, there has been a 54% decline in the population trends of organisms dependent on inland aquatic ecosystems, while the decline in those species of meadows and agricultural systems is 34%, and those of forests and scrublands is 12%.

In short, except for the biological crisis that is certainly taking place in the ecosystems of springs (Cantonati et al., 2020), which are the most biodiverse aquatic habitats in the Mediterranean biome thanks to their hyper-concentration of biological richness (Pascual et al., 2020), the alluvial fluvio-riparian area is undoubtedly the part of the Catalan and Iberian territory where the most important and critical battle against biodiversity loss will have to be fought (Erős, 2019; Riis et al., 2020). The LIFE ALNUS project has been promoted with the aim of taking the first steps in this fight.

2.2. Towards fluvial "meta-restoration": the conceptual and methodological approach of the LIFE ALNUS project

2.2.1. Base conceptual framework

Modern European biodiversity conservation policies had envisaged that the physical and legal protection of alder forests and related alluvial forests through the *Habitats Directive*, coupled with the restoration and safeguarding of a representative sample of these forests within a European network of natural areas, would be sufficient tools in themselves to reverse their precarious state of conservation. Today, 30 years after the enactment of this directive and more than 20 years since the implementation of the Natura 2000 network, alluvial forests continue to degrade, while aquatic and riparian biodiversity silently perishes with them.

Our hypothesis to explain this reality is that alluvial ecosystems cannot be conserved by means of the "mosaic" scheme implicit in the strategies that form part of European biodiversity conservation policies. In short, we believe, in line with current thinking on the concepts of the *watershed continuum* and the *fluvio-riparian meta-ecosystem*, that the conservation of these ecosystems cannot be guaranteed without maintaining the integrity of every single level of functional ecological organisation (as well as the relationships between levels) that govern "fluvial logic":

1) the *river reach* as an unique and unrepeatable enclave, with its own ecological features and idiosyncrasies, which is the result both of intrinsic factors (specific and exclusive to the reach) and of the integration of the territorial dynamics that converge on it;

2) the *river continuum*, as the structure on which the ecological and biocenotic succession typical of these ecosystems is based along the longitudinal axis;

3) the *networked ecological structure* (which obeys and imposes the functional rules of "networked systems");

4) the organisational system of *basins* and *sub-basins*, as compartmentalised and subordinate units, that configure a system of hierarchical and progressive integration of the totality of dynamics and transfer flows of matter, energy and information;

5) *intra-basin biogeographic and ecological compartments* that explain part of the heterogeneity or diversity of each watershed (e.g. ecological floors, fluvial morpho-ecological types, etc.);

6) *regional and inter-regional (inter-basin) biogeographic compartments* or sectors;

7) and vertical connections and *reciprocal regulation between surface and groundwater hydrosystems.*

The integrity of these levels of spatiotemporal organisation of dynamics and processes is crucial for the full development of all the structures and functions that characterise alluvial forests. Any destabilisation or degradation of just one of these organisational levels, or the disruption or diminution of the continuity or relationships between them, has definite, cascading ecological effects, ultimately affecting the overall ecological structure of the FRE and its biological systems (Harvey et al., 2016).

Most of the pressures currently affecting river systems result in geomorphological, hydrological, chemical, and biological destructuring, disconnections and discontinuities between these levels of organisation (Cid et al., 2021). As such, a growing number of authors are highlighting the need to address the conservation of FREs, and especially that of their alluvial forests, advocating the restoration of these levels of ecological organisation. This entails the renaturalisation of the dynamics, processes and flows that govern them, as well as removing the hydro-geomorphological or chemical barriers, disconnections and discontinuities that prevent the *watershed continuum* from being maintained intact. In short, they point to the urgent need to address river restoration by applying the *meta-ecosystem theory*, as well as from a holistic and systemic perspective that considers all organisational levels, including those at a basin, regional, and interregional scale (Cid et al., 2022; Havrdová et al., 2022). It is therefore necessary to base recovery strategies for FREs and their alluvial systems on *meta-restoration* plans or projects aimed at restoring ecological dynamics and structures at every organisational level, thus restoring the organic functionality of the *watershed continuum*.

Accordingly, it can be argued that neither the mosaic protection and management measures provided by the Natura 2000 network, nor the habitual morphological or plant restoration projects limited to isolated river stretches or environments, can by themselves reverse the current ecological degradation of the Mediterranean fluvio-riparian ecosystem. It is therefore unavoidable and urgent to approach FRE conservation strategies from the perspective of *meta-restoration* (Cid et al., 2021; Havrdová et al., 2022).

The progressive understanding of the FRE as a *meta-ecosystem* that preserves the *watershed continuum* (Stevens et al., 2022) has shown that its functioning is highly complex. This complexity lies not only in its many levels of structural and functional organisation, and in the interdependencies between them, but also in its highly dynamic nature and the spatiotemporal integration of the various ecohydrogeological processes that govern it. For this reason, modern fluvial ecology argues that this complexity responds to the predominance of stochasticity, disturbance, discontinuities, imbalance, variability or dynamism and resilience. Ultimately, this complexity means unpredictability, which forces us to rethink restoration trends, abandoning the idea of recreating preconceived equilibrium scenarios and instead focusing on the simple restoration of natural processes (Beardsley et al. , 2019). Accordingly, the naturalness of these processes and the resulting ecological structures cannot be artificially recreated by human hands through "intervention engineering" projects aimed at creating and fixing idealised ecological structures and scenarios, which will inevitably lead to a simplification of the rich natural mosaic and its spatiotemporal unpredictability and plasticity. In this sense, both specific hydro-geomorphological restoration projects for small stretches or landscape environments, and *meta-restoration* plans at higher scales, should resist the temptation to attempt to consolidate preconceived structures, forms, or ecological scenarios. Restoration, at all levels of intervention, should focus on the simple restitution of processes and dynamics, or on removing the pressures that make them impossible, so as to take advantage of the extraordinary resilience and ecological plasticity of FREs, which are capable of self-regeneration in short periods of time. In conclusion, restoration should be *passive* (non-interventive), adopting the *principle of minimum intervention* and relying on the natural ecological *resilience* of the system (García et al., 2011).

2.2.2. The LIFE ALNUS project: first experience of meta-restoration of alluvial forests at a regional scale

Despite the scientific, social and political challenge of conserving alluvial alder forests, there are currently only isolated and local restoration experiences in Europe, usually aimed at the improvement of river stretches or limited to specific natural areas. In other words, no EU-wide project has been launched to date that adopts an integrated approach to the conservation of alder forests, considering regional and inter-regional scales, and establishing basins as the basic ecohydrological units within which to implement *meta-restoration* plans.

This is the scenario in which the *LIFE ALNUS* project has emerged; that is, (i) faced with the challenge of tackling one of the greatest ecological and biological crises confronting the European Union today, (ii) and faced with the need to review the approach to the conservation of the 91E0* habitat and the need to accumulate valid experiences to address it.

The project has also constituted an attempt to move towards a better understanding of the *meta-restoration* of fluvio-riparian systems and their alluvial alder woodlands (the 91E0* habitat), based on the idea that future habitat conservation strategies should consider all its levels of functioning and organisation, as well as improving the ecological resilience of the FRE at a regional scale. It is the first project to propose adopting this integrated, regional and multiscale ecosystem approach to alluvial forest restoration, using ecological resilience at the territorial level as a restoration tool (*passive restoration*). Furthermore, it is a pilot and experimental strategy to improve the role of the Natura 2000 network in the functioning of the ecosystem at a territorial scale.

The *LIFE ALNUS* project has been implemented in Catalonia (northeast Iberian Peninsula). While it is necessary to consider and integrate all territorial levels in the design and promotion of a strategy for the *meta-restoration* of fluvio-riparian ecosystems at a regional scale, the executive and management phase must be based on the logic of the key ecohydrological functional units, namely river basins. Accordingly, a regional and interregional strategic approach is required in the design of the *meta-restoration* project, which must be subsequently implemented through instruments that deploy restoration strategies for each river basin and network. Therefore, in addition to analysing the factors and pressures that explain the problems of habitat conservation at different territorial levels, the project has involved developing and executing *Habitat Restoration and Conservation Plans* (HRCPs) in three river basins: the upper Segre, which belongs to the Ebro river basin, and the basins of the Besòs and Ter rivers, within the scope of the *River Basin District of Catalonia*. They have been selected as pilot basins to test the development and implementation of the plans due to the fact that they contain representative samples of most of the regional ecological manifestations (variants) of the habitat, and because the main pressures that characterise the regional problems concur in them. The three pilot basins cover more than 50.5% of the geographical distribution of the 91E0* habitat in Catalonia (Figure 1).

Given that FREs are highly complex socio-ecological systems, their meta-restoration is equally multi-faceted and multi-scalar. Entailing and influencing everything from territorial planning policies and strategies to the organisation of fluvial spaces, the management of the system of liquid and solid flows, the conservation of each river reach or sector, and the promotion of social uses and the restoration of cultural links with the ecosystem.

Adopting this approach, the design of the *LIFE ALNUS* strategy for the conservation of the 91E0* habitat in Catalonia has involved three work phases:

a) The first phase consisted of conducting a series of baseline studies to characterise and diagnose the state of conservation of the 91E0* habitat and the problems affecting it, both at a regional scale and within each of the pilot basins. The aim of these studies was to determine the real ecological potential of the territory to host alluvial alder forests and, by comparing it with their current distribution pattern and the spatial behaviour of the pressures affecting them, to achieve a better understanding of the causes and pattern of the regional and local depletion of the habitat (Figure 2).

b) The second work phase involved using the results and diagnosis obtained through the baseline studies to design a habitat conservation strategy for each of the three pilot basins. These strategies have been formalised as *Habitat Restoration and Conservation Plans* (Figure 2).

c) The third phase of the *LIFE ALNUS* project has consisted of implementing in the pilot drainage basins the habitat restoration plans through conservation actions and monitoring the results obtained.

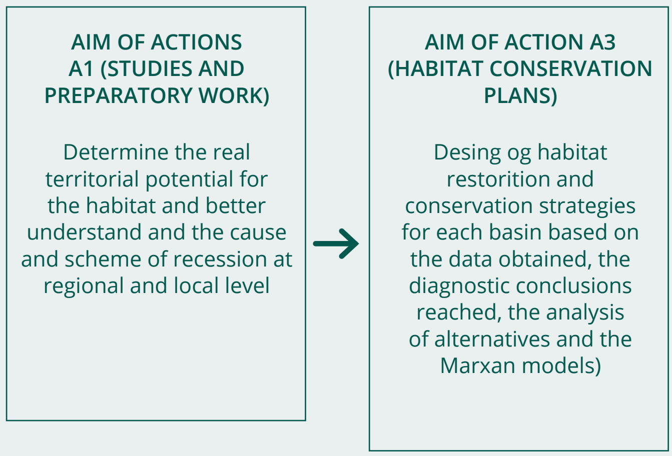


Figure 2 /

LIFE ALNUS is an experimental fluvial *meta-restoration* project that tests alternative conservation strategies for the 91E0* habitat (*alluvial forests of Alnus glutinosa and Fraxinus excelsior* (*Alno-Padion, Alnio incanae, Salicion albae*)) at a regional scale. From a methodological point of view, it has involved conducting a series of baseline studies at both a regional and local scale (pilot basins) (A1 Action) in order to obtain a proper understanding of the problems involved in the conservation of the *fluvio-riparian meta-ecosystem* at all levels of ecological organisation. With the results of the diagnosis, the necessary information was obtained to contact and reach a stewardship agreement with the landowners whose land lies adjacent to the river stretches where the actions were to be carried out (A2 Action). The results of the aforementioned baseline studies were used in order to design the *habitat restoration and conservation plans* for each of the pilot basins (A3 Action). These plans were subsequently implemented (in the framework of the C Actions), and their results are assessed through ecological monitoring programmes (D Actions).

2.3. Multiscale characterisation and diagnosis methodologies

2.3.1. Introduction: diffuse and local pressures, and their multiscale analysis

According to a recent review of the state of the world's aquatic biodiversity (Dudgeon et al., 2006), threats to fluvio-riparian ecosystems may be grouped in five categories: (1) direct destruction and degradation of the habitat and its fragmentation, (2) presence of invasive species, (3) pollution of the aquatic environment, (4) alterations of the natural flow regime and (5) overexploitation.

This simplification is valid for the Catalan river basins. However, for the purpose of designing a *meta-restoration* strategy, it is useful to classify the pressures that affect and explain the degradation of alder forests into two categories: *diffuse* and *local*.

As in other territories, the *diffuse pressures* affecting the Catalan FRE encompass those related to anthropogenic modifications of natural land cover, the overexploitation of surface and groundwater resources, and the hydrological and sedimentological regulation of the basin. Their impact is reflected in the profound alteration of fluvial dynamics throughout the *watershed continuum*. The transmutation of hydrological and morphodynamic balances has hydro-geomorphological effects on the fluvial area and its banks, mainly involving the modification of topographical, morphological, sedimentological and hydrological conditions. Fluvial incision processes also occur as a result of these changes, which, together with the alteration of the natural flow regime, end up compromising the ecological conditions of the riparian and alluvial domains. Their forests are influenced by the topographic disconnection between riverbeds and banks, the reduction of overflow processes, and by the depression and disconnection of the piezometric levels of the alluvial aquifers of fluvial terraces and plains.

In the specific case of Catalan riparian forests, the conservation of "Mediterranean-influenced" alder forests in the face of diffuse pressures is even more complex than for their Central European counterparts. Firstly, the alder forests of the Iberian Mediterranean slope are distributed over a very wide ecological range, due to the orographic and climatic heterogeneity that characterises some of its regions, as is the case of Catalonia. This heterogeneity is expressed in different habitat variants, each of which has its own biological and ecological singularities (all of which are different from those of non-Mediterranean alder forests). This creates a richer mosaic of biodiversity, but one whose conservation is more complex. Secondly, Catalan alder forests mark the southern limit of the habitat's European distribution, which means that the fight for their conservation must be waged in territories that are suboptimal for this habitat. A final weak point is that Mediterranean alder forests are geographically confined to a bioclimatic area that is highly exposed to climate change, which makes them extremely vulnerable. The fact is that alder forests, characterised by their appetite for permanent and temperate flows, are exposed to thermal changes and reduced rainfall, but also, and above all, to the strong hydrological regulation of the basins they inhabit (more necessary and intense as a consequence of moderate rainfall), and to the intra- and inter-annual variability of rainfall typical of the Mediterranean climate, where large dams and reservoirs are particularly strategic, and where hydrological use is therefore especially incisive. Sub-optimal ecological conditions, climate change and hydrological regulation are negative factors that also have a concomitant effect, which means that the magnitude of their impact is due to positive feedback mechanisms between them.

Diffuse pressures on fluvial dynamics are difficult to resolve, which means that in order to minimise their impact it is essential to increase the resilience and adaptation of the habitat to these pressures at local and regional scales. To this end, it is crucial to understand how these pressures are exerted on the territory from a spatiotemporal perspective, as well as to analyse their relationship with the geography and the state of conservation of the habitat. As such, the first actions of the *LIFE ALNUS* project consisted of conducting a series of studies, *at a regional scale*, with the aim of studying and understanding these diffuse pressures and their geographical and ecological relationship with the potential and actual distribution of the habitat.

In addition to diffuse pressures, which propagate and accumulate through the *watershed continuum* and its fluvial network, there are *local pressures* that also affect the habitat, be they hydrological, geomorphological or chemical. In the case of alder forests and other alluvial forests, physical alterations are of particular importance. These may be direct alterations to the biotic fraction (eradication or degradation of riparian forests) and geomorphological alterations (occupation or morphological transformation of the riparian corridor). Both types largely explain the current scenario of erosion and ecological destructuring of Iberian and Catalan alluvial forests, but the main barrier that prevents both their natural recovery and their restoration is the absence of suitable "space" for their development (Calleja, 2009); that is, a lack of availability of environments with appropriate conditions in terms of physical and ecological stability. Therefore, strengthening the physical and legal protection of fluvial areas is an *essential* condition for enabling the functional restoration of the *fluvio-riparian meta-ecosystem* and its alluvial forests.

The aforementioned physical pressures lead to the direct destruction of the alluvial forest habitat, and with it to its fragmentation and isolation. As a result, riparian forest of headwater streams usually remain well preserved, but the riverine formations of fluvial terraces, valley bottoms and depositional floodplains of the middle and lower reaches have disappeared. The surviving forests suffer from ecological degradation and biological impoverishment, partly as a result of forestry and livestock practices, but also as a consequence of their functional disconnection from fluvial dynamics. All this ultimately leads to the recession and geographical fragmentation of the habitat (distribution area) and the disappearance of its most valuable and endangered elements (lowland forests).

The *LIFE ALNUS* project is based on the idea that the fragmentation of the habitat, and the disconnection or decoupling of the aforementioned levels of interconnection and ecological organisation, lead to a loss of functionality at different scales, to biological impoverishment and, ultimately, to a reduction in the ecological resilience of the system, in some cases causing the functional collapse of the entire *fluvio-riparian meta-ecosystem*.

The working hypothesis of *LIFE ALNUS* is based on this idea: alluvial forests cannot be conserved on a mosaic basis; that is, without respecting and restoring their organisational and functional structure. Therefore, the conceptual and working framework of the project is the testing of *meta-restoration* actions with the aim of improving the various structural and functional levels of the FRE, thus increasing the regional and intra-basin ecological resilience of the habitat.

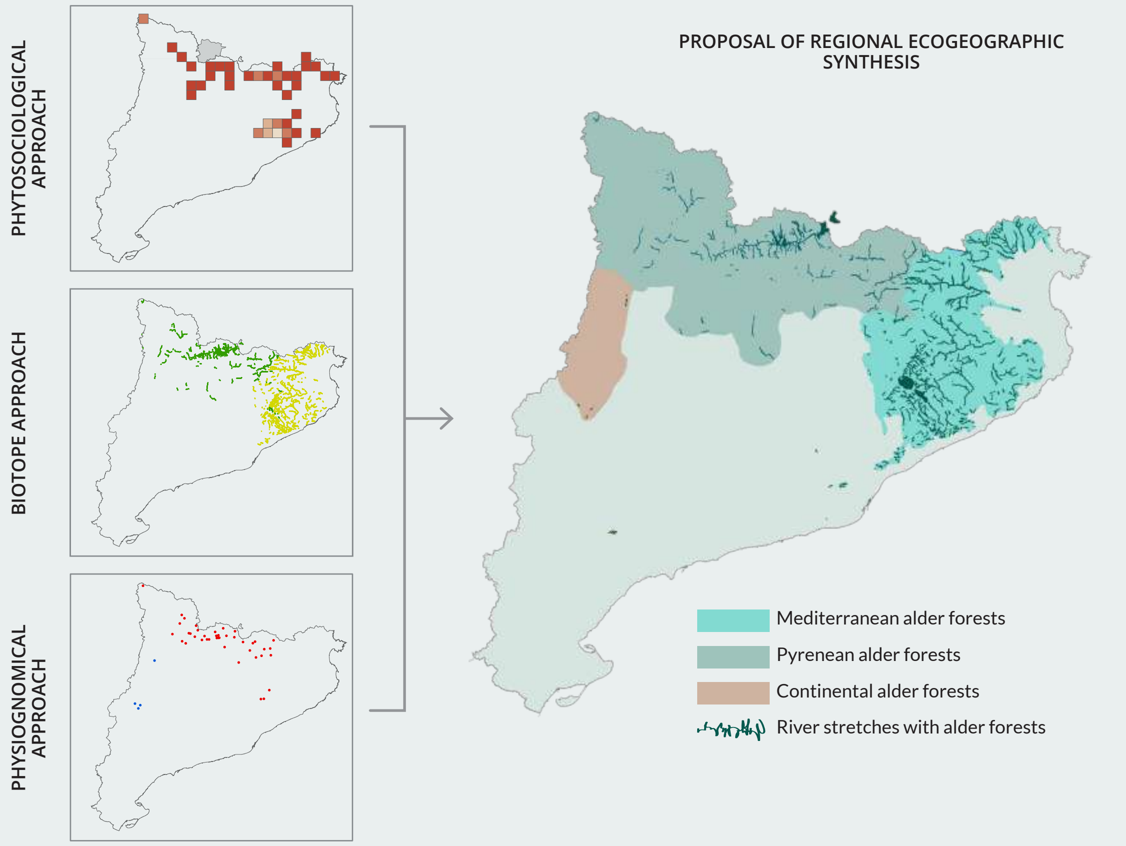
This idea has been put into practice through the design and execution of *meta-restoration* strategies at a river basin scale in three different areas (upper Segre, Besòs, Ter), but always from a regional diagnostic perspective (Figure 1). To this end, the regional studies have been complemented with specific studies that have analysed the effect of diffuse and local pressures within each river basin unit, as well as the state and spatial conservation structure of the habitat. On the basis of this systemic and multiscale approach, the aforementioned *Habitat Restoration and Conservation Plans* were drawn up for each basin.

2.3.2. Studies at a regional scale

Within the framework of the regional studies, four lines of study were established (MN Consultants, 2019):

<u>1. Determining the ecological and biological variability of the 91E0* habitat</u>

The first line of study aimed to (i) clarify and delimit conceptually and typologically the definition of the 91E0* habitat in the region, (ii) as well as to identify, define and delimit all its ecological variants in order to be able to consider and integrate them appropriately in the regional strategy for the restoration and conservation of all biological diversity depending directly on this biotope. (Figure 3).



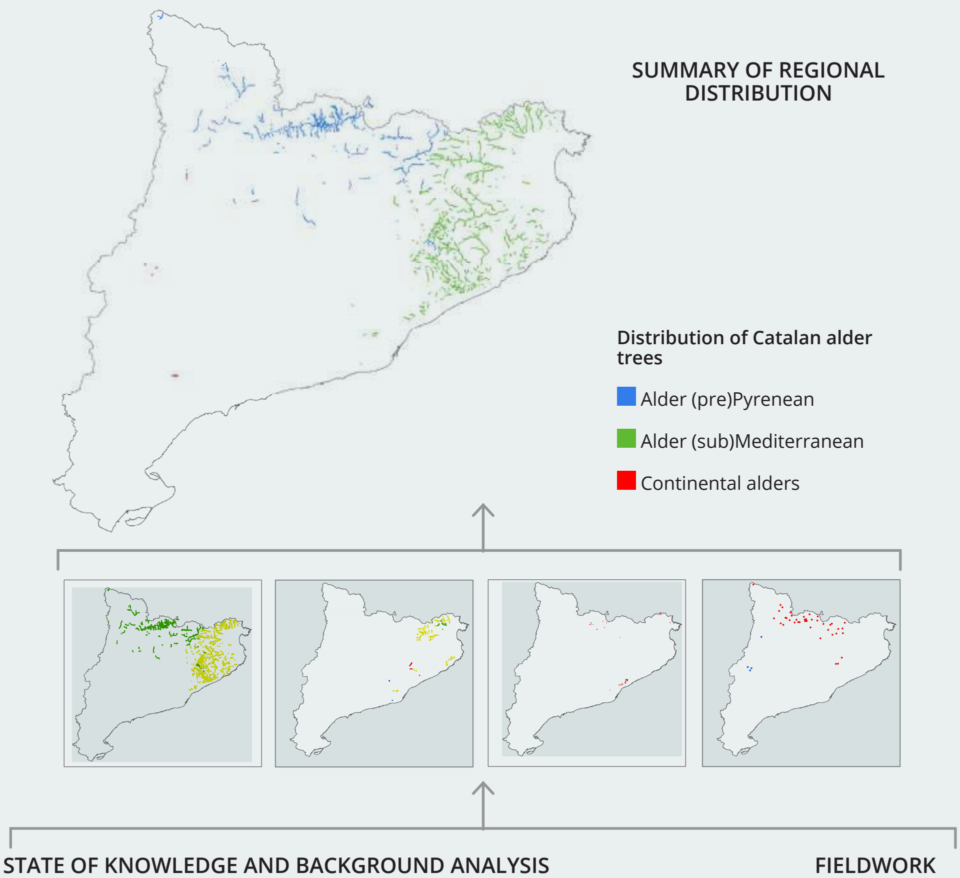
ECOLOGICAL APPROACH (CEC, 1991; DTS, 2012; Carreras et al., 2015)			PHYTOSOCIOLOGICAL APPROACH (Folch, 1981; Ballesteros 1981; Font, 2017)		PHYSIOGNOMIC APPROACH (Lara et al., 2007)
Level 2. Legend	Level 3. Legend	Legend Habitats of Catalonia	Association	Description	Denomination
44.3 Central European Alder	*44.316+ Alder with remote Carex*	---	*Carici pendulae-Alnetum glutinosae = Angelico-Caricetum remotae*	Alisenda con *Carex remota*	Catalan Pyrenees (sub-Mediterranean Catalans)
	44. 3431+ Alder (and poplar) with Circaea lutetiana	44e	*Equiseto hyemalis-Alnetum glutinosae =Carici pendulae-Alnetum catalaunicum = Alno glutinosae-Equisetetum hyemalis*	Alisenda típica	Pyrenean Catalans (sub-Mediterranean and continental mesotrophic Catalans)
	44.3432+ Alder (sometimes poplar) flexuosum	44f	*Lamio flexuosi-Alnetum glutinosae = Alno glutinosae-Lamietum flexuosi*	Alisenda con ortiga blanca	Sub-Mediterranean Catalans (Catalan Pyrenees)
44.5 Alder and southern laurels	44.515+ Laurel or alder trees with bay leaf	44g	*Osmundo-Lauretum nobilis*	Alisenda con laurel	Sub-Mediterranean Catalans

Figure 3 /

The studies have analysed, compared and contrasted for the first time all the approaches previously adopted in order to characterise the regional variability of the 91E0* habitat (*Alluvial forests of Alnus glutinosa and Fraxinus excelsior* (*Alno-Padion, Alnio incanae, Salicion albae*). This has made it possible to classify them as three ecogeographical subtypes (useful for planning purposes), to map their distribution and to obtain their correspondence with previous classifications. Source: MN Conservation Science Consultants, 2019.

2. Study of the current distribution of the habitat

Through this second line of study, all previous maps, bibliographical references and other sources of information on the distribution of alluvial forests of *Alnus glutinosa* in Catalonia were identified, analysed, integrated and synthesised. The studies were conducted in conjunction with fieldwork in order to validate the ecotypes described. This methodology produced the best possible synthesis of the regional mapping of the current distribution of each subtype (Figure 4). The mapping obtained made it possible to diagnose the geographical and ecological distribution of the habitat using official sources and other references, and to analyse the behaviour of certain parameters regarding the occupied area, cover, continuity, and physical-legal protection within the various territorial levels (regional, basin, sub-basin) for each ecological subtype.



- Corine Cartography of Catalonia, v.2 (CHCv2, 2008-2012)
- Mapping of river habitats in Catalonia (PEFCAT Programme)
- Mapping of the habitats of protected natural areas in Catalonia
- Northern Spain riparian vegetation database (Lara et al., 2007)
- Work of field identification, classification and digitization of the alluvial forests of Siurana (undescribed communities of 91E0*)
- Other bibliographic sources

Figure 4 /

Synthesised regional map of the 91E0* habitat, and of each of the three described ecological variants. Source: MN Conservation Science Consultants, 2019.

Mixed riparian forest with presence of robinia (*Robinia pseudoacacia*) and other non-native species. Middle course of the Ter River. Photo: Jordi Bas.

3. Determining the territorial ecological potential for the development of the habitat.

Once the current distribution of the habitat was determined, it was possible to begin to assess the region's ecological suitability for hosting alder forests, as well as to determine the specific potentiality of each basin, sub-basin and fluvial network in order to develop and sustain the forests. To this end, mathematical models were developed to simulate the ecological potential for the whole fluvial network of the region. In parallel, the models were compared with reconstructions of the geography of the habitat obtained through other methodological approaches, namely phytosociological maps of potential vegetation of the region and the analysis of the *Cartografia dels hàbitats de Catalunya* (*Habitat Mapping of Catalonia*) (Figure 5).

The *mathematical habitat simulation model* for the region has made it possible to establish the ecological suitability of each stretch of the hydrological network and of each basin to host alder groves. The model was developed for the two dominant variants (ecotypes): *sub-Mediterranean* and *pre-Pyrenean* alder forests. These models have made it possible to compare the actual distribution of the habitat remaining in Catalonia today (obtained in the previous work phase) with its ecological potential. The modelling has proved to be an extremely useful tool for designing the conservation strategy for each pilot basin (*restoration plans*), as well as for analysing FRE conservation at a regional scale.

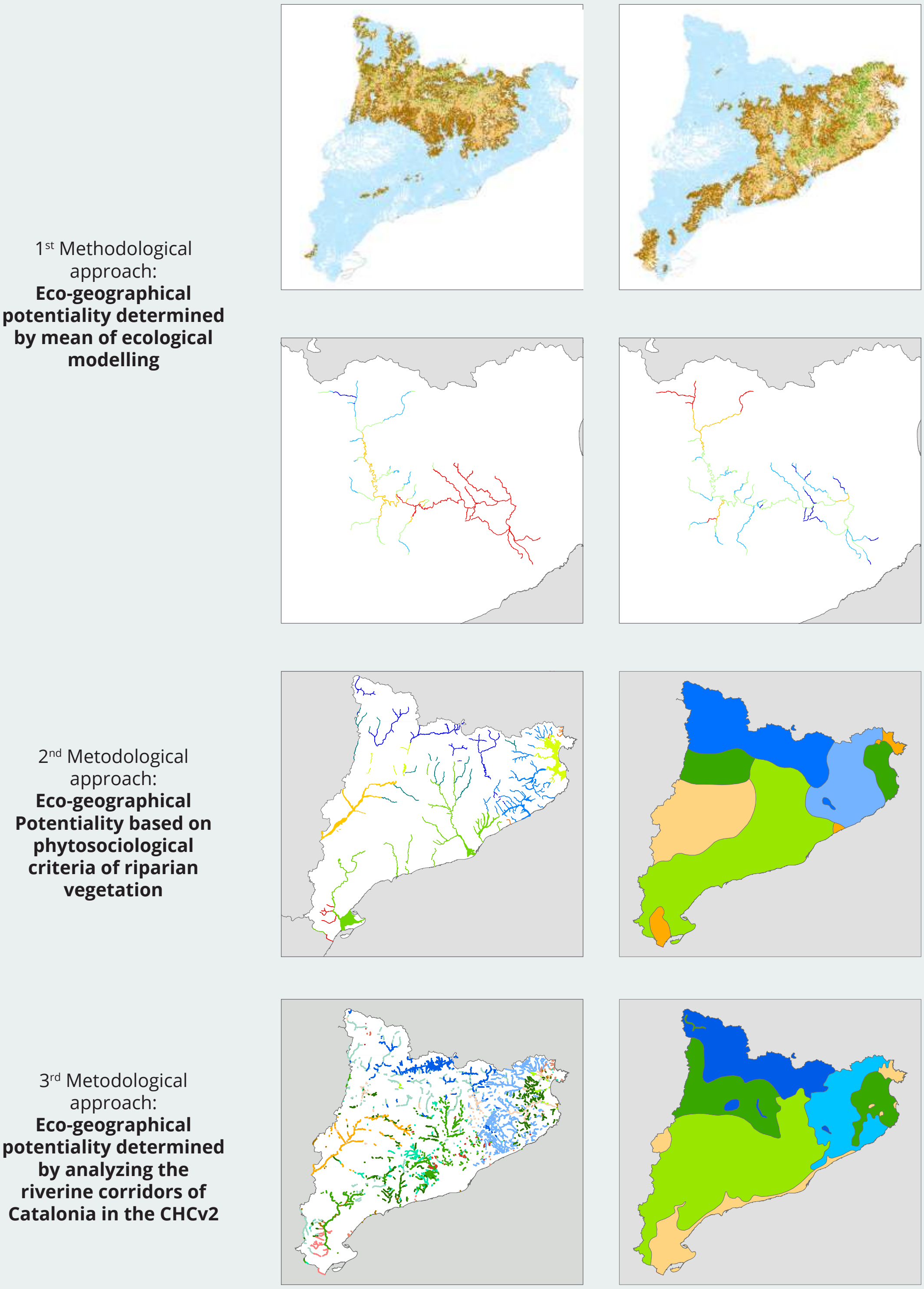


Figure 5 /

The potential geography of the 91E0* habitat for the region has been obtained for the entire regional fluvial network by means of the mathematical modelling of climatic, topographical and hydrological variables. This methodological approach has been compared with the distribution obtained through the phytosociological reconstruction of the habitat, and with that obtained through the processing and analysis of the second version of the *Cartografia dels hàbitats de Catalunya* (*Habitat Mapping of Catalonia*). Source: MN Conservation Science Consultants, 2019.

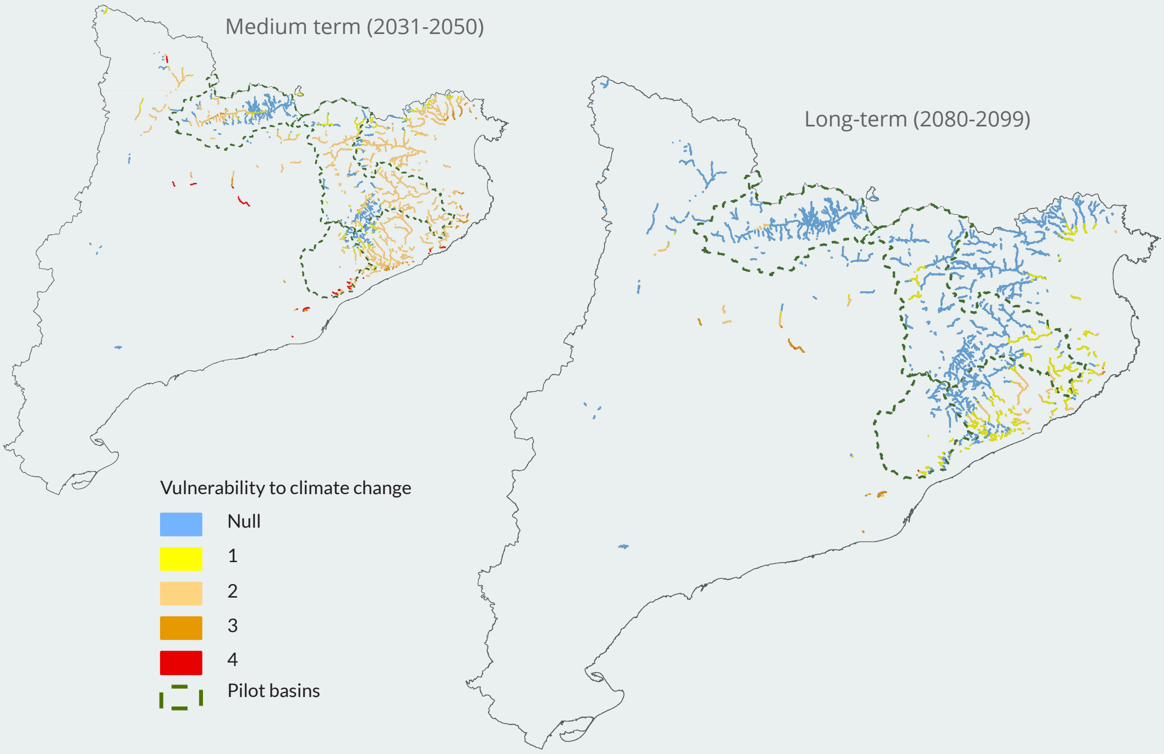
Dam with hydroelectric use in the middle section of the Ter River. Photo: Jordi Bas.

4. Analysis of the spatial pattern of diffuse pressures

Diffuse pressures are the main factors that need to be properly understood and considered in order to design the future restoration and conservation strategies for the regional alluvial ecosystem. Therefore, the final regional-scale line of study focused on examining the pressures that limit and explain the current conservation status of the habitat and its geographical and spatial distribution pattern.

The spatial relationships between the regional biogeographical potential for the habitat, its current conservation status, and the various pressures on the hydrological regime and fluvial hydrogeomorphology were analysed.

However, the main focus was the study of the possible effects that climate change might have on the fluvial ecosystem and its alluvial forests. To this end, various *vulnerability models* were developed on the basis of climate projections (scenarios) from the latest reports of the Intergovernmental Panel on Climate Change (IPPC) of the European Union (EU) adapted to the region of Catalonia, considering AR5 (2031-2050) as the medium-term projection, and AR4 (2070-2100) as the long-term projections (Calvó, 2009; Calvó et al. 2017). Based on these medium- and long-term climate scenarios, both the vulnerability to climate change of the *sub-Mediterranean* alder forests and the sensitivity to climate change of the *pre-Pyrenean* variant were modelled at a territorial scale. These models were applied to obtain climate vulnerability maps for the entire fluvial network of the region (Figure 6).



Variable	Medium term (2031-2050)		Long term (2080-2099)	
	Variation	Limits	Variation	Limits
Average annual temperature	+1.3°	+0.7° / +2.1°	+3.5°	+2.2° / +5.1°
Average summer tempera-ture	+1.6°	+1.1° / +2.5°	+4.1°	+2.7° / +6.5°
Average annual rainfall	-0.1%	-12.6% / +8.0%	-12%	-27% / -4%
Average summer rainfall	-12.3%	-24.8% / +9.5%	-24%	-53% / -3%

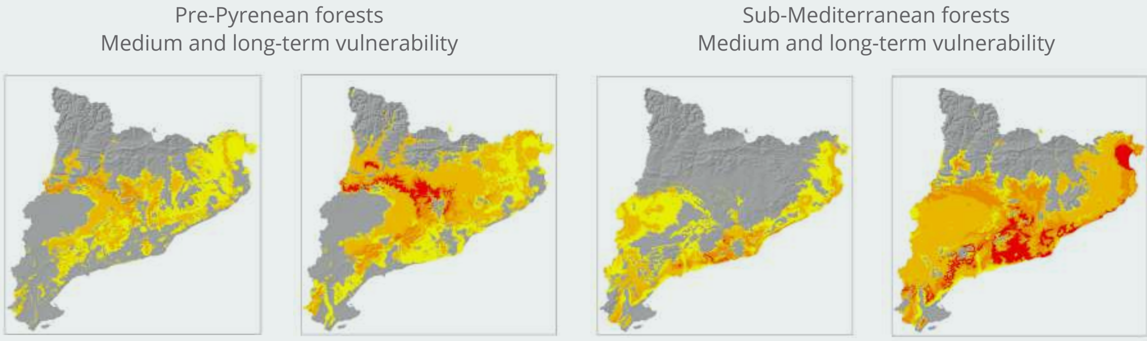


Figure 6 /

Results of modelling the vulnerability of the 91E0* habitat to climate change based on climate projections from the latest EU regional reports for medium-term (2031-2050) [AR5] and long-term (2080-2099) [AR4] time scenarios. Source: MN Conservation Science Consultants, 2019.

The results of these studies have shown, by way of example, that the best alluvial forests in Catalonia are also the most resilient ecosystems in the face of climate change (Figure 7), which makes them strategic nuclei for maintaining the ecological resilience of the habitat. The areas where the habitat is on the verge of extinction, and where it does not seem to be able to survive, will expand in the coming years to encompass much of its current distribution. This data has been decisive for the design of the strategy for improving and extending the Natura 2000 network, as well as for the design of the *meta-restoration* actions in each pilot basin.

Finally, and also in the framework of the analyses of diffuse pressures, other specific studies have been carried out, such as the analysis of the possible underlying causes of the decline observed in alder populations in the basins studied (see Valor et al., 2020).

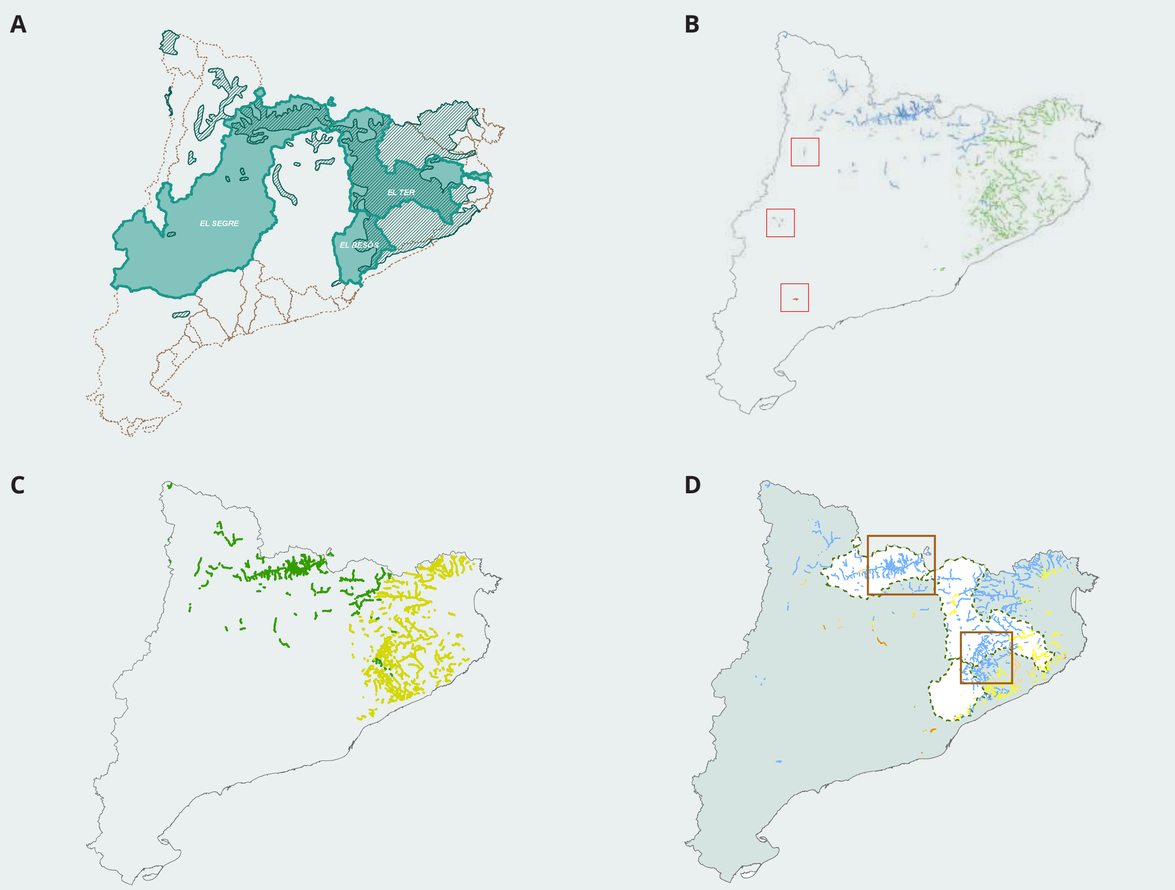


Figure 7 /

Example of some of the results of the macro-territorial studies that help to increase the understanding of regional issues. The studies revealed not only the ecological and biological diversity of the 91E0* habitat that needs to be considered in future habitat restoration, planning and management processes (A), but also important findings such as the fact that the alder forests of the *continental* variant are fragmented, isolated from each other, not very well known, and threatened at a regional scale (B). Other examples of key concepts identified through multiscale studies are, for example, the role performed by the Ter river basin in the interconnection all the ecotypes at the regional scale (C) or between the parts of the habitat that are most resilient to climate change (D). Regional studies have also been useful to identify the upper Segre watershed -as it passes through the Cerdanya territory-, as the fluvial landscape that preserves the best expression of the 91e0* habitat, and as the most relevant fluvio-alluvial ecosystem with the greatest hydrogeomorphological integrity of Catalonia. Source: MN Conservation Science Consultants, 2019.

2.3.3. Meso-scale studies (pilot basins)

Once the analysis at regional level was completed, more detailed studies were carried out along the river continuum (in the so-called *Alnus network*, covering approximately 1,000 linear kilometres) of the three pilot basins (Ter, Besòs, upper Segre), by means of two lines of study: (1) ecological *characterisation*, (2) and *diagnosis* of the FRE.

The entire *Alnus network* was surveyed by a team of botanists and limnologists in order to reconstruct the original lateral area of the river corridor (which, in line with previous studies, was called an PFA, or "potentially fluvial area" (MN Consultors & Aqualogy, 2012), mapping its riparian ecosystems and describing them by means of multiple hydrogeographic, geomorphological and forest structure parameters, and characterising them on a phytosociological level, studying their floristic composition, inventorying the mosaic of habitats and allochthonous species, determining the state of health and conservation of the alders, etc. All the information collected was synthesised into three *ecological characterisation* maps that have provided an understanding of the ecosystem that is essential for the design of the *LIFE ALNUS* meta-restoration actions: (1) the spatial reconstruction of the PFA; (2) the general characterisation variables of the FRE; (3) and the silvicultural and ecological characterisation of the alluvial alder forest (Figures 8 and 9).

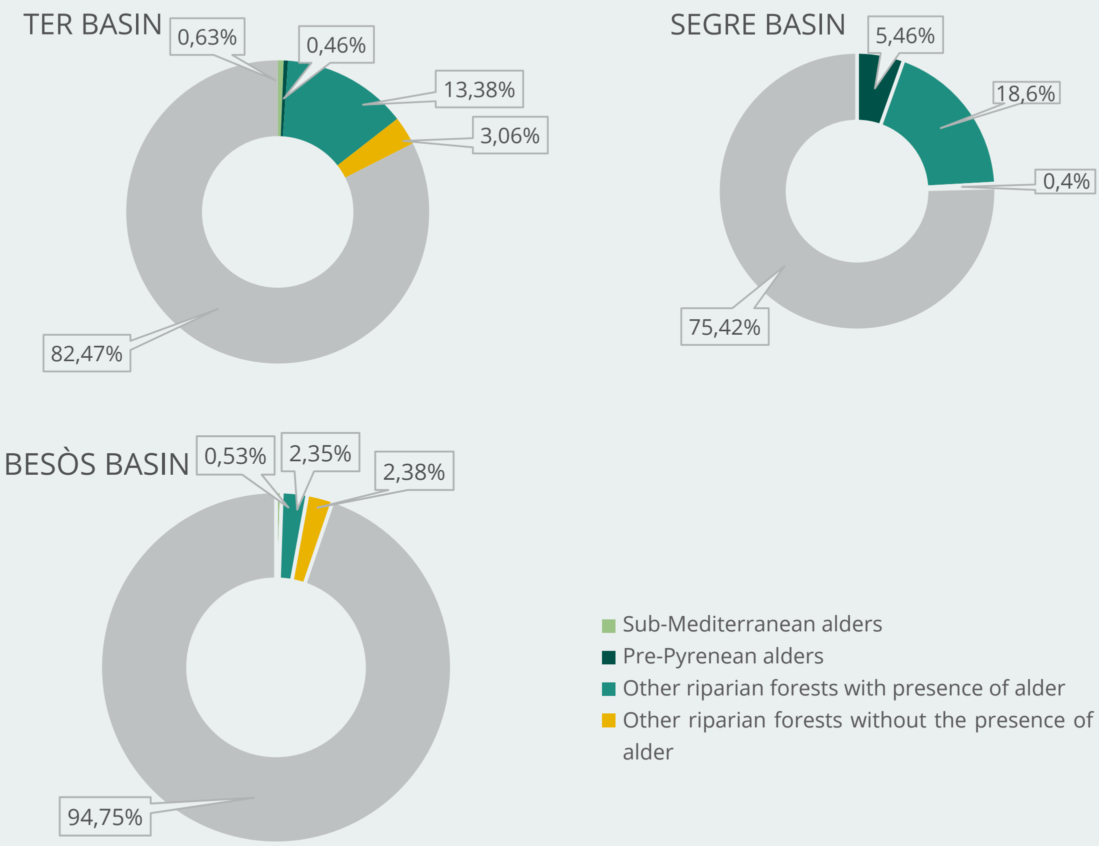


Figure 8 /

Example of some of the results obtained by characterising the *fluvio-riparian ecosystem* of the pilot basins (Ter, Besòs, upper Segre). As the analysis of the riverbank structure shows, the Segre river basin conserves the river corridors with the highest ratios of forest cover and integrity (24.6%). As for alder-dominated forests, these are already residual in the Ter river basin (1.1% of PFA) and Besòs river basin (0.5% of PFA), but are still remarkably well represented in the upper Segre river basin (5.5%), which contains the most relevant manifestations and the best reserve of the habitat, and an ecosystem mosaic of a distinctly alluvial character that is unique at the regional scale. Source: MN Conservation Science Consultants, 2019.

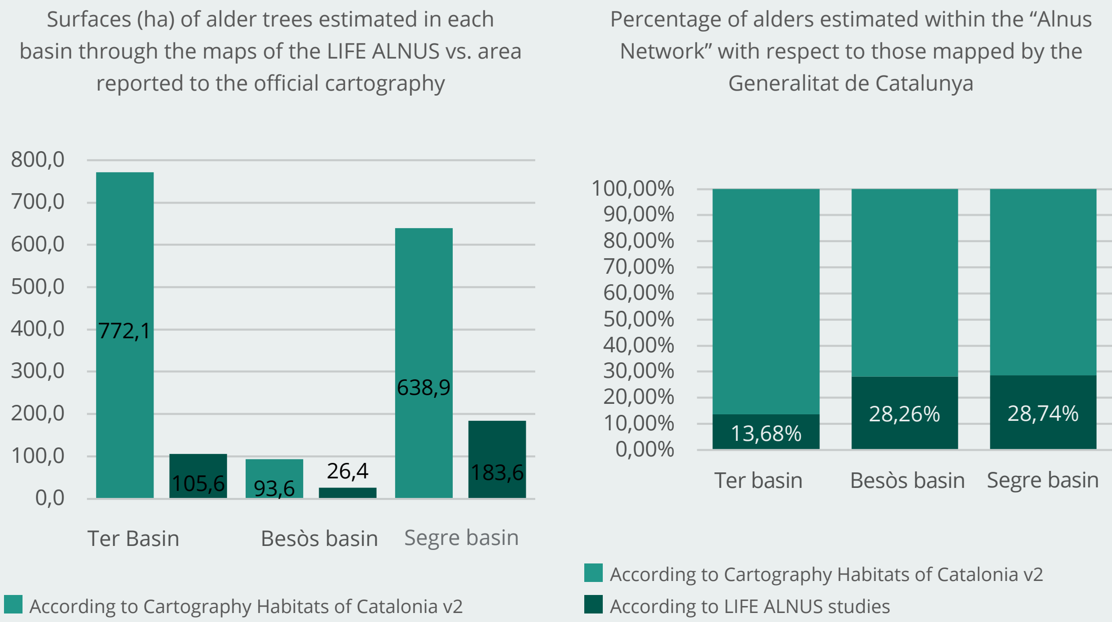
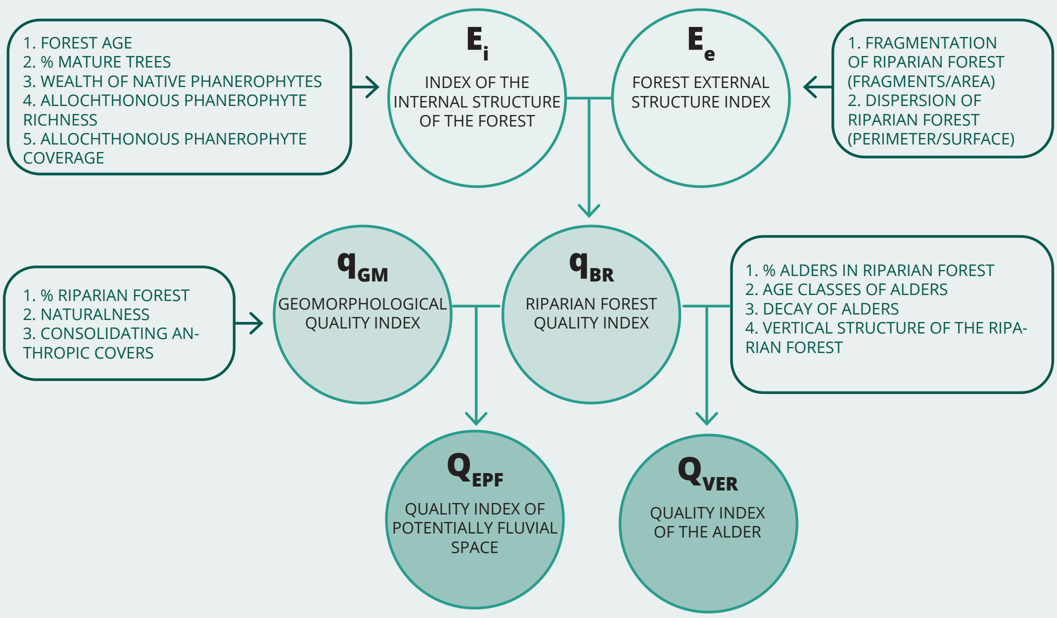


Figure 9 /

Another example of some of the important overall results obtained from the characterisation studies: data obtained during the study of the *Alnus network* indicates that official estimates for the habitat in the region may be overestimated. In the more than 1,000 km of fluvial network analysed, only 316 ha of true alder riparian woodland have been inventoried, while official mapping reports more than 1,500 ha for the same network; that is, five times more. If this disproportion between the actual surface area of habitat and the mapped cover reported by environmental administration were true, and we were to extrapolate this data to the rest of the region, the 5,509 ha currently estimated would be reduced to a mere 1,157 ha. The upper Segre river basin maintains the last vestiges of truly alluvial forests in Catalonia (and is the main reservoir of the *pre-Pyrenean* ecotype), while the Ter river basin emerges as a strategic fluvial territory for maintaining the regional resilience of the habitat through the interconnection of the fluvial network of the various internal basins of Catalonia, and between these and those of the Ebro river basin (see Figure 7C). The Besòs river basin contains the alder forest that is the most Mediterranean in character (unique communities), but it only survives in mountain refuges, and some of its refuges (southern core) are severely endangered (see also Figure 6). Source: MN Conservation Science Consultants, 2019.

Subsequent work focused on obtaining a *diagnosis* of the state of conservation of the FRE and its alder forests, and on determining their ecological role in the river corridor. To this end, taking some of the variables studied in the field and by means of GIS analysis, various indices and thematic maps were obtained to evaluate the geomorphological and ecological quality of the fluvial ecosystems and the alder forests (Figure 10).

INDEX / SUBINDEX	ORIGINAL VARIABLE	ACR.	PARAMETRIZATION	WEIGHT
EPF QUALITY INDEX(Q_{EPF})			**$(1/2)\cdot(q_{BR} + q_{GM})$**	0.5
RIPARIAN FOREST SUB-INDEX (q_{BR})			**$(1/2)\cdot(E_i + E_e)$**	0.5
Internal structure (E_i)			**$E_{ip}/(1+ E_{in}^{2/3})$**	0.5
Positive variables(E_{ip})			$(V_B/3) + (V_C/30) + (10\cdot V_D/63)$	0.6
	Forest age: EDAT_BOSC	V_B	jove = 3; jove, adult = 7; adult = 10)	1/3
	Percentage of trees with DN≥40 cm: PERC_ARB_MAD	V_C	$V_C/10$	1/3
	Taxonomic richness of autochthonous phanerophytes: RIQ_AUT	V_D	$10\cdot V_D/21$	1/3
Negative variables (E_{in})			$(3\cdot V_E/7) + (0.07\cdot V_F)$	0.4
	Taxonomic richness of allochthonous phanerophytes: RIQ_ALLO	V_E	$10\cdot V_E/7$	0.3
	Percentage of coating of allochthonous: PERC_ALLO	V_F	$V_F/10$	0.7
External structure (E_e)			**$10 - 5\cdot[2-(Ln(V_{G(MAX)})-Ln(V_G))/(Ln(V_{G(MAX)})-Ln(V_{G(MIN)}))-(V_{I(MAX)}-V_I)/(V_{I(MAX)}-V_{I(MIN)})]$**	0.5
	Fragmentation of riparian forest: $10000\cdot\sum N\_POLIG_{BR}/\sum AREA_{BR}$	V_G	$10\cdot(V_{G(MAX)}-V_G)/(V_{G(MAX)}-V_{G(MIN)})$	0.25
Discarded	Average compactness of riparian forest:$\sum[2\cdot(\pi\cdot AREA_{BR})^{1/2}/PERIMETRE_{BR}]/N\_POLIG_{BR}$	V_H	$10\cdot V_H$	0.25
	Dispersion of riparian forest:$100\cdot\sum PERIMETRE_{BR}/\sum AREA_{BR}$	V_I	$10\cdot(V_{I(MAX)}-V_I)/(V_{I(MAX)}-V_{I(MIN)})$	0.25
Discarded	Continuity of the riparian forest: $\sum LONG\_ARC_{XH}/N\_POLIG_{BR}$	V_J	$10\cdot V_J/V_{J(MAX)}$	0.25
GEOMORPHOLOGICAL SUBINDEX (q_{GM})			**$(5/2)\cdot(V_A + V_K + 2\cdot[1-V_L])$**	0.5
	% of riparian forest in l'EPF: $\sum AREA_{BR}/AREA_{EPF}$	V_A	$10\cdot V_A$	0.25
	Naturalness of EPF: $\sum AREA_{CN}/\sum AREA_{EPF}$	V_K	$10\cdot V_K$	0.25
	Artificialization of EPF: $\sum AREA_{CAC}/\sum AREA_{EPF}$	V_L	$10\cdot(1 - V_L)$	0.5
ALDER QUALITY INDEX (Q_{VER})			**$(1/2)\cdot q_{BR} + (1/8)\cdot(V_M/10 + V_N + V_O + V_P)$**	0.5
	RIPARIAN FOREST SUB-INDEX (q_{BR})	q_{BR}		0.5
	Percentage of alders in riparian forest: PERC_VERNS	V_M	$V_M/10$	0.125
	Age classes of alders: EDAT_VERNS	V_N	all = 10; seedling, young = 7; young, adulot = 5; young = 3; adult = 2; ND = 2	0.125
	Decay of alders: DEC_VERNS	V_O	none = 10; some = 6; many = 2; ND = 2	0.125
	Vertical structure of the forest: ESTR_VERT	V_P	arboreal, shrubby and lianoid stratum = 10; tree and shrub stratum (Z≥1285) = 10; tree and shrub stratum (Z<1285) = 7; tree stratum = 3; ND = 3	0.125



- Mapping of riparian geomorphological quality (qgm)
- Mapping of the internal structure of the forest (ei)
- Mapping the external structure of the forest (ee)
- Mapping the quality of riparian forest (qbr)
- Mapping the quality (conservation status) of alder trees (91E0*) - qver
- Cartography of singular alders

Figure 10 /

Variables studied and indices used in order to produce the diagnosis of the *Alnus network* of the three pilot basins, along with the resulting maps. Source: MN Conservation Science Consultants, 2019.

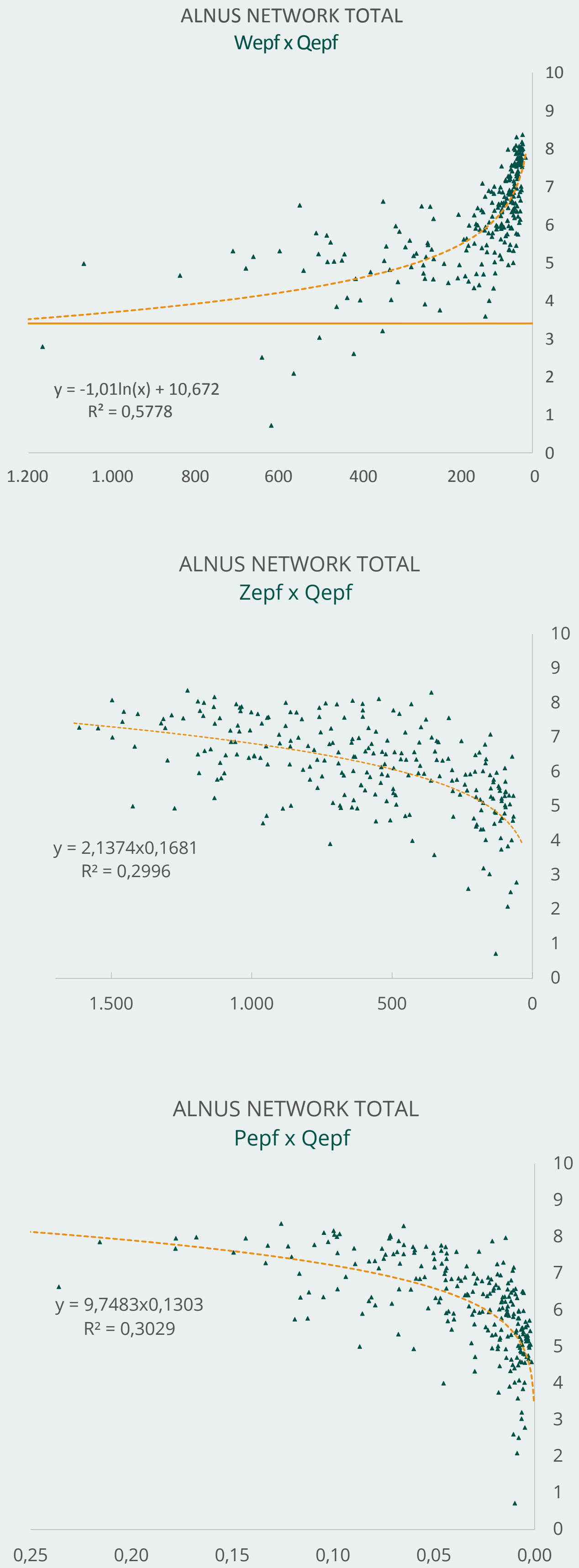


Figure 11 /

Analysis of correlations between the morphometric parameters of the river stretches studied in the *Alnus network* (width (W_{pfa}), altitude (Z_{pfa}) and slope (S_{pfa})), which are indicators of their geomorphological type (upper, middle and lower courses), with respect to the overall ecological quality index obtained for the *potentially fluvial area* (Q_{pfa}) of each reach analysed. These results reaffirm the idea that no alluvial forests are preserved under natural conditions in the studied basins. The least degraded stretches are almost exclusive to high mountain fluvial systems, while the fluvial terraces of the middle courses have a moderate or low level of conservation, and the alluvial plains (true manifestations of the alluvial forests defined by the 91E0* habitat) have been heavily occupied, degraded and transformed, to the extent that they can be considered a landscape on the verge of extinction in Catalonia. Source: MN Conservation Science Consultants, 2019.

2. 4. First experience in the meta-restoration of Mediterranean alluvial forests

On the basis of the results and conclusions of the work caried out at a regional scale, in the chosen pilot basins and the fluvial network, a series of *studies and analyses of alternatives* were conducted in order to design a strategy for the conservation of alluvial alder forests for the Ter, Besòs and upper Segre river basins.

Each strategy was designed through a long, complex process that also involved carrying out field work in order to verify the technical feasibility of the proposed alternatives, to seek social consensus, and to facilitate the legal process with local governments and sector-specific administrative bodies. Accordingly, the conservation strategies of the 91E0* habitat for each pilot basin were progressively outlined over a two-year period, and were finally set out in the so-called *Habitat Restoration and Conservation Plans* (HRCP) (MN Consultants, 2020).

Having obtained a geographical and causal outline of the regional problems, and of the specific problems of the FRE of each basin (obtained through the previous work phases), it was then possible to design the intervention strategy for each of them, which is included in the aforementioned HRCPs. These plans are designed to test, on the one hand, *structural meta-restoration* approaches and techniques (through measures aimed at obtaining legal protection, the physical adaptation of the river corridor at a spatial level, the surface area increase of the habitat, defragmentation, the recovery of the heterogeneity and dynamism of the biotic mosaic, and the reconstruction of biocenoses); and, on the other hand, *functional meta-restoration* approaches and techniques (which aim to reactivate dynamics, processes and flows of matter, energy and information), from the perspective of the integrated and systemic management of river basins as basic eco-geohydrological units (*Watershed Continuum Model* - WCM). The ultimate goal is to increase the overall resilience of the meta-ecosystem.

The structure of the *Habitat Restoration and Conservation Plans* reflects the lines of action of the *LIFE ALNUS* project, which means that their chapters coincide with the *conservation actions* set out in the project documentation. The actions have been grouped into four chapters in each HRCP:

1- The first chapter is devoted to analysing the "*physical and legal protection of the habitat*". It sets out potential strategies for the improvement of the habitat at different levels of ecological organisation, from the fluvial network scale to the inter-regional scale.

The legal framework involved in the planning and management of river areas is extremely complex, given that it encompasses regulations related to hydrological planning (management of water resources, risks related to river dynamics, protection of the aquatic and riparian environment, safeguarding of the public water domain and other areas in the public domain, etc.), to spatial planning (town planning and land use, infrastructures, etc.), to nature protection (natural areas and biodiversity conservation, etc.) and to sectoral uses (forestry, agriculture, livestock and fish farming).

In respect of the region of Spain as a whole, Catalonia's regional legislation boasted unique provisions until recently: a set of specific legal provisions regarding regional town planning regulations, both for the planning of river areas in terms of environmental protection (the "*River area*" concept), and in order to manage their geomorphological and hydraulic risks (the "*Water system*" and "*Flood zone*" concepts). However, this uniquely pioneering legislation (even at the European Union scale) was repealed just before to the start of *LIFE ALNUS* project.

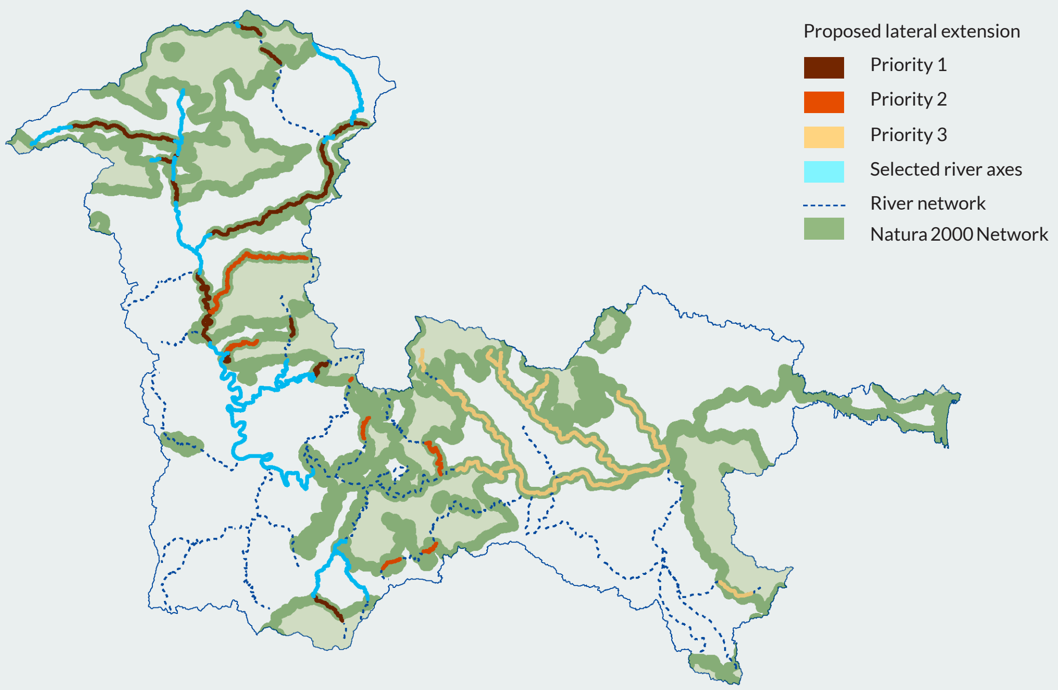
For this reason, although the initial plan was to implement (as an experimental and demonstrative initiative) a strategy to improve the physical-legal protection of the FRE by means of a coordinated combination of different legal provisions (the aforementioned town planning regulations, the regulation of the regional network of natural spaces, and the provisions regarding areas in the public domain set forth in the national Water Law), it was finally decided to base this strategy solely on extending and improving the Natura 2000 network.

As mentioned above, this review and functional improvement of the spatial structure of the Natura

2000 network was designed from a regional and inter-basin perspective (on the basis of the results of the territorial scale studies; see Figures 3-7), but also considering the restoration of intra-basin levels of organisation, which was made possible by the many multivariate analyses conducted in each pilot basin, as well as by the generation of mathematical models for the optimisation of organic or systemic planning processes. These models enabled the identification of priority areas for the conservation and restoration of alder forests. They were generated through the *Marxan* spatial planning software (Ball et al., 2009), which is frequently used to facilitate decision-making processes in land management and biodiversity conservation (Decker et al., 2017, Hermoso et al., 2015).

On the basis of the aforementioned studies, analyses and models, a proposal was drawn up for the improvement of the Natura 2000 network, optimised for each basin, considering the functional perspective of its FRE. Various levels of prioritisation were set out, including both the lateral re-delimitation of the river basin and the longitudinal extension of the river network protected by the areas already designated, and even the declaration of new Special Areas of Conservation (SACs) (Figure 12).

The various strategies and priorities were passed on to the Catalan public administration bodies responsible for the planning and management of the Natura 2000 network. In September 2022, the Natural Environment Planning Service of the Government of Catalonia initiated the standard legal procedure for public consultation and governmental approval.



	Priority 1	Priority 2	Priority 3	Total
Preselected longitudinal improvement (linear km)	124	-	-	124
Longitudinal improvement (linear km)	77.8	40.3	101.9	220.1

Figure 12 /

Example of the alternatives considered for the remodelling of the Natura 2000 network in the Ter river basin. The data is expressed in linear kilometres. Source: MN Conservation Science Consultants, 2020.

Stretch of river with a clear cutting of the riparian forest. Fornès River, Ter basin. Photo: Jordi Bas.

It should be highlighted that this is the first process for the modification at a regional scale of the Natura 2000 network carried out in Catalonia since its approval. It will eventually lead to an increase of around 900 ha of the regional surface of Natura 2000 (see chapter 9).

2- The second chapter of each plan, entitled "*Restoration of the continuity and ecological quality of the habitat*", contains all the strategies, measures and physical interventions aimed at achieving the functional rehabilitation of the *watershed continuum*, the ecological restoration of the FRE and the improvement of the ecological quality of the habitat.

Specifically, for each basin, a complex and diverse package of conservation actions was designed, organised into four sub-chapters: (i) *control of invasive species*, (ii) *forest management*, (iii) *defragmentation of the FRE*, (iv) and *reintroduction of the habitat* in courses where it has disappeared (restoration of potential geography).

As in the case of the first chapter ("*Physical and legal protection of the habitat*"), the design of the spatial structure for the implementation of each action within each pilot basin involved the use of specific methodologies (Figure 13). *Multivariate analyses* were carried out based on the parameters for characterising the pressures, ecological features and conservation status of each stretch, and *prioritisation indicators* were designed. In parallel, *Marxan* systematic planning models were generated. Using the results of the analyses and the generated models, the final selection of intervention stretches for each chapter and sub-chapter of the HRCPs was undertaken (Figure 15). This decision-making optimisation process enabled the prioritisation of the most ecologically important river stretches. The added value of the HRCPs is the possibility they offer of planning habitat conservation and restoration actions in the future, beyond the implementation period of the *LIFE ALNUS* project.

1. Measures for the elimination and control of invasive plant species	**3. Measures to restore longitudinal habitat continuity**
2. Measures to improve the forest structure	**4. Reintroduction of habitat in stretches where it has become extinct**

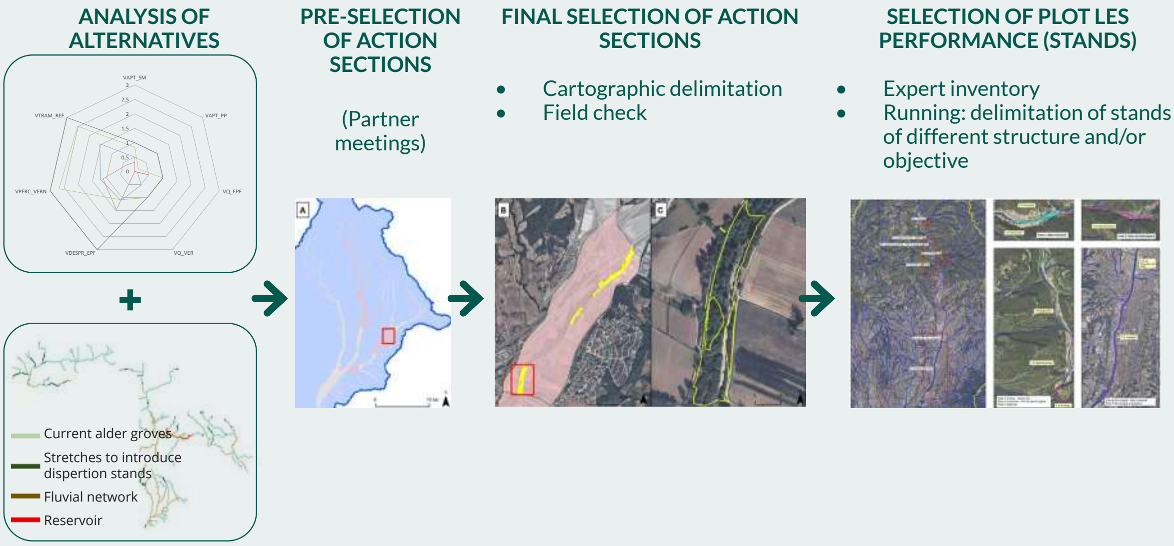


Figure 13 /

Example of the workflow employed for the design of the intervention strategy set forth in each chapter of the *Habitat Restoration and Conservation Plans* of the pilot basins. The case shown in the figure is the "*Restoration of the ecological quality and continuity of the habitat*", which is structured in four sub-actions: (1) Removal and control of invasive species, (2) Forest management, (3) Defragmentation of the habitat and (4) Restoration of the area of distribution (Reintroduction of the habitat). As shown in the flow chart, the design and spatial planning of the interventions included in each of these sub-chapters was in each case based on the analysis of alternatives and the calculation of *suitability* or *interest* indices for each stretch, as well as the generation of prioritisation models using the *Marxan* software. The stretches that were initially identified due to their strategic interest were subsequently studied in greater detail through fieldwork and reviewed by the partners responsible for (and knowledgeable about) each pilot basin. All this was done with the aim of making the final selection of the stretches in which to intervene. The final selection of the stretches was followed by specific studies aimed at selecting the action plots. These studies consisted of an analysis of the structure and possibilities for intervention within each stretch in terms of spatial availability, ecological characteristics, and other social and legal aspects. Source: MN Conservation Science Consultants, 2020.

3- The third chapter of the HRCPs includes the conception and implementation of pilot projects or experiences focused on fine-tuning and testing restoration techniques to address uniquely complex problems that tend to affect the habitat at a local or stretch scale. These projects, of an experimental nature, were distributed among the different pilot basins, as follows: (1) Restoration of alder forests on alluvial plains (upper Segre river basin), (2) Restoration of the habitat in highly modified urban stretches (Besòs river basin), (3) Improvement of the habitat in heavily hydrologically regulated stretches (Ter river basin), (4) Restoration of heavily impacted or geomorphologically modified rivers (Ter river basin) (See the corresponding chapters of this publication).

4- A fourth and final chapter complements the previous chapters by addressing specific problems detected in each basin and related to public riparian use.

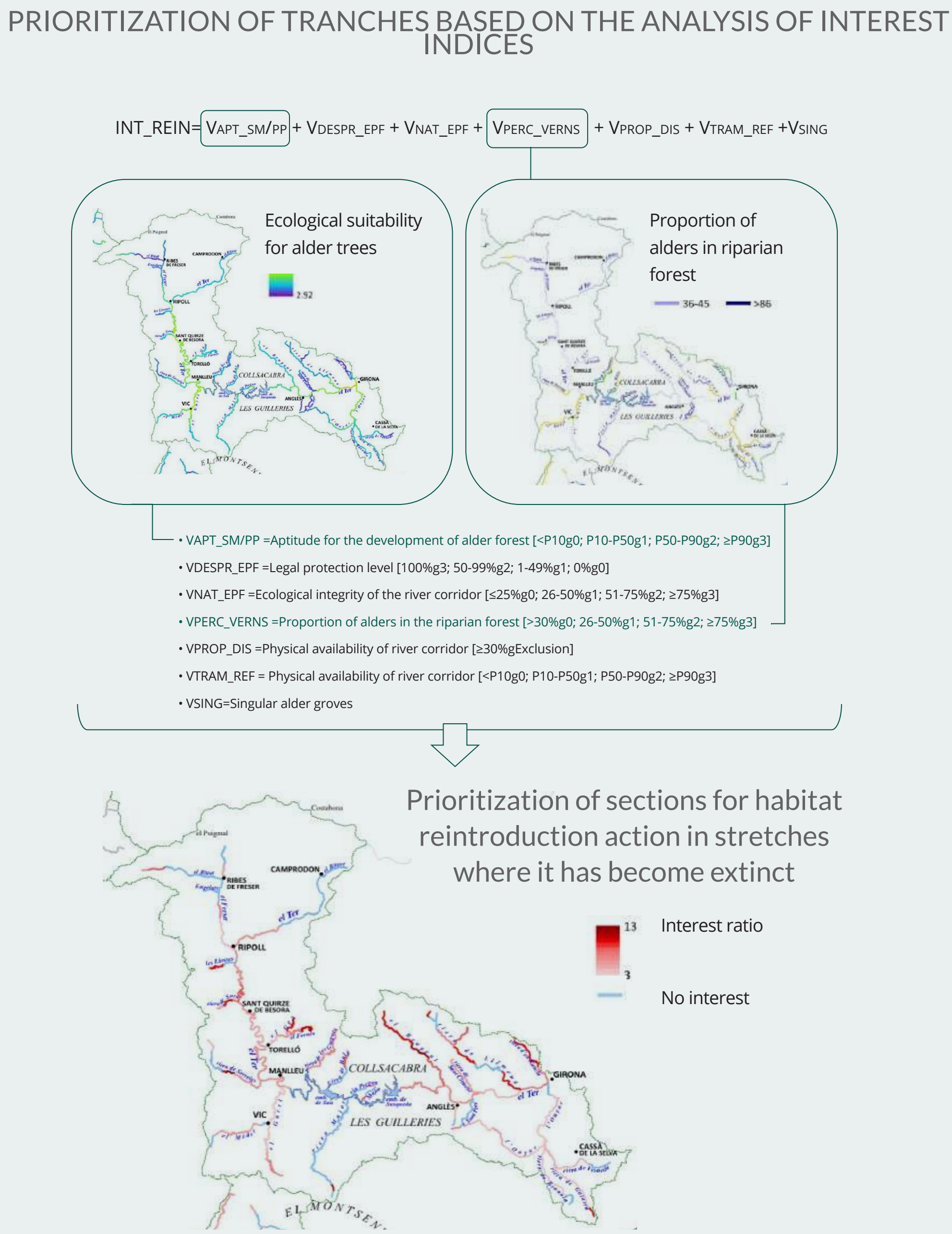


Figure 14 /

The spatial design of the intervention strategies for each of the chapters that make up the *Habitat Restoration and Conservation Plans* has been fed by two complementary models. One of them has been obtained by means of multi-parametric analyses based on ecological characterisation and diagnostic variables. These analyses make it possible to obtain a plotted model of the *strategic interest* of each stretch for each restoration action. The figure shows the process for calculating the *interest index* for the action of *reintroduction of the habitat aimed at restoring the geography (distribution)* of the alluvial alder forests in the Ter river basin. A second model for each action and sub-action has been obtained using the *Marxan* systemic planning software (see Figure 15). Source: MN Conservation Science Consultants, 2020.

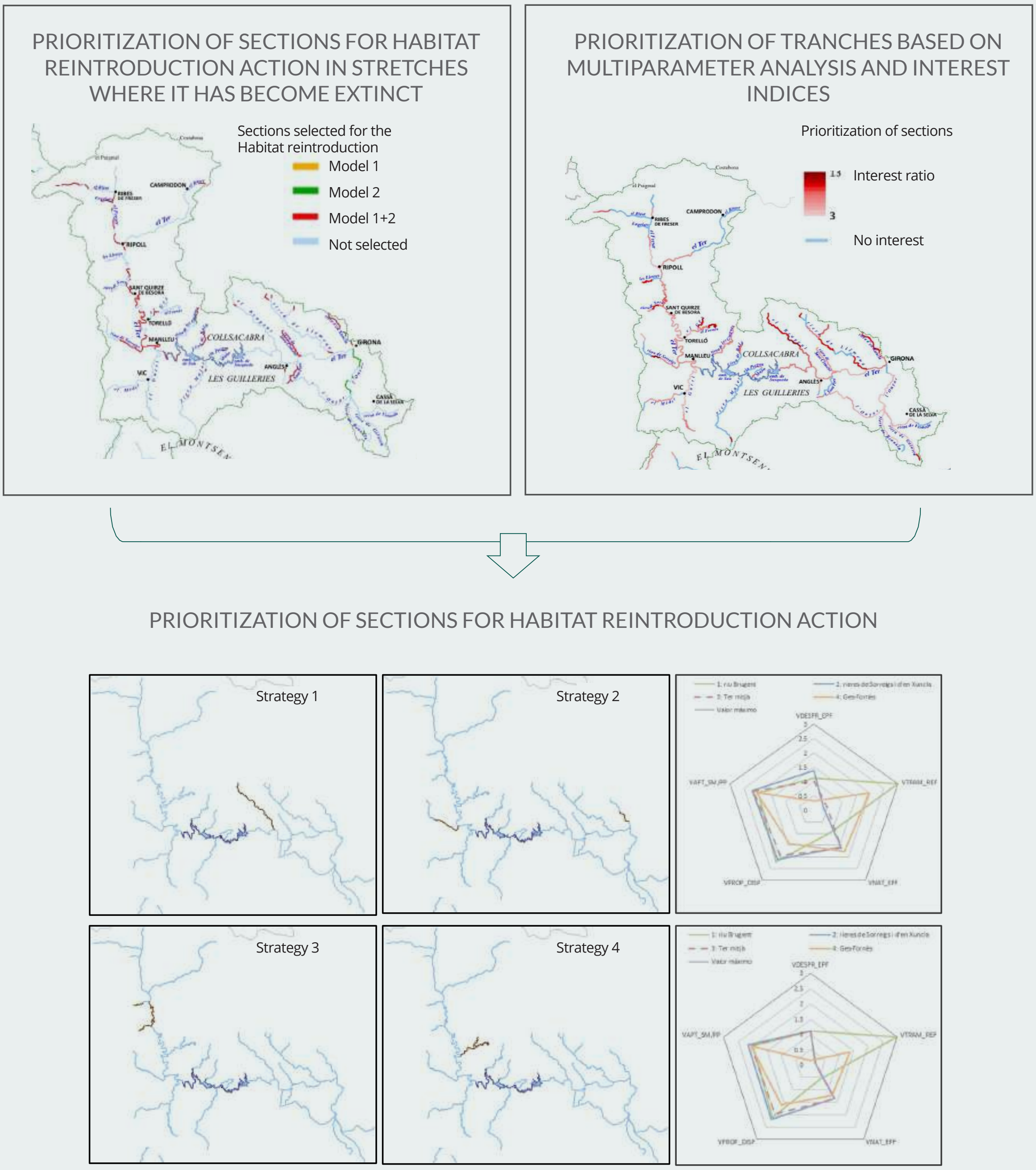


Figure 15 /

Using the two approaches adopted for the design of the spatial strategy for the implementation of each action and sub-action (*Indices of Interest* and *Marxan Software*; see Figure 14), the final selection of the intervention stretches was made. The figure shows the result of this process for the action of *Reintroduction of the habitat aimed at restoring the geography (distribution)* of the alluvial alder forests in the Ter river basin. Source: MN Conservation Science Consultants, 2020.

CONCLUSIONS

1. The *fluvio-riparian meta-ecosystem* (FRE) is the most complex, multifunctional and essential ecological system of each biome. The organic functioning of the entire ecological matrix of each basin depends on it, and vice versa. It constitutes in itself the most heterogenous, biodiverse, dynamic and plastic ecological mosaic of continental landscapes

2. The most serious crisis of biodiversity loss on a planetary scale is taking place in the FRE. This is due to the direct destruction of its heterogeneous ecological mosaic, but also, and above all, to the destructuring of the various functional levels that make this *meta-ecosystem* unique and highly complex.

3. The aforementioned ecological degradation and the resulting biological crisis is not homogeneous along the spatial continuum of the FRE, but rather it is especially severe in its depositional morphodynamic domains; that is, in fluvial terraces systems of the mid-mountain valley bottom, and on the outwash plains and floodplains of the lower alluvial reaches. Alluvial systems have been described as "disproportionately strategic" (*lifelines of the landscape*) and are considered one of the most endangered ecosystems on the planet.

4. The ecological and biological crisis of the FRE is particularly acute in Europe, especially in the Mediterranean basin, encompassing the Iberian Peninsula and the Catalan eco-hydrogeological territory.

5. The conservation of FREs and, in particular, that of their alluvial forests, must be approached through the restitution of all its levels of ecological organisation, the renaturalisation of the dynamics and processes that govern them, and the removal of the hydro-geomorphological or chemical barriers, disconnections and discontinuities that impede the integrity of the *watershed continuum*. It is urgent to reorient river restoration on the basis of the *meta-ecosystems theory*, as well as from a holistic and systemic perspective that considers all levels of organisation of the FRE, including at the network, drainage basin, regional and interregional scales, as well as through passive restoration and by making the most of their ecological plasticity and resilience.

6. Starting from the hypothesis that the failure of European policies for the conservation of alluvial forests is due to their "mosaic-based" or "sample-based" preservation strategy (they only protect and manage "representative samples" of each habitat within the territorial ecological matrix, which is incompatible with the functional logic of the FRE), the *LIFE ALNUS* project proposes the use of *meta-restoration* strategies based on the functional reassembly of the FRE in order to improve the protection and conservation of Mediterranean alluvial alder forests (Mediterranean alluvial alder forests (the 91E0* biotope in *Annex I* of *Directive 92/43/EEC*) by boosting their ecological resilience at a territorial scale.

7. To this end, the *LIFE ALNUS* project has developed and tested multiscale characterisation and diagnosis methodologies (region, drainage basin, fluvial network) in three pilot catchments (Ter, Besòs and Segre). The studies have confirmed the serious crisis affecting the Catalan alluvial system, especially aggravated by climate change and hydrological regulation, and point to the possibility that alluvial forests are on the verge of extinction in Catalonia. The analysis of the distribution and conservation status of the habitat, the *simulation of territorial ecological potential* and the mathematical models of *vulnerability of the habitat to climate change* have been useful for the identification of the *habitat refugia* and the FRE structures most essential for the maintenance of regional and intra-basin resilience. The FRE of the Ter river basin is strategic in terms of regional connectivity, while the upper drainage basin of Segre river contains the best core (refuge) of the habitat and the last "genuine" manifestation of alluvial alder forests on a floodplain of Catalan territory. The main pressures behind the collapse of the 91E0* biotope are the regulation of the hydrological regime and climate change, the incision and staggering of the fluvial profile, the territorial model of occupation of the fluvial area, and silvicultural practices in terms of the management and use of the habitat.

8. *Habitat Restoration and Conservation Plans* (HRCP) for the three pilot watersheds have also been designed and implemented, on an experimental and demonstration basis, adopting the concept of *meta-restoration*, where the drainage basin is the eco-geohydrological management unit, and prioritising measures to boost the resilience of the FRE. Thanks to models of analysis of alternatives and systemic planning, these HRCP have led to the improvement of the Natura 2000 network in Catalonia, and to the defragmentation and restoration of the FRE at different scales

White willow willow (*Salix alba*) in a pond on the river island of the Middle Ter (Illa del Sorral, Masies de Voltregà) / Photo: Jordi Camprodon.

3 /

RIPARIAN FOREST CONSERVATION AND MANAGEMENT

3 / RIPARIAN FOREST CONSERVATION AND MANAGEMENT

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3.1. Riparian forest particularities affecting management

Spontaneous riparian forests are one of the forest systems most impacted by agricultural and extractive activities, the construction of hydraulic infrastructures, or being replaced by productive forest plantations. Riparian vegetation was intensely exploited and replaced mainly during historical periods with a high demand for cultivation areas and wood, especially from the mid-18th century until the mid-20th century. During the last century, riparian areas have continued to deteriorate and break down within the Iberian region, especially in alluvial plains. Riparian areas are moist and extremely fertile lands and, therefore, highly regarded for agriculture and livestock farming, both in large alluvial plains and flat areas along mountain fluvial areas. For this reason, most of the potential width that a natural riparian forest would occupy has been reduced, usually leaving an irregular strip a few metres wide by the side of the river course, where the land's stability and poor access have prevented further damage, and which disappears for dozens or hundreds of linear metres along river sections.

Therefore, outside of profusely planted headwater areas, woody riparian vegetation in alluvial plains is a narrow and fragmented system that runs along the river course between the sheet of water and lands for cultivation, pastures or suburban use. However, in steeper areas or with hydromorphic soils, and also in river islands, riparian structures can grow wider and become stands of a significant size.

The main characteristics of riparian forests that determine their management are the following:

a) Small, narrow and irregular surface areas.

b) Forest structures with scarce mature elements, a substantial proportion of coppice trees and an unusual abundance of invasive alien species.

c) Strong small-scale diversity, especially following a depth gradient of the groundwater table and light availability. As a result, these are often mixed forests, with a wide variety of woody species.

d) Hydromorphic soils, which are often fragile and sandy.

e) Dynamic areas that are exposed to sudden or regular floods, which can cause mechanical damage, hydromorphology changes and increase fertility.

f) Difficult access, especially in headwater areas.

g) High water availability, which accelerates undergrowth and forest growth dynamics and increases the diversity of species. These forests have a lower fire risk than most Mediterranean forests.

h) Legal constraints: EU directives, water legislation, environmental legislation and, often, land regulations, where competences are shared between multiple administrations.

As a result of these constraints, riparian forests often lack planned management. The exception to this rule are some mountain areas, with a greater commitment to forests, where the riparian forest strip is usually treated as an intervention component within forest planning.

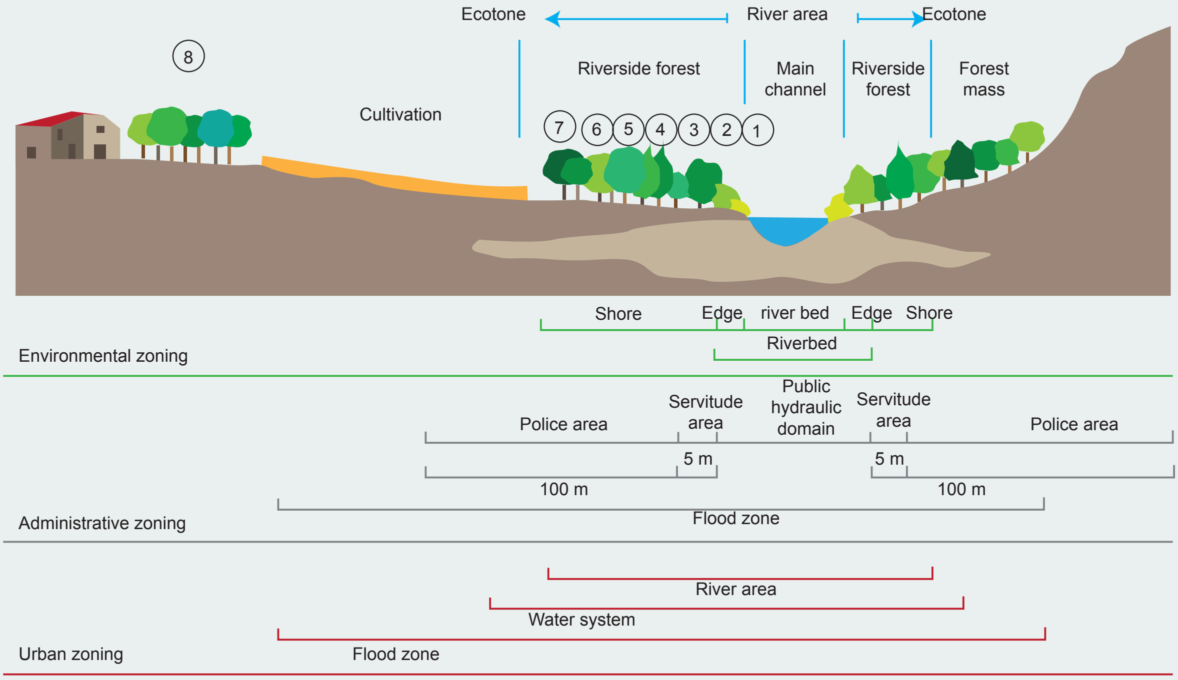

Figure 16 /

Cross sections of the system, space or fluvial area usually used for planning. Adapted from Prat et al., 2008.

Alder grove with regrowth alders en the Segre River. Photo: Jordi Bas.

3.2. Cross-sectional zoning of riparian forests

Despite its intrinsic diversity (both in terms of forest structures and the different river sections), riparian forests can be cross sectioned into zones (that is, in sections perpendicular to the riverbed), following different ecological, administrative and urban models (Figure 16). Zoning following a practical approach designed to enable forest management and the conservation of fluvial areas is presented below:

a) **Riparian Strip (RS)**. This is the strip closest to the riverbed, which predominantly aims to restore and preserve the (structural and functional) ecological integrity of riparian vegetation. The potential width and complexity of the RS in a certain section are proportional to the watercourse flow. Ideally, the RS should occupy the entire Potential Fluvial Area (PFA); if it is narrower, the habitat is regarded as deteriorated and restoration actions should be considered. The minimum recommended RS width would be the Public Water Domain (PWD, Figure 17), with a suggested lateral extension depending on the width of the PWD itself, and in any case never less than the existing riparian forest width. It can also approach the minimum RS width it occupies based on the bankfull method (Camprodon et al., 2012). It corresponds to the bank's sharp change in incline (bankfull) which is usually defined by the outer edge of the most recurring floods (recurrence period: 10 years), with the addition of a predetermined width (Figure 17). The chapter dedicated to forest management in riparian areas in the fluvial area restoration and ecological management manual named *Restauració fluvial i gestió ecològica* (Camprodon et al., 2012) suggests different cases demarcating the minimum width of the RS. The restoration and conservation of the RS will enable compliance with European directives (see section 3.6).

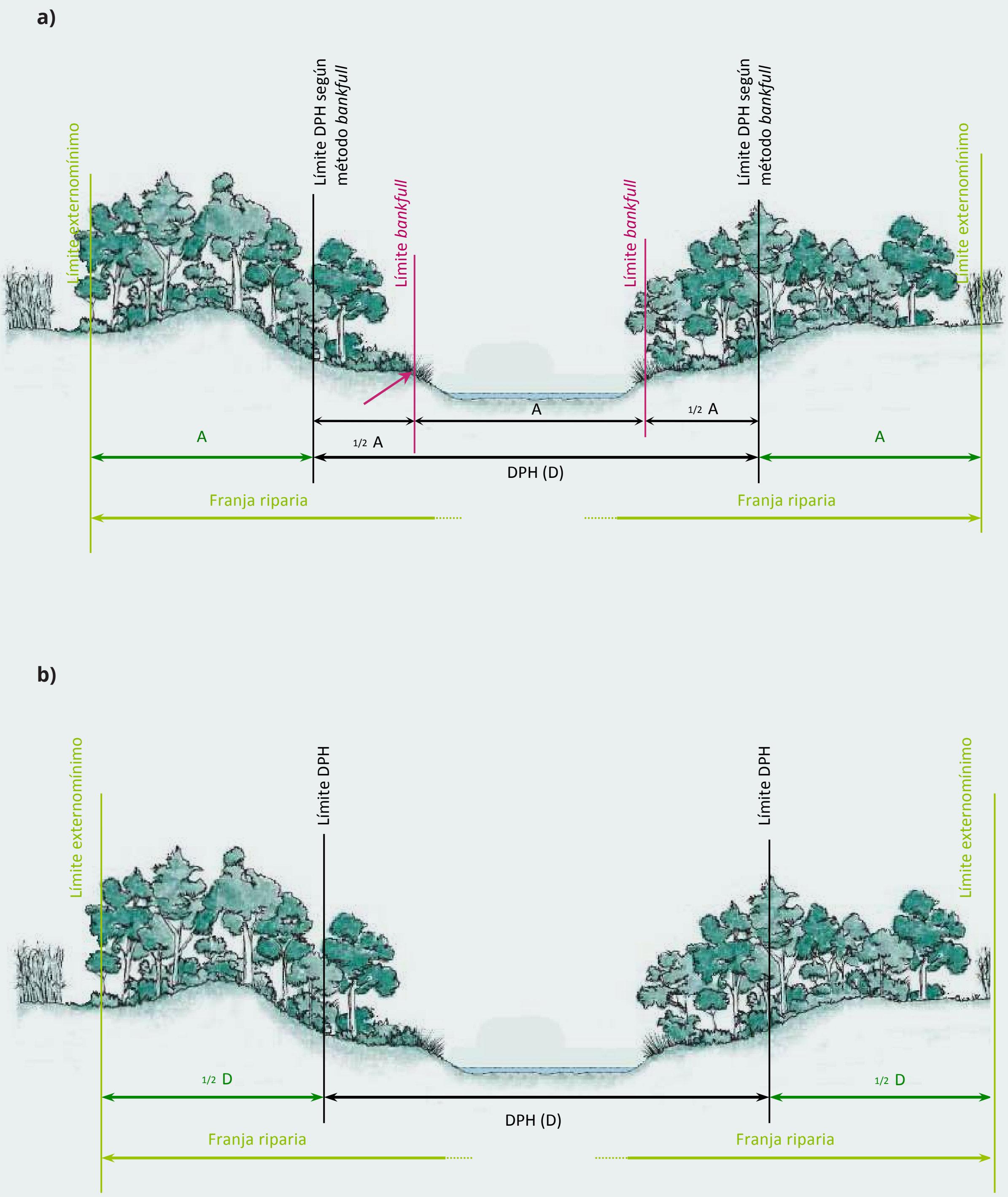

Figure 17 /

Example of the minimum riparian strip demarcation of a bankfull river measuring 2 to 10 m wide, by sections where: a) the PWD limit is known, b) the PWD limit is unknown. RS = (bankfull limit + ½ A) + A. Bankfull limit = outer edge of the waterway where the slope ends. A = bankfull width. In the second case, the suggested PWD limit is merely an approximation. Source: Camprodon et al., 2012.

Within the RS, we distinguish between:

- **First line or Protective Riparian Strip (PRS)**. Area in contact with the watercourse or permanently influenced by the groundwater table. River islands are also included in this category. The most characteristic structures of this line are reed swamps and wetlands, and tree species include alder, white willow, and other smaller Salicaceae; white poplar and, often, black poplar. The main purpose of this line is conservation, and it is also of particular interest to scientific activities. Interventions should be limited to one-time actions that resolve situations that would aggravate the area's natural progression: trees that compromise infrastructures or paths, treatment of exotic invasive species, etc. The vegetation in this area is particularly relevant to the fluvial ecosystem, physically protecting banks (mechanically retaining soil), the flora and fauna associated to the riverbank-water ecotone (algae, birds, fish, mammals, amphibians) and regulating the light and water temperature; therefore, maintaining and promoting the integrity and stability of vegetation in this area is essential.

- **Second line or Multifunctional Riparian Strip (MRS)**. Vegetation that is highly influenced by the groundwater table but separated from the riverbed by the PRS. The most prevalent species include, as well as black poplar and alder, other vegetation associated to riparian areas, such as elm, ash and, depending on the area, other species that only occupy riparian areas such as the common hazel, box elder, nettle tree, field maple, aspen, or walnut tree. This area has a multifunctional purpose and may include interventions that generate financial returns (use of timber resources, especially high-quality wood) compatible with the area's conservation values, even leaving some areas or sections to naturally evolve or under strict protection, as in the case of Natural Fluvial Reservoirs, provided by the Spanish Water Law. This situation can occur in alluvial forests with a high degree of maturity and naturalness or with biodiversity elements of particular interest, like populations of endangered species of flora and/or fauna.

The boundary between these two lines is often vague and it cannot be strictly standardised according to species, distance to riverbed or return periods of flooding. Both must be demarcated on-site by technical staff, taking into account the structure, dynamics, and purpose of each river section and the existing vegetation.

b) Forest structures at the edge of the Riparian Strip:

- **Wooded structures attached to the riparian strip**. A more or less naturalised structure with vegetation that can include typical riparian forest vegetation as well as other species not strictly connected to this ecosystem. Again, the boundary between these structures and the MRS can be subjective. This area has a multifunctional purpose, although the constraints imposed by the riparian influence are less noticeable than in the MRS.

- **Commercial tree plantations**. These plantations are regular, even aged, and often pure or monoclonal, with a productive purpose. These systems are usually implemented in areas that used to be used for agriculture or arid extraction, and enable the wooded strip to be widened, creating more distance between the agricultural border and the watercourse. Nevertheless, these plantations do not cover the same biological functions as a well-structured riparian forest due to their simplicity (a single homogenous layer in a regular layout), regular tilling of the soil (during the first years) to keep it free from weeds, and its use for clear felling in short rotations (12-18 years). Despite these limitations, over time, these plantations can share some characteristics with well-structured riparian forests: an adult tree layer and certain colonisation by flora elements (basically undergrowth) and fauna (especially associated to the tree layer) typical of natural riparian areas. Section 3.4.5 includes some suggestions to enable the naturalisation and multifunctionality of these areas.

This zoning represents a usage and purpose gradient, prioritising the conservation values in natural values the closer we get to the riverbed, the productivity aspects in areas further away from it, and the multifunctionality (conservation and production) of intermediate areas. Current legislation allows these purposes to be adjusted, according to the characteristics of each section, their ownership, existing and potential natural values or the socio-economic context of the area (Figure 18).

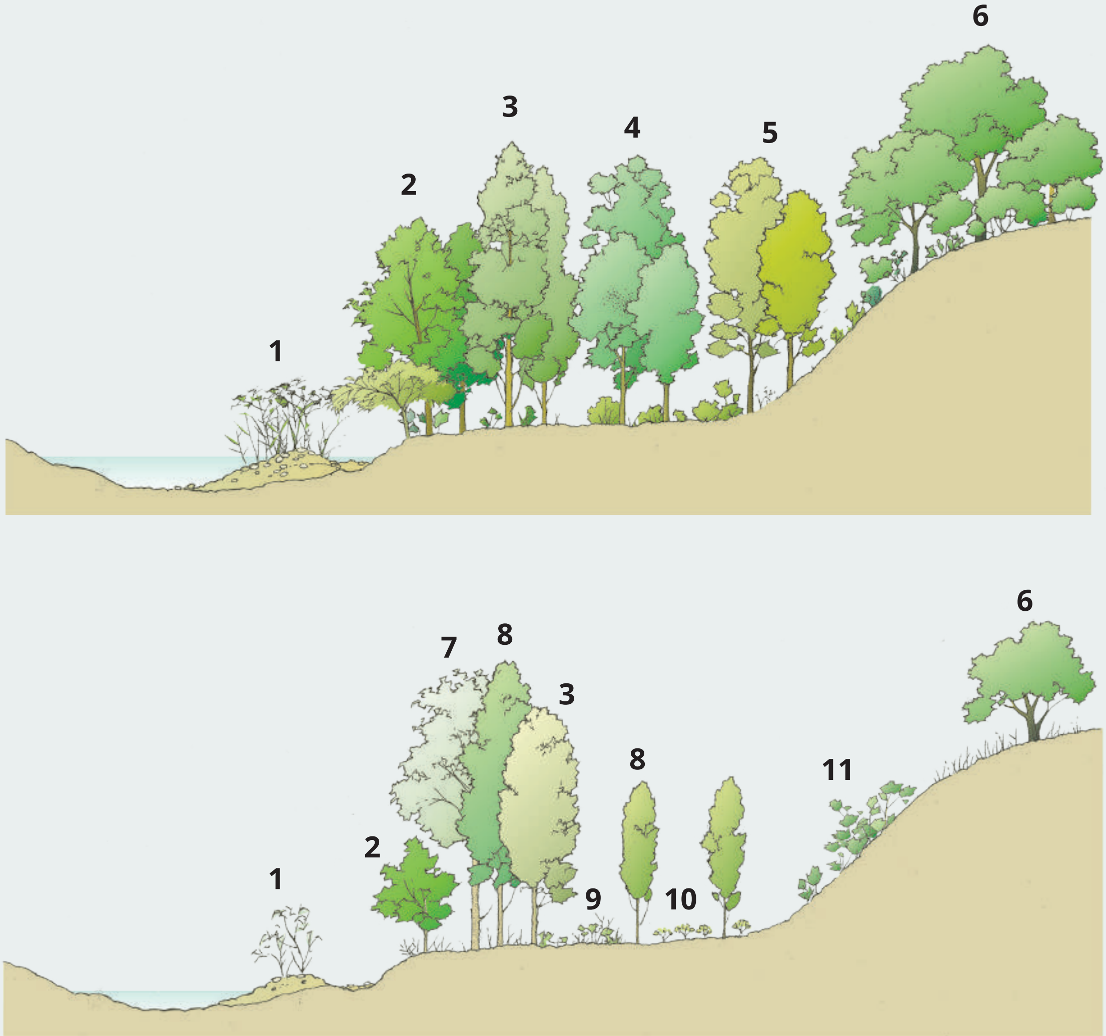

Figure 18 /

Different profiles of riparian vegetation. Top: potential riparian forest in a Mediterranean river typical of the northwestern Mediterranean Region, the middle and upper course of the Ter river. Bottom: example of anthropized riparian vegetation due to farming and forest uses and a lack of stream flow. The ideal riparian strip (RS) would be the top case at the most, and an intermediate situation between both extremes at the least. Legend: 1) willow grove of *Salix elaeagnos*, 2) alder grove with *Alnus glutinosa* and *Salix purpurea*, 3) willow grove of *Salix alba*, 4) elm grove of *Ulmus minor*, 5) ash grove of *Fraxinus excelsior* or *F. angustifolia*, 6) oak wood of *Quercus pubescens*, 7) subspontaneous *Populus deltoides* and *Platanus x hispanica*, 8) black poplar plantation with bramble undergrowth, 9) subspontaneous invasive woody species *Robinia pseudoacacia* and *Ailanthus altissima*, 10) pastures and crops with oaks. Illustration: Pere Rovira.

The following sections include forest management proposals, treatments and techniques that can be applied to the riparian forest, adjusted according to this zoning.

3.3. Riparian forest management: a multifunctional approach for complex ecosystems

Sustainable forest management is defined as "the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions (Figure 19), at local, national, and global levels, and that does not cause damage to other ecosystems" (MCPFE, 1993). Sustainable forest management is based on the **multifunctionality** of forest systems to simultaneously supply a wide range of ecosystem services.

The sustainable forest management phases are the following (Figure 20):

a) **Diagnosis**: collecting all the information required to characterise the environment: climate, soil, vegetation, current and potential natural values, factors or agents of change, hydromorphology processes and dynamics.

b) **Zoning**: identifying areas with similar characteristics. In the case of riparian forest zoning, the criteria described in section 3.2 must be taken into account.

c) Assigning **management objectives** for each identified zone: according to their characteristics and purpose, specific goals for each area are established.

d) Defining the required **interventions** to achieve the objectives established in each identified zone. Section 3.4 describes the main forestry interventions that can be contemplated in riparian forests.

All this information must be included in a Forest Management Plan (FMP), and implemented following technical conditions adapted to the particularities of each area. Section 3.5 includes practical examples of forest management applied to a riparian forest, in several demonstrative stands of the LIFE ALNUS project.

Thus, multifunctionality can be achieved at forest management level, simultaneously responding to multiple demands (conservation, bioeconomy, landscaping and recreational aspects) although specific objectives can be prioritised or coordinated in each identified zone. For example, a specific riparian forest section can seek to maintain and promote biodiversity indicators, its protective functions and, at the same time, achieve financially sustainable interventions. Specific treatments to achieve these global objectives would vary widely according to the forest area: allowing its natural progression, promoting large trees, girdling some trees to create dead wood, removing invasive alien species, applying thinning to reduce competition and promote the development of trees of commercial or conservation interest, plantations to restore or enrich degraded areas, etc.

Figure 19 /

Alluvial alder forest flooded partially. Segre river, Prullans, La Cerdanya county. Photo: Jordi Bas.

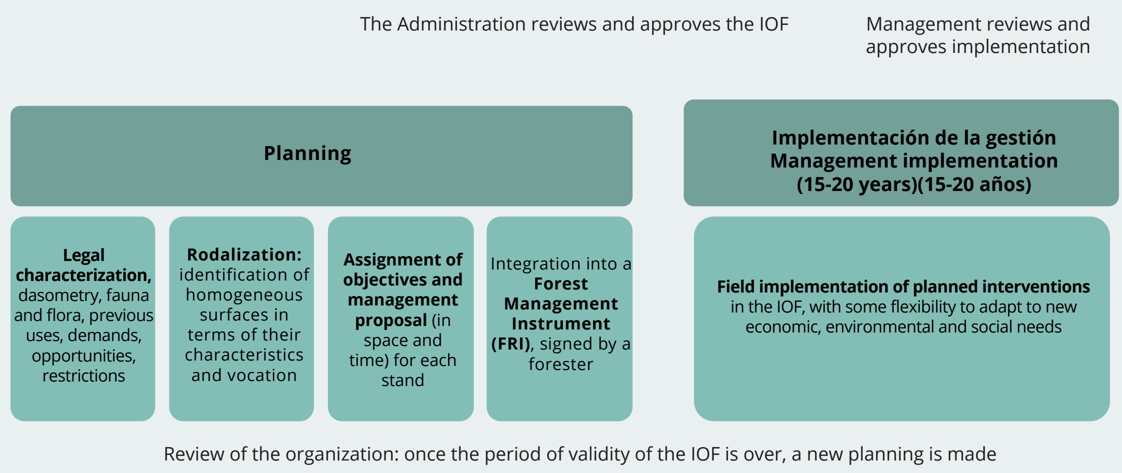

Figure 20 /

Forest management procedure. Adapted from Coello et al., 2021.

So, riparian forests can be appropriately harvested while maintaining their biological and ecological functions, in accordance with European directives (Habitats, Birds and Water Framework Directives), state and autonomic regulations, detailed in section 3.6. With this frame of reference, the following sections suggest a series of recommendations to restore and preserve ecological processes, which can be integrated into riparian forest management and that also allow us to:

a) Preserve, recover and restore a strip of riparian vegetation to ensure the functionality of ecological processes and associated biodiversity, while promoting all the ecosystem services of the aquatic and riparian environment. Protecting flora and fauna species means maintaining viable populations, so that the activities implemented are compatible with the conservation of these populations. Special attention must be paid to protecting and promoting the quality of critical areas (for example, breeding colonies, Figure 21), especially in the case of endangered species. Species with broad living domains and structural requirements, such as otters, adapt to the changing dynamics of riparian areas and, therefore, can tolerate certain changes to the space and time of tree structures. However, small changes to the riparian forest structure can cause the disappearance of critical areas for other flora and fauna species: for example, trees that are home to heron breeding colonies or that have cavities with bat colonies. Additionally, changes to the wooded structure in the contact area between the riverbank and the riverbed (mesic habitats) can alter the soil and shading of the riverbed, having a severe impact on aquatic (growth of algae, macroinvertebrates, fish) and semi-aquatic communities that feed on the river and take shelter on the riverbank, such as the Pyrenean desman, the Mediterranean water shrew and the Southwestern water vole. In these cases, declaring strict forest reserves is recommended, even if they are not large.

b) Use forest products, a renewable resource with many uses (timber for bioenergy, construction, packaging or furniture; mushrooms, pastures, and other non-timber resources) which makes the bioeconomy of rural areas more dynamic and reduces the dependence on imported and/or non-renewable raw materials. This use may make the set of management measures, including conservation measures, financially sustainable.

c) Consistently integrate and manage the many uses and demands within these and adjacent areas: agricultural use, farming, infrastructures, leisure and educational activities, etc.

Figure 21 /

Black-crowned night-heron (*Nycticorax nycticorax*) transporting material to make the nest placed in an alder grove in the river Ter, Osona county. Photo: Jordi Bas.

The riparian forest is part of the fluvial system. Interventions on the riverbank affect the fluvial dynamics and reciprocally. Sediment extraction activities must be completely excluded from the fluvial system. Actions in the riparian forest must take into account geomorphological, hydrological, fluvial ecology and species biology criteria.

The general principle that should rule any treatment action on riparian vegetation is that the system cannot lose any attributes of its ecology status or the ecosystem services it provides.

3. 4. Forest management actions

This section includes a general description of the main actions that should be considered when planning and implementing sustainable and multifunctional riparian forest management. Section 3.5 includes specific and quantitative examples applying these principles and recommendations to demonstrative stands of the LIFE ALNUS project.

To guide the decision and prioritise the actions to be taken, it is useful to rely on indexes assessing the status of riparian forest structures, especially the Riparian Forest Quality Index (QBR, Munné et al. 2003). These indexes will allow us to identify which elements are altering the quality of the ecosystem to a greater extent, and which ones restoration actions should focus on.

A premise for forest planning and any action, whether involved in the restoration of fluvial areas, forest multifunctional management or preparing for natural dynamics, must include prior (expert or comprehensive) inventories, careful planning and stand mapping of actions, marking the trees that will be intervened and the planting areas, and a follow-up and evaluation of these actions and the impact on bioindicators. Evaluating these actions allows us to carry out adaptive management, enabling us to apply corrections to future interventions. Working with operators who are accustomed to working in riparian forests is the best way to ensure that works are executed efficiently and to a high standard.

Figure 22 /

Selective thinning of alien species (*Robina pseudoacacia* and *Ailanthus altissima*) in a mixed riparian forest on the Ter River in Osona county. Photo: Jordi Camprodon.

3.4.1. Forest improvement actions

Forest improvement actions aim to increase the vitality and stability of riparian forests, to gradually turn them into structures that improve the provision of ecosystem services: biodiversity indicators, products of interest to the bioeconomy, landscape and conservation values, etc. The main actions contemplated are:

Thinning

Thinning consists of reducing the tree density, to regulate competition and increase the vitality and growth of the remaining trees. Thinning should be applied following individual tree selection criteria, marking the trees that should be kept and/or trees to be felled, according to the current and potential role of each tree. Thinning should be applied in conjunction with interventions removing exotic species (see Chapter 4), among which the ailanthus (*Ailanthus altissima*), black locust (*Robinia pseudoacacia*), box elder (*Acer negundo*), weeping willow (*Salix babylonica*), sweet acacia (*Acacia farnesiana*), mulberry (*Morus sp.*), wild olive (*Eleagnus angustifolia*) or hybrid plane (*Platanus x hispanica*) are noteworthy (Figure 22).

In the case of very dense and underdeveloped stands and/or of artificial origin planted in rows, thinning is usually applied systematically, that is, following predetermined criteria (e.g., one row out of every three; one road 2 m wide every 8 m) without paying attention to the characteristics of each tree, to cut costs or maintain a regular layout. The intensity of thinning is a key decision, which depends on the vegetation's development and the site's purpose and productivity.

Thinning is an investment that does not usually generate benefits or pay for itself, except for highly stocked stands with good accessibility.

Figure 23 /

Thinning in a white willow (*Salix alba*) grove. Photo: Jordi Camprodon.

Turning coppice into high forest

Species with strong sprouting capacity, which are the most common in riparian forests, respond to felling, mechanical damage or being eaten by herbivores by sprouting from stumps or roots. Forests where sprouting trees are strongly predominant, especially those that result from repeated felling and are then abandoned for decades, usually have genetic impoverishment issues, since a small number of individuals can occupy a significant area and their high density hinders the trees' fruit-bearing and sexual regeneration capacity (Figure 23). Additionally, if stumps are old, they can have low levels of vitality and health and stability problems. For example, alder sprouts decline after 25-30 years due to stump exhaustion, whereas seed-origin alders can live up to 100 or 130 years (Claessens et al., 2010).

To turn these forests that were traditionally regenerated through vegetative mechanisms (coppice) into sexually regenerating forests (high forest) sprout selection is essential. This equates to thinning applied to each stump, that is, some sprouts are removed to encourage the vitality of the remaining sprouts, also called "standards". Just like with regular thinning, the most interesting (current or potential) standards from an ecological (presence of microhabitats, stability, large size, high fruit-bearing capacity) and commercial (straight and upright, in good shape, healthy) point of view should be encouraged. The global effect on the forest is, like with regular thinning, progressively reducing the density, so that the sprouts that have been respected can extend their crowns and increase their seed production, which will encourage the stand's sexual regeneration, as detailed in section 3.4.2.

The intensity of sprout selection must be adapted according to the species and the individual and collective stability and vitality of the sprouts: older sprouts that are less vital, with underdeveloped crowns, are less reactive and the most vulnerable to falling due to the mechanical effect of the wind or a flood (Figure 24). Therefore, in these cases, a gentler selection should be performed than in the case of young, flexible and vigorous stumps and sprouts. In the case of stumps with crowded and unstable sprouts, where any intervention would jeopardise the remaining sprouts, consider two alternatives: completely removing all sprouts, to allow the sunlight to come in and promote the sexual regeneration of nearby trees (or the possibility of selecting future sprouts more safely), or not intervening, to avoid destabilising the stump and allow it to continue its role within the system.

We must take into account that the reproductive strategy of riparian forest species is largely based on vegetative reproduction. Therefore, more than turning the whole area into high forest, we are interested in increasing the proportion of sexual regeneration and, therefore, the gene flow. Conversion treatments, mainly sprout selection, also result in an improved forest structure, more mature physiognomy, and increased vitality and resistance to drought phenomena. Therefore, as a transitional phase or as a long-term plan, the goal is seeking a coppice-with-standards structure, where seed trees (with multifunctional interest: conservation, quality wood production, etc.) and coppice trees (of particular interest for firewood and woodturning production) coexist.

Figure 24 /

Stump sprouts in an alder grove. Photo: Jordi Bas.

Undergrowth clearing

Clearing the undergrowth layer (small shrubs and trees and vines) is done to enable movement through the stand, promote viability and natural regeneration, reduce competition for the soil's water and reduce vulnerability to fires, although these last two criteria are not usually a priority in riparian forests. Clearing the undergrowth is a costly intervention that can have a damaging impact on biodiversity and the soil, so it must be defined following technical criteria and preferably applied:

- Selectively: without affecting the protected vegetation (Figure 25) and maintaining all the species present as much as possible (except those identified as invasive exotic species to be removed) and especially those connected to the riparian environment (reed swamps and wetlands, hygrophilous grasslands and *Vitex agnus-castus* formations), rare species, those that generate better trophic resources, substrate to hide nests, microhabitats and/or shelter capacity for fauna. In the case of areas that are vulnerable to forest fires, special attention must be paid to ladder fuel, that is, the undergrowth that creates vertical continuity between surface fuel and the bottom of the tree crowns. If fire risk is minimal, it should be maintained, as it is a key component of the ecosystem.
- Partially: 30-50% of undergrowth coverage should be respected to maintain its ecological functions, and these values should be higher if this vegetation plays an important role retaining soil (e.g.: undergrowth in contact with the riverbed) in the case of partially submerged individuals. Again, this recommendation should be adjusted in the case of interventions eliminating exotic invasive species.

One way of making it more cost-efficient would be to partially clear the undergrowth organised according to roads and/or glades, that is, clearing up interconnected surface areas that encourage access and regeneration but leaving a large part of the undergrowth intact.

Figure 25 /

Selective undergrowth clearing. Photo: Jordi Camprodon.

3.4.2. Regeneration actions

These interventions seek to make sexual forest renewal viable. Depending on the area, financial sustainability may also be sought to be able to continue applying the set of forest management measures (including diagnosis, planning, or conservation and improvement actions) or, in the case of productive plantations, generating the profitability that motivated the planting. There is a wide range of riparian forest regeneration methods, applied depending on species temperament and sprouting capacity, some of which are included below.

Clear felling and planting

This intervention, applied to productive plantations, consists of completely felling the plantation, followed by treating the stumps (physically, chemically or biologically) to prevent them from sprouting, and is completed with artificial regeneration through planting. This intervention seeks maximum profitability while complying with regulations and trying to create the most suitable conditions to start a new planting cycle.

This felling is performed mainly on plantations from the *Populus* or, less typically, *Platanus* genus. In the first case, they are usually clonal plantations (a single vegetatively multiplied individual) with hybrid material, the result of crossing two American species or an American and a European species. Choosing the clone well is essential, making sure that it is well adapted to the soil (texture, salinity, pH), frost risk and has access to the groundwater table. The desired product is high-quality timber for rotary-cut veneer, which is used to make lightweight and resistant plywood pieces, to make packaging, boards and furniture parts. The most common rotations range between 12 and 16 years, with distances of between 5 and 7 m between trees (Figure 26). To supply the high water requirements of these species, they can be planted as a sett 4-5 m long so that it has access to the groundwater table from the moment they are planted, or shorter setts that depend on irrigation; the future of this second option seems increasingly less viable given the context of climate change. Main maintenance interventions include pruning (whose frequency depends mainly on the clone) and managing spontaneous vegetation.

Other less common planting models include:

- Short rotation plantations for biomass production: planted at extremely high density (10,000–20,000 trees/ha), coppiced every 2-3 years with adapted agricultural machinery, with the aforementioned species or others from the *Salix* genus.

- Buffer strips and bioremediation: planting fast-growing species, at high or very high density, sometimes complemented with perennial grass vegetation, whose main purpose is to reduce excess nutrient load or potentially polluting products right over a river course. The goal is for vegetation to act as a filter to preserve the quality of the water while achieving a neutral or positive economic balance. As well as the aforementioned species, birch is also commonly used for this purpose.

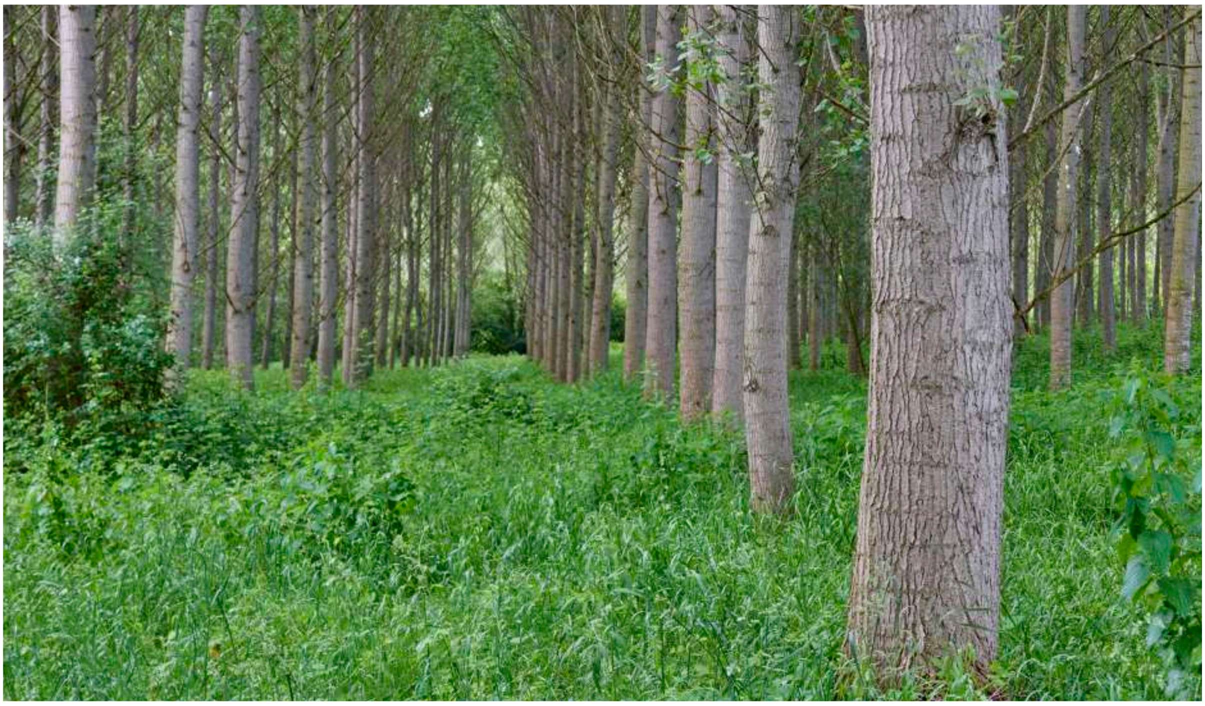

Figure 26 /

Adult black poplar grove. Photo: Jordi Bas.

Strip or group clear-cut natural regeneration

This action is a variant of the previous, so the conditions for its application would be similar to the previous case. It consists of completely felling small surface areas, in rounded, irregular or strip-shaped groups. This intervention seeks to find a balance between focusing the felling impact on small areas and performing an inexpensive action that simplifies felling and timber extraction. Unlike the previous case, it seeks to create light conditions within the felled surface area that enable the forest's natural regeneration, without the need for planting.

The position, shape and size of the groups are adapted to the site (minimising the visual impact when possible) and the temperament of the species, that is, the light intensity they need during their first years of life. Soil erosion should be avoided, as well as very visible felling in highly frequented areas (roads, inhabited areas).

Shelterwood cutting (result: even-aged stand)

This intervention is applied when we want to regenerate a high forest stand. It consists of progressively felling the adult layer, applying 2-3 density reduction interventions, during which the tree stand is left to sexually regenerate. The length of the regeneration phase can vary between 10 and 20 years, according to the species and the felling and regeneration rate, and results in an even-aged stand. Like in the previous case, felling can be organised into groups or strips. This type of intervention enables certain canopy coverage to be maintained at all times (trees of different sizes, mixed individually or in groups) which can adapt to multiple situations. The most common phases are:

- Preparatory cutting (optional): thinning applied when a stand is very densely populated and crowns are underdeveloped; it seeks to expand these to increase the stability of remaining trees and their fruit-bearing capacity.

- Seed cutting: thinning in favour of the most interesting trees to regenerate the stand (well formed, developed crowns, diverse species) which will be the seed source.

- Final/removal cutting: once regeneration has been consolidated, and before it lignifies, most or all the residual adult trees are felled.

Selection system (result: uneven-aged stand)

Selection system is a combination of thinning and regenerative felling applied simultaneously and periodically (every 10-25 years, depending on the species, the intensity of the intervention and site productivity), which results in a mixture of sizes and ages (figure 27). This mixture can occur homogeneously in the forest (uneven-aged stand tree by tree) or in groups of trees (in the case of riparian forests, small sizes are recommended, up to 1,000 m^2, figure 28). This system results in complex structures (large diversity of ecological conditions within the stand and, therefore, more capacity to host biodiversity), continuous coverage of the soil and continuous revenue, since trees of commercial interest can be extracted in every intervention.

Figure 27 /

Competition is regulated in riparian forests by felling the exotic species that compete with the woody species native to the riparian community. Photo: Jordi Camprodon.

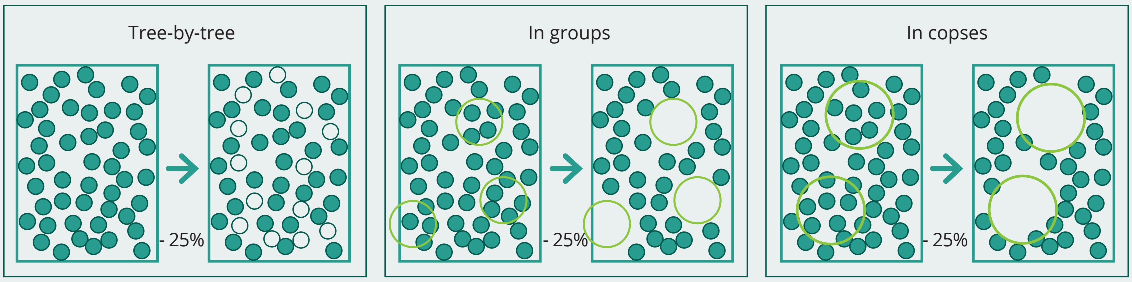

Figure 28 /

Distribution diagram of tree-by-tree selection system (left), in groups (centre) and small copses (right), which in total do not surpass 75% of the canopy cover. Image: Pol Guardis.

3.4.3. Close-to-nature forest management: an approach to integrate improvement, regeneration and restoration with efficient resource use

Close-to-nature forest management (also called Pro Silva) is an approach that seeks to use natural dynamics that are favourable to management to reduce costs and maximise the return of ecosystem services, including biodiversity and the generation of valuable timber. This prioritises efficiency and detailed application, that is, it pays attention to the current and potential (ecological and commercial) role of each tree within the ecosystem. It is based on thinning or selection felling defined at tree or small group level. Other improvement interventions can also be included, such as sprout selection, clearing the undergrowth, pruning, etc.

Close-to-nature management adapt well to the particularities of riparian forest management. It is based on four main principles (adapted from Pro Silva, 2012):

a) Conservation of the ecosystem: to ensure the persistence and integrity of the ecosystem's processes and elements.

b) Protection: to guarantee the forest's protective role for the soil, water, air, nutrient cycles and landscape, avoiding high-intensity interventions.

c) Production: to promote the forest's role as a source of renewable raw materials, seeking the financial sustainability of its use and associated bioeconomy.

d) Forest recreation, amenity and cultural aspects: to promote the forest's role as recreational areas, inspiration and cultural bonds.

At a practical level, the management principles that encourage close-to-nature silviculture include:

a) Seeking management efficiency, using natural processes to reduce costs: allowing an intense competition phase in young areas of the stand to enable natural pruning and more vigorous trees to distinguish themselves; maintaining moderate lateral shading to avoid the appearance of epicormic shoots on adult trees if a goal is to make high-quality timber; maintaining a shaded microclimate that limits the development of undergrowth, etc.

b) Maintaining continuous cover, with low-intensity and highly selective interventions.

c) Promoting mixed stands: to maintain all present species, paying particular attention to endemic and scarce ones.

d) Promoting uneven-aged structures, with continuous sexual regeneration.

e) Maintaining maturity indicators, such as dead wood in different sizes and formats, large trees with microhabitats, not altering rock formations or bodies of water, etc.

f) Promoting individual and collective vitality and stability.

g) Promoting high added value forest products to encourage the financial sustainability of management.

h) Maintaining areas within the forest reserved for strict conservation (natural dynamics) or public use (educational and informative itineraries).

The application of these principles at tree level is called "single-tree silviculture" (Mori & Pelleri, 2014) and is usually defined by assigning trees to three possible categories (Figure 29):

- Future crop tree: to be actively promoted due to its (current or potential) commercial or ecological interest. In the first case, these are well formed trees (straight and upright, without obvious defects) from species that produce high-value wood which would only be felled following technological criteria (when their permanence in the forest will no longer increase their commercial value). The second case would include living trees with interesting microhabitats, large trees, from scarce species or fruit-bearing trees for fauna, which can be kept standing indefinitely. Depending on the stand's development condition, 100-250 future crop trees can be identified per hectare.
- Competitor tree to be removed: these trees hinder the lateral expansion of the future crop tree crown. Removing these competitors will help maintain the vitality and growth of future crop trees. Competing trees are not always the ones whose trunks are located closest to a future crop tree, but rather are trees of a similar size to it, and competition occurs mainly at crown level. One to three competing trees should be removed in each intervention; this number will be smaller the more unstable the future crop tree is (underdeveloped crown) and the higher its susceptibility to generate epicormic shoots.
- Trees to be maintained: other trees can be left standing, unless felling may be interesting for financial reasons (profitable felling), logistics (opening up hauling roads, enabling other works), inducing regeneration, etc. In any case, a "forest microclimate" must be maintained in most of the forest. Additionally, future crop trees aimed at producing high-quality wood should be surrounded by neighbouring trees that do not compete at crown level, since this lateral trunk shading prevents the appearance of epicormic shoots that could reduce the quality of the wood.

In short, close-to-nature silviculture enables us to respond to the particularities and potentialities of such a particularly complex ecosystem as the riparian forest, in all its zoning. Nonetheless, this approach requires broad technical knowledge to bring it on-site, and marking each intervention is essential.

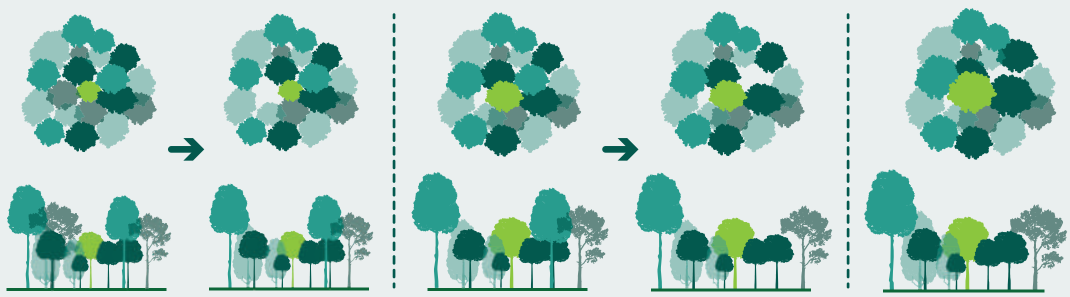

Figure 29 /

Example of the application of single-tree silviculture over time, with the progressive release of a future crop tree (orange). The blue dashed lines represent a time lapse between two consecutive interventions. Adapted from Mori & Pelleri (2014).

General management recommendations for forest actions

First line or Protective Riparian Strip (PRS)

The purpose of the PRS is conservation. It is preferably used for natural progression, and non-intervention and passive restoration will be prioritised.

- Active management will only be applied when fully justified. Encouraging or accelerating natural dynamics and restoration will be limited to help transition areas towards natural dynamics. A high tree cover (or canopy cover) is required, ideally above 75%. Large scope actions can be considered, like hydromorphology or forest restoration if large expanses of exotic invasive vegetation are eradicated. One-time actions are also contemplated, such as the removal of trees that put infrastructures and paths in danger.

Second line or Multifunctional Riparian Strip (MRS) and forest structures attached to the riparian strip

MRS and forest structures attached to the riparian strip have a multifunctional purpose and can include interventions that generate financial returns that are compatible with the area's conservation values.

- Prioritising close-to-nature silviculture or uneven-aged stands is recommended, with a minimum canopy cover of 70% in the MRS and 60% in the forest attached to it to protect the soil and preserve the forest microclimate and structure. If the initial cover is below these figures, improvement and restoration measures must be taken to meet them.
- Clear felling is not recommended for different reasons: a) the tree cover disappears regularly and maturity is never achieved; b) risk of soil erosion, especially when there is no undergrowth cover; c) the biodiversity associated to the tree layer disappears, which cannot be recovered until the woodland has considerably grown; d) a drastic change in the tree cover of areas where protected and endangered riparian and aquatic fauna breed and seek shelter can lead to their disappearance; e) strong light can cause bramble patches, nettles or alien species to proliferate, which hinder the regeneration of indigenous woody species; f) insolation can cause the water temperature to rise (harmful to fish) and algae and macrophytes to proliferate, more evidently during low flows.
- It is important to avoid felling trees with microhabitats, especially rarer ones: all trees with natural cavities, hollowed out by woodpeckers or by any other agent, will be respected; as well as trees where birds of prey or birds from the crow family nest (when the leaves fall, they can be easily distinguished, so keep this in mind for marking). During felling, removal or girdling alien trees that compete with indigenous ones will be prioritised.
- No interventions will be carried out in riparian sections where colonies of herons, cormorants and other protected species gather (in trees or on natural walls). They are usually very localised and occupy small areas, which makes them more vulnerable, but also makes management easier. Establish a safety perimeter without interventions (approximately 100 m around colonies): it must both shield the colony from frequent works and allow it to expand to neighbouring trees.
- At least ten thick trees (average diameter above 35 cm) per linear kilometre and riverbank side must be preserved, even if they present signs of decrepitude. If there are many candidates to be maintained, those located on steep slopes, near the water course and/or with poor accessibility should be prioritised. Large seed-origin trees tend to be more resistant to pounding floods than coppice trees of a similar size.
- It is preferable to turn coppices into high forests or coppice-with-standards, which combine different-aged seed trees with coppice trees. We must not forget that stump or root sprouting is an adaptive strategy of riparian trees, which are greatly exposed to natural disturbances. In density-reducing interventions (thinning and sprout selection) cover density of at least 70% should be kept after the polewood phase.
- It is best to avoid full undergrowth clearing. Selective and partial clearing is best in any case, to have

minimum impact on the diversity of woody species, associated animals and soil protection.

- Damaging, compacting or increasing the risk of soil erosion by using heavy machinery or during logging should be avoided. Paths should not be opened up along the riparian forest or crossing the riverbed. In general, works should avoid impacting the riverbed and bodies of water (ponds, swamps, marshes, wetlands, fountains, etc.), except in the case of restoration actions, like knocking down large trees in the riverbed to create mesic habitats. Apply biosecurity measures to prevent fauna and flora from spreading emerging and infectious diseases. In this regard, see the protocols established by Life Tritó del Montseny (Fernàndez et al., 2020).
- After felling, debris should preferably be shredded and spread to reincorporate nutrients into the soil. Trunks and stumps should not be uprooted to avoid damaging the soil. Keep large amounts of crown debris (leaves, branches) from falling in the riverbed. This is particularly important in the case of alien conifer needles or hybrid plane leaves which have slow decomposition rates. If they accumulate in large quantities, they can cause anoxia or lower pH levels (Vayreda & Comas, 2022). This alters the trophic system, reducing productivity and taxonomic diversity.
- Leave naturally fallen dead wood as microhabitat, both from indigenous and naturalised species (macro-debris). Woodland debris with a diameter of 15 cm or more is very important for biodiversity, as a microhabitat for fungi, plants and invertebrates and as substrate for food, nesting and shelter for several species of vertebrate fauna. Keeping felled trees perpendicularly inside the riverbed creates sediment traps and mesic habitats for aquatic communities. These trees can be stabilised by fastening their trunks to stumps of living trees. Occasionally, fallen trees that are susceptible to moving due to flooding can be fastened with cords, tapes or chains, but this is not highly recommended since these are artificial elements.
- Fallen trees must only be removed in the case of massive felling (due to strong one-time disturbances). Trees that have fallen across paths, urban, peri-urban and urbanised areas, where there are human infrastructures and settlements, can be removed (or cut to length), especially water courses that are sensitive to flood risks and with nearby hydraulic infrastructures (bridges, for example) to ensure the riverbed’s drainage.
- In the case of dead trees that are still standing and are used by different species for nesting and shelter, at least 10 trees/ha with an average diameter of at least 20 cm will be kept.
- Alder regeneration may be consolidated through small glades (1-1.5 times the height of dominant trees in diameter). Action should be taken during a good alder seed production year, especially after a flooding episode that has eliminated undergrowth competition. This same flooding may have caused some trees to fall and naturally opened up glades that favour regeneration. Glades can be occupied by nitrophilous species, such as brambles *(Rubus ulmifolius*, *R. caesius*), whose clearing could benefit the regeneration of alder and other riparian species. Nevertheless, brambles and other undergrowth species are structural elements of riparian areas, they protect from soil erosion and provide shelter and food to riparian animals (Figure 30).
- Quality pruning could be applied for high-quality wood production if the branches to be removed are thinner than 4 cm in diameter at their base (6 cm in the case of oaks) or if they stem from trunk sections measuring less than 12 cm in diameter.

In those sections classified as highly torrential areas, forest management objectives will focus primarily on soil and riverbank protection, especially favouring species that are particularly good at securing riverbanks, such as shrub-sized indigenous willows (*Salix atrocinerea, Salix elaeagnos, Salix purpurea*, among others). These sections have a torrentiality index (Qci/Qn ratio) equal to or greater than 250.

Reference documents for riparian forest management

Productive plantation management is described in detail in several publications, among which the following are particularly noteworthy: Tusell & Mundet 2008 and Rueda et al. 2019. Another featured publication are the proposals for good practices in black poplar groves in alluvial plains, black poplar groves in headwaters and mountain regions and hybrid plane plantations and plantations of other non-riparian species in fluvial settings: Camprodon et al. 2012.

The ORGEST (*Orientacions de Gestió Forestal Sostenible* [Guidelines for Sustainable Forest Management]) handbook series identify the main forest typologies in Catalonia, and suggest a series of silvicultural models for each of them depending on multiple objectives, with quantified improvement and regeneration intervention proposals. One of the ORGEST handbooks most related to riparian forests is the one detailing management models for common ash, birch, common aspen and common hazel forests.

In recent years, two close-to-nature management handbooks have been published in our context: Coello et al. 2022 (focused on sub-humid Mediterranean conditions) and Beltrán et al. 2020 (focused on Pyrenean conditions).

The good forest practices handbook in fluvial areas within the scope of the Montseny Natural Park (Vayreda & Comas 2022) offers further information on forest structural elements (dead wood, microhabitats, etc.) and good practices in riparian forests.

To identify dendro-microhabitats in temperate forests, there are manuals or diagrams, such as the guide by Bütler et al. 2020.

The Directives for managing the Natura 2000 network areas in Catalonia (Agreement GOV/112/2006), include directives for habitats associated to continental waters.

Figure 30 /

Small glade in an alder grove colonised by brambles. Montseny Natural Park. Photo: Jordi Camprodon.

3.4.4. Actions focused on restoring natural dynamics

These measures seek to restore or promote natural dynamics that encourage ecological processes.

Selection of areas under natural dynamics

The purpose of allocating a stand to natural dynamics involves letting ecological processes follow their own progression, without human intervention. The hydromorphology dynamic (groundwater availability altered by floods and droughts) will be the driving factor that determines the riparian forest's progression towards advanced silvogenetic cycle phases (maturity and senescence) and its renewal (decline and regeneration). Natural fluvial reservoirs would be framed within this management modality. These areas are of great scientific and educational interest, in terms of understanding ecosystem functions and natural processes (Figure 31).

A forest can be devoted to natural dynamics for different reasons: because it has a high degree of naturalness, acts as an effective shelter area for biodiversity and/or because the natural processes that lead it towards higher maturity states can be achieved without further human intervention (Europarc-España, 2020). In any case, it should be periodically assessed in case one-time measures to reinforce these processes are needed.

Figure 31 /

Riparian forest under natural dynamics. Its uneven-aged structure, with seed and coppice trees, is the result of the fluvial dynamics. Photo: Jordi Camprodon.

Areas transitioning towards natural dynamics

In areas that are clearly focused on conservation, transitional interventions towards natural dynamics may be necessary to achieve it in the short term. The type and intensity of these actions must be suited to the forest's initial condition. This approach will primarily be applied to stands that appropriately move towards maturity and that show a high degree of naturalness, but with scarce structural diversity, which makes them not very resilient to changing factors.

Stands with a strong direct (or indirect, like a high density of exotic species) human footprint would not be a priority, since they require several interventions and plenty of time to move towards phases of greater maturity and diversity.

Management recommendations for restoring natural dynamics and processes

The main interventions that should be considered in this sense include:

- Promoting the presence of large trees with interesting microhabitats. To do this, some trees that hinder the lateral expansion of the most interesting tree's crown must be removed, following the principles of single-tree tree silviculture (section 3.5.3).
- Increasing the amount of intermediate (20-40 cm in diameter) and large-sized (above 40 cm in diameter) dead wood stumps standing or on the ground, at different states of decomposition. For this, trees can be chosen (the aforementioned competitors, for example) for girdling, felling or cutting leaving a tall stump. Dead trees should not be cut or removed, except if they are dangerous to people or infrastructures (Figure 32).
- Encouraging well-established copses of advanced regeneration by opening up glades, at a size adapted to the temperament of the present species, to promote horizontal diversity. Small glades can also be opened up occasionally to contribute to horizontal diversity and induce regeneration.
- Encouraging the vertical diversity of vegetation and diameter classes, removing trees of the most abundant sizes, to encourage regeneration and promote indigenous and scarce tree species over exotic or abundant species.
- Strengthening seed trees and selecting young sprouts to increase their vigour, fruit-bearing capacity and growth in diameter.
- Maintaining or generating enough cover and diversity in the shrub and lianoid layer.
- Eliminating exotic species, especially those with invasive temperament.

The handbook *Bosques maduros mediterráneos: características y criterios de gestión en áreas protegidas* [Mature Mediterranean forests: management criteria and characteristics in protected areas] (Atauri, 2020) is a good reference for defining mature forests and actions to promote natural dynamics.

Figure 32 /

Trees laying on the riverbed of the Cànoves stream (Besòs basin). The aim is to create a sediment trap that becomes a mesic habitat for aquatic communities. Photo: Jordi Camprodon.

Forest restoration

Active forest restoration seeks to recover (in open areas) or diversify (in areas with forest cover that needs to be enriched or encroached) vegetation, mainly in the form of planting (woody species) or sowing (grasses). This measure should be applied when the objectives are not expected to be met spontaneously within a reasonable timeframe. Restoration includes a series of phases:

- Diagnosis of the site and goal setting: assessment of climate, soil and past and present usage, zoning of the area to be restored based on the restoration's objectives and technical and economic capacities.
- Restoration design: for each identified zone, the right plant material must be chosen (species – preferably various, with strong functional and structural diversity; provenance – preferably local; sapling or stake format, age and size), soil preparation techniques (sub-soiling, tree pit dimensions and technique, micro-basins, etc.) and planting techniques (soil conditioners, mulching, protection against herbivores), density and species layout. All these decisions must be taken as a whole and taking into account the required maintenance entailed. In general, the most cost-efficient way is planting in groups, prioritising the most favourable micro-sites.
- Document with technical execution conditions, follow-up and tending plan.
- Implementation, follow-up and tending according to the plan.

Passive restoration is an alternative or complement to active restoration and consists of taking benefit of the highly dynamic fluvial systems through the seed bank and propagules transported by the river. The main measure of passive restoration consists of recovering fluvial dynamics, for example, removing cross-sectional and lengthways barriers from the river. The second consists of creating glades where sediment traps (logs fastened perpendicularly to the riverbed) are created to ease the installation of the seed bank and propagules transported by the river.

Passive restoration is cheaper than planting and avoids the risk of losing the investment made in the case of extraordinary droughts or floods during the first years after planting. Its main disadvantage is the unpredictability of the final result, especially if we want to diversify the habitat with certain species, achieve a given tree density, avoid predatory damage or meet a certain goal within an established timeframe.

Figure 33 /

Plant production for the LIFE ALNUS in the nursery of Forestal Catalana, in Breda. Saplings were obtained of alder seed (like those in the image), European ash tree, narrow-leafed ash, poplar, elder, and common dogwood, among others. Also, white willow, purple willow, bitter willow and grey willow produced from stake. The seeds and stem cutting were collected in the same basin, from trees and bushes close to where the restoration projects were carried out. The aims were to preserve genetic variability and, at the same time, to achieve a best plant adaptation / Photo: Jordi Camprodon.

Management recommendations for the restoration of fluvial areas

- If active restoration is the chosen management option, alternatives must be analysed in depth to choose the most efficient option. This is not so obvious if we take into account the complexity of changing factors that interact: hydromorphology dynamics in conjunction with the vegetation structure, droughts, floods, permeable barriers or that do not affect the groundwater or superficial stream flows, etc.
- Bioengineering actions must be fully justified. For example, stabilising slopes or vegetation on the riverbank with terraces or other techniques should be considered only if there are objectives that take precedence over the fluvial dynamic: natural elements to be preserved, such as large body debris; populations of endangered species that could disappear from the river section if left to their own dynamic; public uses regulation, etc.
- Planting should be done with seeds and/or stakes collected from the same or nearby stands from the same river course or basin; or, at least, from the same region of origin. Protecting the saplings or stakes with shelters or fences to keep herbivores away may be necessary (Figure 33). These will be removed once the plantation is established and tall enough to escape herbivores.
- Planting in a concentrated and densified manner in more favourable locations for each species or set of species may be more effective. For example, planting riparian shrub species, such as box elder or common dogwood, in areas with low tree and/or shrub coverage, may provide premature protection and shade to the undergrowth, protecting the soil from erosion and avoid exotic invasive species proliferation.
- The Society for Ecological Restoration has published the “International Principles & Standards for the Practice of Ecological Restoration” (Gann et al., 2019), which should help to guide and promote forest restorations, especially in complex areas such as the riparian forest

Maintenance and fostering connectivity

Riparian forests, especially in alluvial plains, are often fragmented, distributed in small stands that are often disconnected, with simplified structures under multiple anthropogenic pressures. Restoring the connection between fragments restores the riparian continuum, which maximises multiple forest functions, including the conservation of geomorphological and hydrological processes and biodiversity conservation. At the same time, they act as biological corridors for flora and fauna.a.

3.4.5. Forest management and climate change adaptation

Rising temperatures and changes in the frequency and intensity of rainfall and extreme phenomena (storms and floods) are a current challenge to riparian forest management in the Mediterranean. Processes of alder decline are becoming obvious at several headwater areas (for example, at the Ter and Besòs basins), which can be connected to recurring droughts that have caused a reduction in stream flows (Valor et al., 2020). This effect is worsened by higher evapotranspiration due to an increase in forest growing stock in headwater areas since the mid-20th century, as a result of agricultural, livestock and forestry activities being abandoned. So, climate change and land use changes can lead tree populations to regress or disappear at the borders of their distribution area. This is the case of the alder in Mediterranean headwater areas, while the community reorganises with new species associations (Thom et al., 2017).

Forest management for climate change adaptation is based on increasing resistance (tolerance) and resilience (capacity of recovery after being affected) to disturbances. A key measure is encouraging the ecosystem's complexity (Gross et al., 2014; Dănescu et al., 2018; Gustafsson et al., 2019).

The measures to implement are silvicultural interventions regulating density (thinning, sprout selection, clearing the undergrowth) and forest restoration (for example, through enrichment planting).

Management recommendations for climate change adaptation

- Promoting forests rich in species, with a diverse range of functional traits: tree and shrub species with different temperaments, vital and reproductive strategies.
- At the same time, maintaining certain redundancy (several species with similar behaviours, e.g. common ash and narrow-leaved ash); Figure 34. Communities with a greater redundancy of functional traits will be more capable of adapting to climate stress factors. These traits include, among others, tree height, wood density and structure, specific foliar area, resprouting capacity, bark thickness and root depth (Vayreda & Comas 2022).
- Regulating the competition.
- Encouraging structural diversity, with trees at different vital stages. This involves creating small discontinuities to encourage sexual regeneration and also avoid excessive forest capitalisation, that is, a high proportion of large trees across the entire area.
- Preserving a "dark and humid" forest microclimate, avoiding interventions that involve a drastic increase in the canopy and soil's exposure to sunlight and wind. Furthermore, the soil (which tends to have a coarse texture in riparian areas) can lose significant moisture and trees can become unstable, both physically (risk of falling) and physiologically (sudden increase in transpiration).
- Promoting trees that show a higher tolerance to different disturbances (drought, wind, floods...): take note of vigour, stability, health condition, crown density and development, origin (prioritise high forest trees over coppice trees) or those occurring in particularly favourable microhabitats (Valor et al., 2020). Maintain a certain proportion of senescent trees with signs of weakness or that are physically more exposed, even though they are more vulnerable to disturbances (Bennett et al., 2015; Lutz et al., 2018).

These principles can become contradictory when applied on-site, for example, how to promote species that have entered a period of decline such as the case of alders in many headwater areas. In this case, we must find a balance between maintaining all present species and at the same time favour (existing trees or through planting) those that show greater future viability, which can involve progressively modifying the relative proportion of species. In this ecosystem, we must keep in mind that the area occupied by trees in decline (e.g., alder) could become occupied by invasive alien species if active measures to encourage alternative species (e.g., ash, willow) are not taken.

Figure 34 /

Mixed forest with different tree species in a riparian forest in the Ter basin. Photo: Jordi Bas.

Management recommendations for managing alien and invasive species

Chapter 4 specifically delves into treatment methods for alien species in riparian areas. Below is a summary of those guidelines.

- When treating exotic species, we must prioritise eliminating those with a higher capacity for seed or vegetative proliferation (invasive character) such as reeds, black locust, ailanthus and box elder. In the case of individual non-invasive and established exotic species, such as hybrid plane, hybrid poplar, walnut tree and chestnut tree, we can consider keeping them if they play a noteworthy ecological role: large size (creating microhabitats), shading the riverbed or protecting the riverbank.
- When planning where to intervene when treating invasive species, LIFE ALNUS has prioritised actions in riparian forest stands with incipient invasive competition. It would not be efficient to act on stands where the habitat is mainly occupied by invasive species. In this last case, if the open area left after removing exotic species is not subsequently restored with fast-growing indigenous species (for example, Salicaceae and Betulaceae families), it will be easily recolonised by these, through sprouting from the stump or the root, through the seedbank or seeding from untreated neighbouring trees.
- When treating invasive species in a stand, a buffer area must be established to reduce the arrival of propagules from neighbouring individuals or populations. As a guideline, a treatment distance that is twice the dominant height of the outermost trees in the action area can be established.

3.4.6. Wood debris and flood management

Previous sections have shown how forest management can increase the individual and collective stability of riparian forests against several disturbances, including flooding. This disturbance has become even more relevant recently in Catalonia, with episodes in 2018 and 2020 (Storms “Leslie” and “Gloria”), which has brought to light that the fluvial dynamic, conditioned by degraded, abandoned or unstructured riparian environments, can generate significant volumes of displaced and accumulated wood debris (Figures 35 and 36). This debris can damage people and infrastructures, but also contribute to enriching the fluvial ecosystem. Therefore, it is important to rationally manage the debris generated by flooding, following technical and scientific criteria, and thus reduce risks to infrastructures without endangering natural values, especially in habitats of common interest and in protected areas.

In any case, it is the agreement between environmental and water management administrations, with the participation of experts in hydrology, hydraulics, hydrogeomorphology, fluvial ecology and conservation biology, which must resolve particularly complex or controversial cases.

Figure 35 /

White willows (*Salix alba*) with large root balls blown down by Storm Leslie, in October 2018 by the Ter river. They had grown for 40 years since the last extraordinary flood, in 1980. Their high slenderness coefficient (very tall and thin trees, due to high density), coppice origin, proximity to the riverbed and an alluvial substrate dominated by pebbles encouraged tree falling. Photo: Jordi Camprodon.

Figure 36 /

Large seed-origin white willow (*Salix alba*) close to a main river branch on the Ter river. It withstood the Storm Leslie flood, in October 2018. Photo: Jordi Camprodon.

Managing the complex structure of riparian forest ecosystems requires distinguishing between live wood and dead wood (Table 1).

Live wood

Live wood (Opperman et al., 2008) includes all types of living woody plant material on the riverbank and/or waterway: standing and fallen trees and shrubs that are still rooted and alive. It particularly affects the hydromorphology dynamic in the case of trees within the riverbed that are able to continue living with flood patterns. It increases the system's complexity, performing significant hydromorphology functions beyond the most obvious ecological functions. Live wood, in the form of trees with sprouting capacity, will be decisive when there are sexual regeneration problems.

From the perspective of fluvial dynamics, the distinguishing traits of live wood are its stability and persistence within the environment, its structural complexity, hydraulic roughness and sediment retention capacity.

Dead wood

Dead wood elements (roots, stumps, trunks, branches) grant the riverbed and riverbanks more stability the heavier and longer they are, especially if they have complicated shapes (stem with branches) and if they are gathered together in clusters (Figure 36 and 37). Therefore, a common intervention such as cutting to length the trees cut in silvicultural actions reduces stability.

We must also keep in mind that, if the river floods, accumulated vegetation (live, dead or both) retains solids and suspended and floating particles. This is a noteworthy aspect regarding solids, since skidding and transportation are the main source of problems with infrastructures (e.g. bridges). This explains why the more complex the riparian forest is, the less likely it is for dead wood to move downstream.

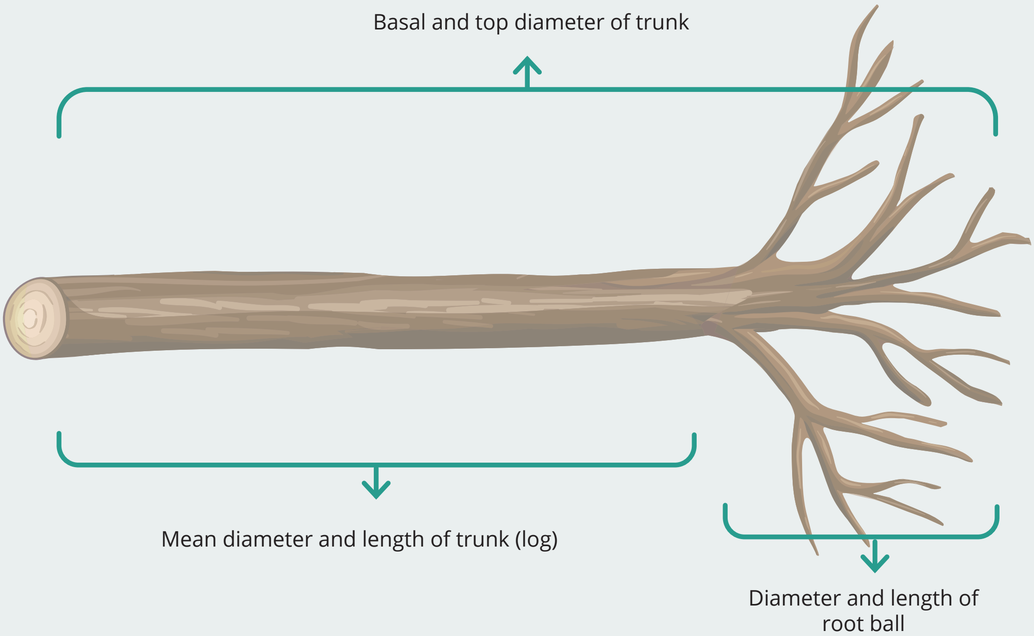

Figure 37 /

Basic measurements of dead wood. Its proximity to the waterway, orientation and anchoring to live wood or the soil are variables that must be taken into account to estimate the likelihood of it moving. Illustration: Pol Guardis.

Regarding wood debris, mainly large wood, coarse bodies, branches and dead wood, it has been proven that, most of the time, wood remains stable in the waterway and can be potentially dangerous to infrastructures only during exceptional high-magnitude floods (Mao et al., 2013). The challenge lies in maintaining fluvial areas in balance in terms of ecology and hydromorphology, while potential risks are analysed and managed (Ruiz-Villanueva et al., 2014).

Large wood (LW) interacts with sediments in the river course and influences the life of riparian vegetation by improving habitat diversity, like interior waterways and flooded pits, for example. It enables them to be maintained for longer, especially during low flows. The wood's influence on stream flow resistance and the geomorphology of streams and river waterways creates more diverse hydraulic mosaics, not just in the waterway, but also between the waterway and the aquifer (due to higher infiltration). Therefore, it increases the diversity and ecological complexity of the waterway morphology (Gooseff et al., 2007; Wohl et al., 2016).

Large undercut stumps are particularly important, as well as logjams which help to cause diverse hydraulic mosaics, due to the variable flow speed around them (Figures 37 and 38). They also reduce the surrounding stream flow speed and help increase organic matter particle retention (Beckman & Wohl, 2014).

Figure 38 /

Large black poplar undercut stumps from commercial plantation reused for restoration. Photo: Jordi Camprodon.

Table 1 / **Hydromorphology and ecological functions provided by trees, live wood and dead wood debris. Source: Opperman et al., 2008.**

Functions	Live riparian trees	Dead riparian trees	Live riverbed trees	Dead riverbed trees
Hydraulic roughness	During flooding affecting riparian vegetation	During flooding affecting riparian vegetation	During flow range	During flow range
Waterway morphology	Appearance of pools and banks stabilised by roots	Banks stabilised by roots	Appearance of pools Riverbed diversity Sediment deposit and storage	Appearance of pools Riverbed diversity
Riparian forest regeneration	Sexual and vegetative reproduction		Sexual and vegetative reproduction	
Structure	Vertical structure within the riparian corridor	Vertical structure within the riparian corridor	Appearance of islands that can lead to forest succession (orizontal and vertical) structure of both riverbanks and waterway	Appearance of islands that can lead to forest succession Mainly horizontal structure on the waterway
Habitat	Substrate for invertebrates (especially terrestrial)	Substrate for invertebrates (especially terrestrial)	Substrate for invertebrates (aquatic and terrestrial)	Substrate for invertebrates (aquatic and terrestrial)
Shading	Waterway shading		Waterway shading (can provide similar shade to riparian trees if debris with branches, leaves... is maintained)	Very localised shading
Presence of exotic species	Exotic species competition and removal		Presence of exotic species	

Management recommendations for wood debris from floods

- To maintain the ecology dynamics of fluvial systems and ecosystem functions and optimise resources, wood debris must be left on-site, especially in low-risk areas where large amounts of debris have accumulated (trees that are standing, broken, supported, fallen or undercut). Therefore, systematically cutting to length riverbank or riverbed dead wood is not recommended as a post-flood management measure.
- Any action on riparian areas, whether due to an emergency, to manage the effects of flooding or for maintenance, can remove large dead wood that does not pose obvious risk, as well as large piles of dead wood, although removing or cutting to length fallen trees that are stabilised and integrated (or tend towards this state) into the system should be avoided. Keep in mind that much of the dead wood that is moved during a flood comes from wood debris that has been felled, cut to length and left on the riverbanks.
- Interventions must be technically justified from different perspectives. Not all wood should be removed from the river section, just those pieces that pose a more obvious risk of moving. At the same time, native species (or non-invasive exotic species if they are the only arboreal vegetation) that have resisted previous river floods must be preserved, to laminate floods and provide ecological functions and ecosystem services of riparian vegetation.

3.4.7. Other management interventions and application criteria in riparian forests

Included below are other interventions that can be considered when managing certain sections of riparian forests.

Silvopasture

This involves using herds to take benefit of forest or tree plantation foraging resources (grasses and undergrowth). This enables a multifunctional use of the forest, which can also contribute to reducing shrub biomass, if desirable for fire prevention purposes. These forest foraging resources are not usually enough to properly feed a herd, so grazing inside the forest is usually part of a livestock itinerary that also includes open and more productive areas, rich in grasses. Also, installing auxiliary infrastructures like fences or drinking troughs is often necessary.

Riparian silvopasture must take particular care to avoid excessive loads, especially during periods when the soil is wet, to avoid erosion or compaction issues. Grazing close to the riverbed should also be avoided, to reduce the impact of defecation on water quality, so electric fencing may be required. Occasionally, some strips can be adapted for livestock to access the riverbed, making sure to limit the aforementioned negative impacts (Figure 39).

Figure 39 /

Cows grazing outside of the riparian buffer, kept out by electric fencing. Photo: Jordi Camprodon.

Agroforestry in tree plantations

Agroforestry systems are a deliberate combination of woody vegetation and crops within the same area. This combination enables available resources (water, light, nutrients) to be used more effectively throughout the year and at different soil depths. Riparian tree plantations are areas of great interest to become agroforestry systems, since the alleys between rows of trees can be cropped (a significant area that would otherwise involve undesired maintenance costs) and continuous income can be obtained since the beginning. There are two types of agroforestry systems to be considered in this context:

- Temporary agroforestry system: cultivating the alleys during the first few years, when the trees do not create significant shade.

- Permanent agroforestry system: cultivating the alleys during the trees' entire rotation. In this case, the cultivated species or variety must be adapted to decreasing light conditions between spring and autumn, or the distance between tree rows can be widened to maintain a balance between the total forestry and agricultural production.

Recommendations for silvopasture and agroforestry plantations

- With suitable loads, silvopasture can be of interest to help control the undergrowth in adult plantations and forests attached to riparian formations, to reduce competition over trees and the risk of fire.
- This practice should be avoided in first- and second-line vegetation, as well as in regeneration areas or those with undergrowth species of high natural value.
- Perimetral electric fencing will keep livestock away from the riparian strip. The fencing should be checked periodically to ensure a good maintenance. Troughs can be installed outside of the riparian strip to avoid herds drinking water from the river.
- One agroforestry model would be to plant trees inside (or along the edges of) agricultural or grazing fields along the periphery of the riparian strip. This would reduce the impact of these activities on the water course (nitrate and agrochemical pollution), help to protect the soil (physical retention, soil carbon fixing) and soften the farming-riparian forest ecotone.

Naturalising and diversifying productive plantations

As previously mentioned, productive plantations are mainly used for financial profitability, although they can provide a series of structural and protective functions that are favourable to the riparian forest as a whole, since they work as a windbreaker, nitrate filter and, in general, as a transitional or buffer area between riparian forests and agricultural or urban uses. Therefore, these systems can be of great relevance to the ecology and landscape. Several measures can be implemented to increase the multifunctionality of these areas, with minimal impact on their profitability, as described below.

Management recommendations to naturalise productive plantations

- Maintain some odd (twisted, branched) low value trees standing for two or more rotations. The trees usually used in these plantations are fast-growing, soft wood, with a short lifespan, and create interesting microhabitats such as cavities in a relatively short period of time. These trees can be arranged scattered or, preferably, in small groups.
- Generate dead wood, standing (girdling and as tall stumps) and on the ground, from low value trees, in locations that do not interfere with subsequent soil preparation and replanting tasks, and that do not put infrastructures or paths at risk. After felling, leaving isolated stakes with woodpecker nests standing is not recommended, as they are easily preyed on and can break easily; they should rather be reinforced by a small buffer around them.
- After the felling, shred the branch debris around the area; prioritise the biological stump treatment (inoculating fungi) or shredding using an auger instead of uprooting them.
- Allocate the perimeter of the plantation closest to the riparian forest (3-5 rows) as a transitional or buffer area between both systems, where an alternative planting model can be considered: mixed composition with short- and medium-rotation species (for example, valuable timber producing species, which can be complemented with undergrowth species); use irregular frames and/or minimise soil work.

Naturalising abandoned productive plantations

This situation occurs in adult poplar and hybrid plane plantations that have lost their productive interest, often because of lack of maintenance, especially pruning. Natural vegetation usually regenerates here under the plantation's cover. These systems can turn into diverse and well-structured forests by progressively applying selective thinning in favour of the (spontaneous or introduced through enrichment planting) regeneration of alders, willows, ashes, elms, limes, maples and other species typical of the site. During the first phases of naturalisation, therefore, the dominant vegetation layer will correspond to the original plantation trees, which perform a temporary diversification function within the ecosystem.

Each intervention must be restrained (especially in the parts closest to the riverbed) and must not reduce more than approximately 30% of the basal area at once. Although felled trees will have a lower value than expected when planted, their sale can cover the cost of the intervention. Additionally, the intervention can be used to encourage dead wood, either standing (dead or girdled trees) or on the ground (fallen or felled). The advantage of girdling is that it results in more gradual light coming in.

Figure 40 /

Forest path at the border between the riparian strip and a poplar plantation. Photo: Jordi Camprodon.

Constraints during forest works

As well as complying with regulations regarding procurement, safety, health, and waste management, among others, the particularities of the riparian forest mean that special attention must be paid to prevent potential impacts on the environment during the application of silvicultural interventions, by incorporating good practices in technical specifications, such as:

- Respect the critical breeding period, from the 1st of March to the 30th of July. Additionally, pay attention to the occasional presence of temporary colonies at other times during the year, such as aquatic birds that use riparian vegetation for roosting (cormorants, herons, ducks, etc.).
- Exercise caution to avoid lubricant and fuel spills, and make sure that all machinery used is in good condition and properly maintained. Also, immediately remove all rubbish generated and especially elements that float (bottles, cans, plastic, etc.), due to the risk of them being swept away if the river floods.
- Trees will be felled making sure that they do not fall onto the water course or modify the inner branches and pools that make up the river in flood-prone areas. Nevertheless, you can decide to fell a tree and intentionally leave it on the riverbed to create micro and mesic habitats for aquatic fauna and to retain sediments. Fallen trees can be fastened to thick standing trees to prevent them from being swept away when the riverbed floods. This action is only suitable in headwater areas that are not subject to strong flooding.
- Wood ground skidding should not affect the soil's morphology or temporary water build-ups or rock formations. Also, ground skidding cannot be performed from the other side of the river course, to avoid damaging the aquatic ecosystem.
- Forest access roads should be planned and executed carefully, to ensure efficient logging with the minimum surface area affected, while avoiding damaging the soil and ecosystem: excessive slopes and widths should be avoided and drainage elements must be incorporated (Figure 40). The surface area affected by these roads in the RS and especially within the PRS must be minimised. Additionally, machinery must not go through water courses. If it is inevitable, the most suitable crossing points must be found and prepared (rocky or well-established soil, to avoid damaging the riverbed and affecting the quality of the water) and the number of trips must be reduced to the minimum. A stable or elevated temporary crossing can also be set up, with the appropriate technical and administrative requirements.
- If the soil is mechanically damaged durign logging operations, corrective measures must be implemented to return it to its original state. If it is available in the area, and financially viable, consider animal or skyline logging.
- Once the works have been completed, paths that do not have right of way and forest roads should be closed to motorised traffic.

3.5. Practical examples of riparian forest ecological improvement and restoration

3.5.1. Introduction to practical examples

Below is a selection of four cases of riparian forest management and active restoration that belong to some of the demonstrative actions within LIFE ALNUS.

These practical examples have been designed based on identifying the potential and priority sections considered in the basin conservation plans, according to mapping information (Chapter 2). After reviewing and confirming its interest during an initial verification visit, we proceeded to sign a public or private agreement with the owner (Chapter 10). Actions were agreed on with the owner and, if it was a natural area under special protection, with the managing institution. Next, we proceeded with listing the characteristics in detail, including stand mapping and an expert inventory of the section. After this, we wrote the proposal of actions. This information, collected by CTFC, was conveyed to the project partners in charge of executing it. The Catalan Water Agency bid for the technical project and executive project in the Ter basin. The Granollers Town Council took charge of the projects corresponding to the Besòs basin, with support from other town councils in the basin and the Besòs-Tordera Consortium. Both partners were responsible for technical supervision, with support from CTFC and CERM staff, who were also responsible for ecological follow-up (Chapter 8). Planting was performed with saplings and stakes collected on-site and produced at a plant nursery by the public company Forestal Catalana.

The first three cases described correspond to river sections selected by systematic planning and/or priority indicator models for their representativeness and location within the basin setting, connectivity, vegetation structure (indigenous and exotic cover) and complementary objectives (co-benefits). The fourth case was selected according to expert criterion since it was not included in the models.

3.5.2. Restauración de la continuidad y la calidad ecológica del bosque de ribera en la Riera Major (Sant Sadurní d'Osormort, cuenca del Ter).

Section description

Alder grove in first line riparian strip, with a coppice-with-standards forest structure, with upper canopy of exotic poplars from an old plantation. There is no second line riparian strip and the alder-poplar grove limits with non-riparian forest (oak - holm oak grove) and with conifer plantations and pastures. There is a lack of thick dead wood. In recent years, otters have been regularly spotted in the area.

Specific objectives

- To eradicate the scattered black locust saplings
- To control the only patch of black locust and replant indigenous species in the area's first and second line.
- To re-establish the alder grove in two areas where black locust has been treated.
- To increase the availability of temporary otter shelters.
- To generate dead wood, especially from the poplars.
- To experimentally select alder sprouts through felling and gridling.
- To regulate the competition in favour of alders by selectively thinning or girdling poplars.
- To broaden the width of the second line alder grove, where possible.
- To improve the alder grove's continuity along the stream.

Actions

- In a previous intervention, black locust was eradicated through tree injection treatments by the Natural Areas Consortium of Les Guilleries-Savassona, as part of the river custody agreement with the Catalan Water Agency. Despite the aerial part dying, some trees had the ability to resprout from the root. An experimental treatment was applied by felling and immediately injecting herbicide into the stump.

- The alder grove was reinforced by planting new alders in high density near pre-existing alders, and by creating groundwater-filled ponds and planting alders in the alluvial plain.

- Otter shelters. Holts were built with branches for otters to seek temporary refuge or reproduce. Several section areas had suitable physical and ecological traits to build holts for otters to reproduce in, given that they were inaccessible areas with very little human presence.

- Selection of alder sprouts. They were experimentally treated using two intensities (low and medium thinning intensity) and two techniques (felling and girdling). Post-treatment follow-up of the growth and vital condition of remaining sprouts. The most vigorous, straight and stable sprouts (thick trunk, symmetrical crown) were promoted, as well as those that contained microhabitats. 8-10 stumps with sprouts (the densest ones) were left untreated, to maintain a diversity of structures.

- The low-intensity sprout selection treatment involved removing 25-33% of the sprouts' total basal area. In practical terms, this translated into:

    a. Stumps with homogenous sprouts: one in three sprouts were removed.

    b. Stumps with heterogenous sprouts: one in two sprouts were removed, removing the thinnest of the two.

- Intermediate intensity sprout selection was applied in conditions where sprouts were more stable: smaller sprouts, that were less slender and/or located in areas more exposed to the wind and stream flow fluctuations. In this case, close to 50% of the sprouts' total basal area was removed:

    c. Stumps with homogenous sprouts: one in two sprouts were removed.

    d. Stumps with heterogenous sprouts: two in three sprouts were removed, focusing on removing the thinnest sprouts.

- Exotic poplars competing with alders were cut or girdled, to regulate crown competition in favour of alders and to generate thick dead wood both standing and on the ground. Those that did not entail a risk to infrastructures in case of falling were girdled. A distance of at least 25 m was left between two gridled trees, with a maximum of ten girdled trees per linear kilometre.

Figure 41 /

Alder grove with predominant coppice trees (left). Dominant poplar that competes with alder trees (right). Photo: Naturalea.

3.5.3. Restoring the continuity and ecological quality of the riparian forest at the confluence of the Mèder and Gurri rivers (Santa Eugènia de Berga, Ter basin)

Section description

Mixed riparian forest, with alder, white willow, white poplar, common ash and elm (mixed forest by copses and tree by tree), intermingled with areas with no tree vegetation. Alders, a scarce species along the Mèder and Gurri rivers, appear as scattered trees or forming small clusters. Before the Mèder river flows into the Gurri river, in urban surroundings, it gets thinner due to channelling of the waterway, the lack of indigenous vegetation and the dominance of exotic species, especially black locust. On the left riverbank of the Gurri river there is a steep margin with incision issues, which prevents the development of a riparian forest.

Specific objectives

- To reduce the erosion of the margin of the Mèder river where it runs into the Gurri river and in a medium section of the Gurri, using soil bioengineering techniques. Restoration of the alder grove in these sections.
- To improve the ecological continuity of alders in the most viable areas for the species.
- To reintroduce alders in areas with the most suitable section in the lower part of the Gurri river by planting stakes.
- To launch a pilot test of black locust removal, both in groups and arranged as a linear forest. To replant the area with indigenous riparian species.
- To regulate competition in favour of alders by cutting hybrid planes.

Actions

- The riverbank was stabilised with living bundles to revert the fluvial incision and to generate the conditions for planted alders to root. This one-time action was chosen to make it compatible with low-impact public use of the section (educational activities for disadvantaged collectives organised by the property) and to reintroduce the alder.
- Terracing to modify the riverbank and plantation, to restore the profile in contact with the minimum average stream flows and enable the insertion of the alder grove. This modification creating fluvial pools on the right riverbank of the Mèder river where it flows into the Gurri river generated two different levels from the riverbed, as already exists downstream. Groups of alders were planted in the new riverbank profile.
- Alders were planted as stakes on both riverbanks. The lower part of the Gurri river has a really narrow section, with steep riverbanks. After the small weir in this section of the Gurri, the waterway section has less steep margins and a wider section. Here, alders were planted in flatter micro-sites with better access to the groundwater table.
- The riparian forest was defragmented on both riverbanks, planting high density alders in the first and second line, to provide continuity to isolated individuals. Black locusts were removed, and vegetation was restored. A) First line of the riparian strip: the released area was restored with clusters of alder plantation. B) Second line of riparian strip: black locusts were replaced by planted indigenous species: common ash and elm (for the elm, we used clones resistant to Dutch elm disease). Herbicide was injected, small black locusts (<7 m high) were felled, and sprouts were treated.
- Hybrid planes were selectively thinned to promote alders and generate dead wood (large pieces on the upper river terrace). Felling the hybrid planes that competed more intensely with the alders was a priority, although we avoided cutting down large hybrid planes that provide structure to the riverbank.

Figure 42 /

Riverbank with incision that needs restoration with living bundles and alder plantation (left). Sub-spontaneous hybrid planes that compete with alders (right). Photo: Naturalea.

3.5.4. Restoring the continuity and ecological quality of the riparian forest in the Ter river (Sant Joan de les Abadesses)

Section description

Main section of the Ter river with two distinguishable sectors. Downstream, the sector is conditioned by a weir for hydroelectric exploitation. The weir backwater and river morphology have created humid habitats in floodplains located on the right riverbank that are highly favourable for the development of the riparian forest. Upstream, the reservoir effect is dampened and the river forms small secondary waterways that do not carry water for most of the year. The riparian forest shows quite a regular structure, dominated by adult white willow, with trees over 20 m tall and a lower layer of alder in the first line, in small clusters and as isolated trees. This river section is of good quality for otters and other semi-aquatic vertebrates, such as the polecat, the Mediterranean water shrew and the Southwestern water vole. The area is rarely visited by humans since its public use is regulated.

Specific objectives

- To improve the structure and composition of the riparian forest.
- To unify the first line alder grove.
- To create shelters for otters.
- To improve the alder grove's ecological connectivity in old river branches

Actions

- The structure of the right riverbank was diversified by: a) selection system felling to improve the woodland conservation condition; b) introducing high density alder patches in the most favourable locations.
- Willows with diameters over 25 cm that dominated adult and young alders were weakened through girdling.
- A holt was built with branches coming from the silvicultural interventions to create a temporary shelter for otters. It was built over the level of ordinary flooding. This keeps materials from drifting in the case of a flood and the structure is fastened to the site. It was placed in the area furthest from human traffic, in a location with no riverbank access.
- Interconnected hollows were created to increase the areas in contact with the groundwater table. On the right riverbank, there were old river branches full of sediments. Part of this area was occupied by woody riparian vegetation, although alder was nearly absent. To improve the alder's restoration capacity in the floodplains, the hydromorphology conditions were improved

by excavating three shallow pits (measuring 75 m^3 each) with a low gradient that reach the groundwater table, since it was very superficial. Alder clusters were planted in the pits.

- An alder grove was planted in the first line, alongside a geomorphological intervention (brush and slope grids measuring 2 x 10 m) to improve planting. It was planted on 245 m of the left riverbank at the end of the weir that showed no woody vegetation. The plantation was protected from the cows from neighbouring pastures with electric fencing. The fence maintenance is at the property's expense.

- A riparian forest section measuring 605 linear metres that was relatively mature and heterogenous, with scarce human impact, was reserved for natural dynamic.

Figure 43 /

Alluvial pools and hollows with superficial groundwater table (top images). Pastures in contact with the riverbed (bottom left) and mixed riparian forest section left at natural dynamic (bottom right). Photo: Naturalea.

3.5.5. Naturalising a hybrid plane grove in Sora stream (Montesquiu, Ter basin).

Section description

Old plantation of hybrid planes (diameter between 45 to 80 cm on average) and some non-indigenous poplars (average diameter of 44 cm). Lower layer of common ash, lime, field maple, downy oak, walnut tree and black locust, the last mainly at the periphery of the forest, either alone or in small clusters. Shrub and lianoid undergrowth consisting of spindle tree, common hawthorn, box elder, common dogwood, old man's beard, common ivy and box. Some of the large hybrid planes are home to black and other woodpecker nests. The area belongs to the Barcelona Provincial Council and is part of the Montesquiu Castle Park. Surface area: 1.1 ha.

Actions

Hybrid planes were selectively felled in favour of indigenous tree species (common ash, small-leaved lime and field maple). The hybrid plane and black poplar trees with microhabitats (woodpecker nests and ivy), which added structure to the riverbank and/or shade the riverbed, were respected. All the standing and fallen dead wood (mainly poplar) was left on site. All young and adult black locusts were cut down.

In total, we marked and felled 58 hybrid planes and 104 black locusts (besides many further individuals below 5 cm in diameter that were not quantified) and 3 black poplars. The basal area removed was 13%. The contracted company covered work costs by selling the hybrid plane wood, outside of the LIFE ALNUS project.

Specific objectives

To naturalise the old, abandoned hybrid plane grove.

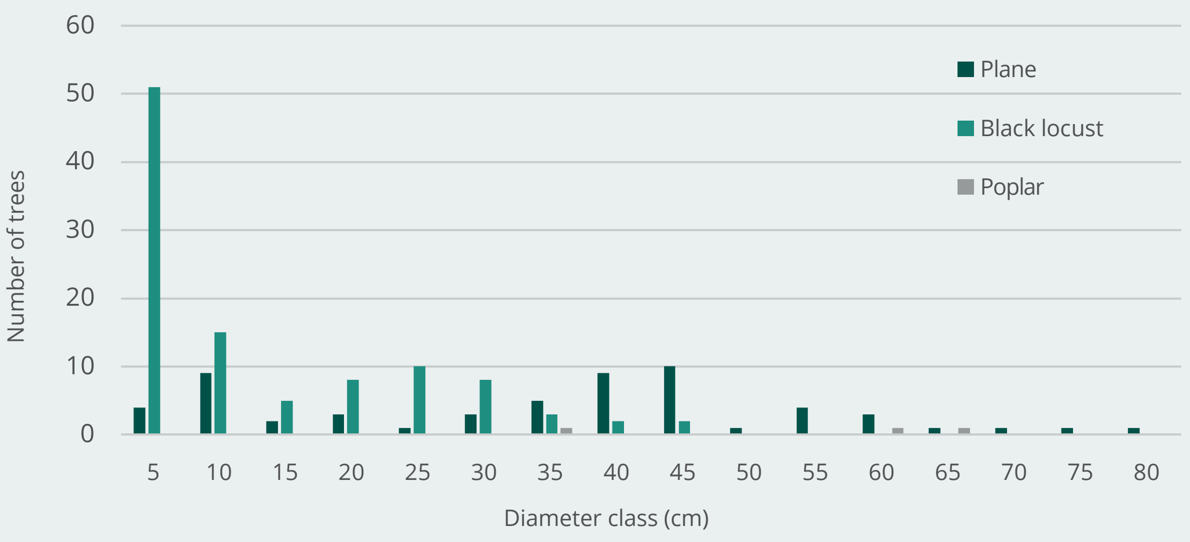

Figure 44 /

Diameter distribution of felled trees by species.

Figure 45 /

Naturalisation of abandoned hybrid plane grove at the Montesquiu Castle Park, in the Sora stream (Ter basin). Photo: Jordi Camprodon.

3.6. Legal framework for riparian forest management and current conservation condition

Riparian forest management in our context is affected by European, national and regional regulations on the environment, forest logging and hydrologic management, among others. At a European level, there are three directives that directly impact riparian management:

- The Water Framework Directive (2000/60/EC), henceforth WFD, whose main objective is for water to reach good ecological status. The hydromorphology structure of riparian areas is considered an indicator of the river course's ecological status (annex V of the WFD). Regarding the definition of ecological status, it is "very good" or "good" when the condition of riparian area corresponds to unaltered conditions completely or almost completely (annex V of the WFD). Natural Fluvial Reservoirs are a protective figure whose aim is to preserve those river sections with an excellent ecological status and with scarce or no human intervention.

- The Habitats Directive (92/43/EEC), henceforth HD, and the Birds Directive (79/409/EEC), henceforth BD, especially impact riparian forest management. Firstly, they condition the objectives and treatments that can be applied to Special Areas of Conservation (SAC) and Special Protection Areas for Birds (SPAs), which derive from these directives. Each region with its own environmental legislation approves certain management instruments for SAC and SPAs. In the case of Catalonia, the directives applicable to riparian area management include encouraging conservation and increasing natural riparian formations (alder groves and other related riparian forests), as well as reserving mature forest plots for those species of EU interest that need them (Godé et al., 2008).

The main Spanish legislation on forestry is *Ley de Montes*, *Law 21/2015, of July 20* (amending *Law 43/2003*), which is developed through autonomic (regional) forestry laws. This regulation encompasses multiple aspects of planning, silvicultural treatments and harvesting, restoration actions, etc.

Aside from strict forestry regulations, there is a large body of European, national and regional sectorial regulations affecting riparian forest management, including those covering biodiversity protection and protected natural areas (with specific regulations for endangered flora and fauna); use of nitrogen fertilisation and plant health, risk and emergency prevention regulations (fire, flood prevention), etc. In this sense, a key regulation is *Royal Legislative Decree 1/2001, Of 20 July, which approves the revised text of the Water Act*, which has included many modifications and is currently being reviewed (end of 2022). Some regulations that derive from this one include the Public Hydraulic Domain Regulation (RDPH). This Regulation defines that one of the purposes of the service area for public use is protecting the fluvial ecosystem and the public hydraulic domain.

In the case of areas within the Natura 2000 network, there are management directives, some of which are specific to riparian habitats (see annex of the *Directrius per a la gestió dels espais de la xarxa Natura 2000* [Management Directives for the Natura 2000 Network Areas], Agreement GOV/112/2006).

Lastly, different sustainable forest management certification standards (FSC, PEFC, etc.) grant special consideration to the conservation of riparian forest systems.

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Black locust *(Robinia pseudoacacia)*, invasive species from North America / Photo: Jordi Bas.

4 /

ALIEN VEGETATION MANAGEMENT IN RIPARIAN AREAS

4 / ALIEN VEGETATION MANAGEMENT IN RIPARIAN AREAS

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4.1. The issue of alien vegetation in riparian areas

Invasive alien species (IAS) are those that, once established in a region outside of their natural distribution area, have the capacity to survive, reproduce and spread, having considerable impacts on ecosystems. But not all alien species are invasive (Table 2); some foreign species have been promoted for their productive use, especially fast-growing species such as hybrid poplars (*Populus* sp.) or London planes (*Platanus* x *hispanica*), a species that has also received silvicultural treatments within the framework of the project, as we will see later.

As has been mentioned in previous chapters, one of the main issues of riparian forest conservation is the biological threat and competition from alien species, and especially, Invasive Alien Species (IAS). In response to this situation, public administrations have developed a significant volume of legislation, such as the *Catálogo Español de Especies Exóticas Invasoras* [Spanish Catalogue of Invasive Alien Species] and *Regulation (EU) No 1143/2014 of the European Parliament and of the Council of 22 October 2014 on the prevention and management of the introduction and spread of invasive alien species*.

In recent decades, the impact of these species has worsened, with a sustained increase of alien species (EXOCAT information system, 2020). These are encouraged by the discontinuity and changes affecting riparian structures, the area's dynamic conditions, their high reproductive and growth efficiency, the abandonment of active managements and the intentional or accidental introduction of these species. As a result, 50% of the habitats of community interest typical of continental waters are in an unfavourable conservation condition (Brotons et al., 2020) (Figure 46).

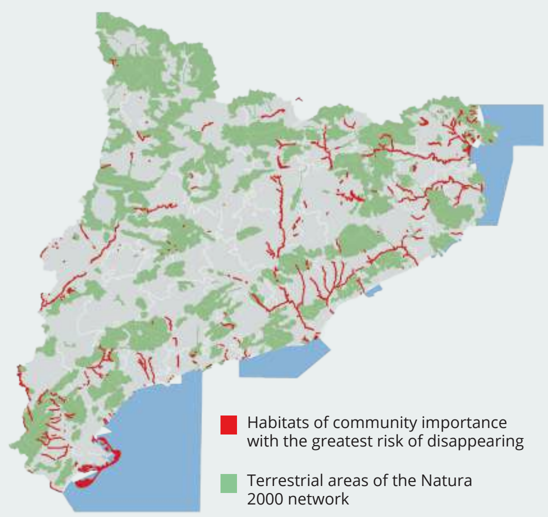

Figure 46 /

Habitats of community importance at a greater risk of disappearing. Source: Department of Climate Action, Food and Rural Agenda of the Government of Catalonia.

In the LIFE ALNUS basins, alien species spread homogeneously across the Ter basin, where only a few isolated mountain sections are free of them, or almost (Figure 47). However, in the sub-basin of the Onyar river, they cover more than 50% of the riparian forest. The most abundant alien species in the basin are London planes and black locusts, with only few well-preserved sections free from them. Box elders and canes appear in the plain of Vic and the lower part of the basin, where *Phytolacca americana* is also abundant.

In the Besòs basin, alien species are widely spread, except for some headwater areas, but they abound in the lower sections of the Mogent-Besòs rivers and their main tributaries, as well as in many points along the Catalan Coastal Range. In some sections, alien plant coverage of the riparian forest surpasses 50%, being planes and black locusts the main species. One of the river courses of this basin, the Congost river, has been subjected to a specific demonstrative action evaluating and controlling invasive flora, as shown later.

In contrast, the Segre basin is in exceptional condition regarding its physical integrity: only 1.8% of the Potential Fluvial Area (PFA) consists of consolidating anthropogenic covers, while almost 40% are natural habitats and the rest are land covers that constitute an agroforestry mosaic of great ecological and landscape importance with few invasive alien elements (2.7%).

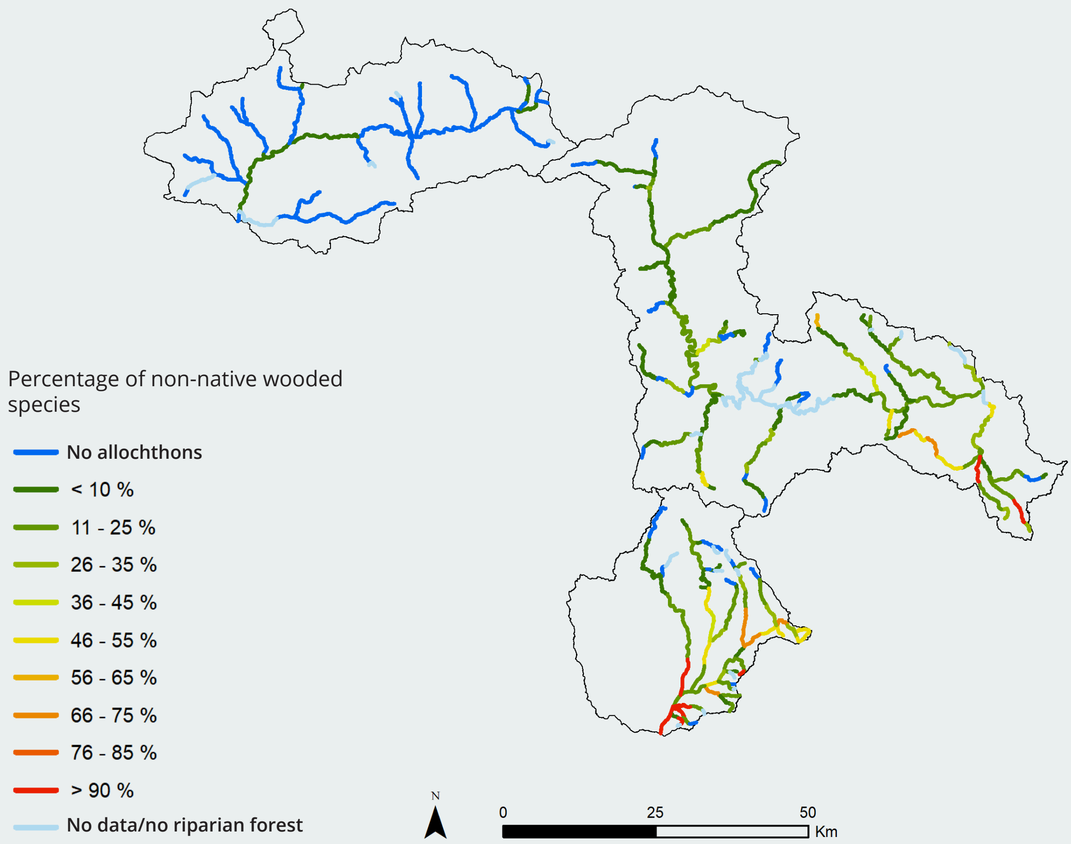

Figure 47 /

Distribution of invasive alien species (IAS) cover in river courses of the ecological territory of alder groves in the Besòs, Ter and Segre basins within LIFE ALNUS. Source: MN Consultants.

Table 2 / **List of the most common alien species in the basins intervened by LIFE ALNUS and their consideration or not within the legal framework on alien species.**

Taxon name	Spanish Regulation	EU Regulation	IUCN2000 100
Acer negundo	No	No	No
Ailanthus altissima	Yes	No	No
Alternanthera philoxeroides	Yes	Yes	No
Araujia sericifera	Yes	No	No
Arundo donax	Only in Canary Islands	No	Yes
Boussingaultia cordifolia (=Anredera cordifolia)	No	No	No
Buddleja davidii	Yes	No	No
Cortaderia selloana	Yes	No	No
Fallopia baldschuanica (=Polygonum aubertii Bilderdykia aubertii)	Yes	No	No
Helianthus tuberosus	Yes	No	No
Lonicera japonica	No	No	No
Ludwigia spp.	Yes	No	No
Myriophyllum aquaticum	Yes	Yes	No
Parthenocissus quinquefolia	No	No	No
Pennisetum spp.	Yes	Yes	No
Phytolacca americana	No	No	No
Robinia pseudoacacia	No	No	No
Senecio inaequidens	Yes	No	No
Tradescantia fluminensis	Yes	No	No
Ulmus pumila	No	No	No

4.2. Decision-making in alien species management

The land managers face the dilemma of how to act when it comes to alien species. Often it is not a straightforward, or easy, decision. LIFE ALNUS has focused its attention on riparian alien plant species, with a selective approach. Firstly, by identifying and mapping out the location of alien plant species at basin level (Besòs, Ter and Segre basins), especially tree species and canes (due to their structural role within the habitat and to ease mapping) and the cover percentage relative to indigenous tree species (see Chapter 2). Secondly, objectives were determined and actions planned (see Chapter 2 for more details).

The number of alien flora species present in the Besòs basin and, secondly, in the Ter basin are among the highest in Catalonia, due to strong urban expansion since the 1960s. This project considered which species were a priority to control due to legal requirements, their verified impact or because their control was feasible at section level. This basically included woody species, but also large lianoids and grasses such as canes. The first priority was given to eradicate tree-sized IAS in fluvial sections where the habitat was relatively well structured with indigenous riparian trees. This entailed a more efficient investment of available resources. In the released areas, alder grove woody vegetation was restored through planting. In the case of acting on large areas of cane, ailanthus or black locust with hardly any alders, willows, ashes, white poplars or undergrowth shrubs, it would have been easy for IAS to recolonise the area, even if indigenous woody saplings were planted: the IAS growth through sprouts or seeds can be much faster.

Sections were selected based on multi-criteria decision-making models, including the mapping done during the project and finally determining the stands or sections to be acted upon with on-site visits (Figure 47). During the planning of works at section level, we detected shrub, lianoid and grass IAS. Usually, they were eradicated from the stretches. As a second priority, if an isolated population of IAS was detected outside of the indigenous woodland cover that could be a source of spreading, it was treated if it involved low technical complexity and all specimens could be removed. This intervention included new populations, undetected in the basin until then, to prevent them from spreading.

Non-invasive alien species were considered selectively. They were not treated if they performed a relevant structuring function within the habitat, for example, by providing shade to the riverbank and/or the riverbed, soil protection and shelter for fauna. Sometimes, these species were introduced so long ago that they have already formed naturalised populations with large trees that perform a very similar ecological function to indigenous forests and can be of considerable (aesthetic, spiritual, historical, identity, etc.) cultural value. Therefore, London planes, non-indigenous poplars, walnut trees and other non-invasive alien woody species were only felled or girdled if they competed with indigenous species trees. To this effect, Chapter 3 describes the treatment applied on an old London plane grove in the Sora stream, Ter basin.

Finally, best practices for treating the IAS were chosen. Wherever possible, manual methods (pulling, felling or girdling) were chosen before resorting to chemical methods. In the case of using chemical means, injection treatments were used when possible (see later). Felled wood was generally removed, as long as accessibility conditions allowed. Fallen trees were left on-site, on the riverbank or across the riverbed, forming microhabitats and acting as sediment traps. Some of the branches and trunks were used to build holts close to the felling site, in the second line of the riverbank, in quiet locations suitable for otters. Black locust wood was the most used due to its outdoors durability.

The results discussed in this chapter are partial and correspond to the actions in the Besòs basin. The same methods will be applied to the Ter basin, but when finalising this manual works were still ongoing.

4.3. Tree species control test by girdling*

**Based on the Experimental protocol for the study of girdling as a silvicultural technique in riparian forests – LIFE ALNUS project. Jaime Coello (CTFC), December 2019.*

4.3.1. Introduction to the girdling technique

Girdling is a technique to devitalise trees that consists of interrupting sap flow by removing tissues from an entire section of the trunk. As a result, the roots stop receiving the photosynthates generated by the crown and the tree progressively dies. The tree can die shortly after being girdled or up to 2-5 years later (Magnér, 2017).

This is a cost-effective method for: i) creating standing dead wood to encourage maturity processes and associated biodiversity; ii) removing trees without suddenly increasing the light passing through the canopy; iii) reducing the stand density of overdense forests, and iv) controlling woody species. This technique is applied to trees of at least 10 cm in diameter on average (Kilroy & Windell, 1999). The main disadvantage of girdling compared to felling is the risk associated to the unpredictability of the girdled tree falling (Smallidge, 2016). Different types of girdling can be described depending on the tissues cut and the type of girdle.

Girdling type according to the tissues cut

There are two types of girdling, although sometimes they are used interchangeably due to the difficulty distinguishing between the two types (Moore, 2013).

a. Girdling without reaching the wood; *ring-barking* (Moore, 2013) or *girdling* (Magnér, 2017)

The bark, phloem and cambium are removed. This prevents translocation, i.e. the downward flow of photosynthates, sugars, amino acids and hormones, among others, from the crown toward the roots. Nevertheless, water and nutrients are still transported from the roots toward the leaves. The trunk and branches above the cut can continue to grow and even show strong development, since the carbohydrates produced at the crown remain available above the cut. Root activity may continue for some time depending on their carbohydrate reserves; once these are depleted, the roots start to die (Taiz & Zeiger, 2002). As a result, trees start to lose their ability to absorb water and nutrients, start to show signs of chlorosis and defoliation, and finally wither and die. This process can last between 2 to 5 years in trees with large reserves and a well-developed root system, but it can be accelerated if there are disturbances such as droughts or floods. With this technique, there is little resprouting from the root.

b. Girdling reaching the wood; *girdling* (Moore, 2013) or *notching* (Magnér, 2017)

The tissues mentioned in the previous case are removed together with the outside part of the xylem (functional xylem), that is, the active veins created during the current vegetative period. This affects both translocation (the abovementioned downward flow) and transpiration (upwards flow of water from the roots toward the crown). The tree withers quickly (often in 24-48 hours), especially if girdling is performed on hot and windy days, since the tree loses its ability to absorb water: the transpiration performed by the crown does not convey soil suction to the roots so they cannot absorb water any more. The problem with this method is that it tends to induce root resprouting and there is a greater risk of the tree breaking at the girdling point.

Girdling type according to the type of girdle

a. Thin girdle plus herbicide

A full or partial cut of the cambium is made using a chainsaw or axe, followed by herbicide spraying (Moore, 2008). This technique is effective with all species. The herbicide must be water-soluble, such as Pathway o Tordon RTU, unless it is applied in spring or early summer, when a herbicide diluted in oil (Garlon 4) must be applied to encourage absorption (Stelzer, 2006). An alternative to reduce the applied dose is using eco-plugs: crystalised glyphosate capsules inserted into the trunk using a drill (Willoughby et al., 2017).

b. Wide girdle

Two horizontal cuts are made using a chainsaw, axe or curved-blade knife (only for species with a thin bark) and all the bark and cambium between the cuts is removed by striking with the head of the axe or peeled with an axe or a chisel (Moore, 2008). If the horizontal cuts are made with a knife, we will know we have reached the wood when it stops feeling like we are cutting "threads" and the blade starts to glide smoothly. The visible surface left must be smooth.

A variation of this technique consists of making this wide girdle using a single cut or tool. It can be made using a chainsaw on thick trees as long as the worker is an expert operator, to avoid an excessive reduction of the trunk section. For thinner trees, and girdles performed in spring or summer, an axe or machete can be used, working the top half of the girdle from the top down, and the bottom half from the bottom up. A higher-performance alternative tool is a powerful sander with a tapered head, a more efficient solution than the chainsaw for trees up to 30 cm in diameter (Kilroy & Windell, 1999).

c. Double thin girdle

This technique would be similar to the wide girdle made with a chainsaw but without removing the bark and cambium between the two girdles. This technique was the most cost-effective applied to large beeches in Vall d'Aran Pyrenean area (Ameztegui et al., 2009) (Figure 48).

Some unpublished works mention a fourth technique, consisting of making a dashed girdle: the entire section of the tree is cut, but not all at the same height, but at different heights. This way the branches die off and fall before the trunk breaks along the girdled section. When the trunk falls, it has few remaining branches and does less damage to surrounding vegetation.

Figure 48 /

Double girdling on a London plane and superficial girdling process on a sycamore using a curved blade. Photo: Pol Guardis/Jordi Camprodon.

4.3.2. Factors that define the success of girdling

A tree's response to girdling depends largely on the species and vitality, the girdling technique, and the season.

a. Species and growth conditions

The species with the highest root or stump resprouting capacity, as well as the shade-tolerant ones, are the hardest to kill through girdling. With these species, it is essential that the cut interrupts the vascular connection throughout the whole section: it has become clear that girdling 80-90% of the section is ineffective in species such as *Eucalyptus camaldulensis, Robinia pseudoacacia, Ailanthus altissima, Platanus orientalis* and *Acacia melanoxylon* (Priestley, 2004; Moore, 2011; Merceron et al., 2016). Additionally, if the tree has many axillary or epicormic buds it can grow shoots below the girdling (Figure 49), which, if they develop quickly enough, can feed the roots again and prevent the tree's death (Reque & Bravo, 2007).

Figure 49 /

Reaction of girdled London plane: epicormic shoots grow under the girdle (A) and phloem bridges (B). Photo: Pol Guardis.

Regarding size and social layer, the largest and most dominant trees with better access to light are more likely to survive girdling than small (Magnér, 2017) or dominated ones (Wu et al., 2017).

a. Practicalities of girdling

The cut must always be made below the cambium. The depth of the cut should be approximately 1.5 cm in the case of young trees 2.5 cm for intermediate trees and 4 cm for large trees (Figure 50).

The width of the girdle must be at least 7.5 cm, although for large trees with high vegetative vigour (for example, *Populus alba*), this width should be increased to 10-12.5 cm (Glass, 2011). Reque & Bravo (2007) and Ameztegui et al. (2009) made girdles 20 cm wide on Pyrenean oaks measuring 15 cm in diameter and on large beeches, respectively, while Merceron et al. (2016) made girdles 30 cm wide on box elders measuring 5-11 cm in diameter.

In terms of height, the girdle must be made below the lowest branches, at a height that is comfortable

Figure 50 /

Girling on one side of a black pine (*Pinus nigra*). Photo: Jordi Camprodon.

to work at. In the future, it is likely that the tree will break at the height of the girdle (Lewis, 1998), so it must be made at a certain height (1.5-1.8 m) to leave a tall enough stump that will still have a positive function from the point of view of biodiversity.

b. Season

Girdling should be performed at the end of spring or beginning of summer (between June and early August), when sap flows predominantly downward and there are less reserves in the roots and less sprouting capacity (Glass, 2011). For some species with high vigour and sprouting capacity, we can plan an initial girdling in June and return in August to rework possible sprouts and even repeat the treatment in the subsequent years.

Girdling at the beginning of the vegetative period, when xylem is particularly active, should be avoided, especially in deciduous species. In this period the tree's reaction is quick (Harris et al., 2004) and sap flow (the carbohydrates accumulated in the roots and trunk during winter) is upward. Girdling should also be avoided in autumn-winter when nutrients are stored in the roots.

4.3.3. Discussion of girdling method

The girdled London planes in the Besòs basin within LIFE ALNUS resulted in many shoots sprouting during the first post-girdling vegetative period, right under the first girdle (lower section closest to the stump). No phloem bridges were found. The following criteria were established:

a) Competition criterion: the tree to be girdled must be vital and compete with one or more indigenous future crop trees

b) Biodiversity criterion: the tree must be alive and preferably well formed to ensure its stability during a certain period. The tree must be large (average diameter above 40 cm) to maximise the benefits to biodiversity as large dead wood. The presence of epiphytes ruled out action. The presence of incipient cavities could be a point in favour of girdling, if the decline of the tree could help consolidating the cavities.

4.4. Chemical control of woody species

4.4.1. Introduction to the herbicide application technique

Herbicide application is the most effective control technique for root-resprouting woody species, such as ailanthus or black locust. Felling these species does not eradicate them and, in fact, it is a counterproductive measure due to their roots' strong resprouting capacity, which can increase the surface area occupied by these specimens. For this reason, applying herbicide is essential, either internally (injection treatment) or externally (foliar application or application on the freshly cut stump), to induce the death of the roots.

In many cases, the undergrowth should be selectively and manually cleared beforehand to individually locate each tree to be treated and enable easier access. During this operation it is necessary to avoid cutting small specimens on the species to be eradicated, to prevent them from resprouting. Therefore, in stands rich in small IAS individuals the effectiveness can be exclusively limited to treated trees, but regrowth can be intense. In these cases, extensive maintenance must be performed, including at least three interventions of undergrowth clearing combined with herbicide application to the leaves when the sprout is between 40 and 60 cm tall. This treatment is described in further detail in the invasive alien flora management protocols, *Protocols de gestió de la flora exòtica invasora*, by the Girona Provincial Council (2017).

4.4.2. Effects of chemical control to eradicate invasive alien species in the LIFE ALNUS project

The evaluated techniques have been adapted to the IAS trees' characteristics:

- For large trees (DC>10): injection treatment
- For small trees (DC<10): stump treatment
- For recent sprouts and tall grass species: foliar treatment

These interventions were applied to 1,458 trees in the Besòs basin, between the beginning of October and the end of November, taking advantage of the fact that the species to be removed still had leaves and were easily identifiable and their sap was flowing downward. The stump and injection treatments are described below:

a. Stump treatment. The tree is cut at the base (horizontal cut) and the cut surface area is immediately (within 15 minutes) painted with a thick brush soaked in herbicide (dyed glyphosate). If this intervention has not been performed within these 15 minutes, a new horizontal cut is made to achieve a fresh cut. The herbicide applied was 45% glyphosate. The effectiveness of this intervention is reviewed during the next vegetative period, in case some specimens have eluded this control or removal has not been completely effective. Stump treatment is particularly recommended for black locust and box elder.

b. Injection treatment. Herbicide (glyphosate) is injected into the trunk. This treatment is especially recommended for trees thicker than 5 cm in diameter and consists of making several boreholes (at a 45 degree angle) using a drill at the base of the stump (the larger the diameter of the stump, the more boreholes). After the boreholes have been drilled, the glyphosate is inserted into the holes at the concentration indicated by the manufacturer (i.e., 25% glyphosate). After performing this operation, and with the certainty that the tree is completely dead, it is felled.

4.5. Treatment of invasive plant species in the Besòs basin (LIFE ALNUS)

4.5.1. General scope and characteristics of the action

There are two ecologically distinguishable sectors (Figure 51):

1. Upper course, including the Montseny-Bertí axis of the Congost river and some of its tributaries (Avencó, Vallcàrquera). This area keeps an elevated level of naturalness although alien species are present in sections and groups (sections 1 to 7).

2. Lower course: from La Garriga onward, where the river runs along the plain of El Vallès. The degree of naturalness is much lower due to the high impact of agricultural and industrial activities and a high population density (section 8).

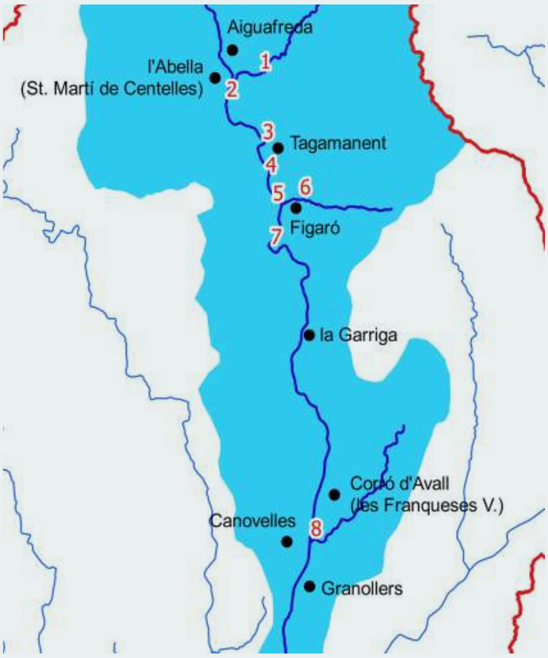

Figure 51 /

Location of the eight demonstrative areas in the sub-basin of the Congost river.

Basic action plan

According to existing previous data, the plan was to treat main target species, specifically: *Acer negundo, Ailanthus altissima, Arundo donax* and *Robinia pseudoacacia*. Based on the field data obtained while performing the action, other secondary target species were defined, which initially went unnoticed, since they were part of the grass layer: *Araujia sericifera, Boussingaultia cordifolia, Buddleja davidii, Ligustrum japonicum, Parthenocissus quinquefolia, Senecio inaequidens* and *Tradescantia fluminensis*.

4.5.2. Types of intervention according to species vital form and characteristics

Before the intervention, and according to their biological attributes, five types of intervention were defined:

- *Root-sprouting woody species (ailanthus, acacia, mimosa, etc.).* Protocol already discussed in section 4.4.1.

- *Woody or tall grass species that only sprout from the stump (box elder, London plane, buddleia, pokeweed, etc.)*: besides the girdling techniques, there are two options for this group: chemical treatment in the same way as species that sprout from the root; or physical treatment (stump pulled out with a digger or using a chain tied to it). This second option is of interest due to not using phytocides. For these species, one or two maintenance actions is usually enough. The protocol is described in detail here: https://seu.ddgi.cat/web/recursos/document/3189/3293/Protocols_de_gestio_de_la_flora_exotica_invasora__Control_de_la_buddleia_CAT.pdf.

- *Vines and creepers.* Due to their biological characteristics, it is essential to start with clearing the specimens, if possible, not long after they sprout in spring. Then we wait for resprouting, which in spring usually takes place within three weeks, and apply herbicide to the leaves. These species often require two interventions.

- *Tall rhizomatous grasses (bamboo, cane, etc.).* This type, which in this project corresponds mainly to cane, requires a precise intervention to remove the rhizomes with a backhoe digger. Previously, the aerial part must be cleared, although in areas that can be accessed by lorry, stems can be mechanically removed. If rhizome removal is done carefully using a combination of machinery and manual workers, it is possible to achieve success with minor maintenance actions. Even so, two interventions must be done to control potential sprouts. The protocol is described in detail here: http://www.agroambient.gva.es/documents/91061501/161549814/Bases+para+el+manejo+y+control+de+Arundo+donax+L.+%28ca%C3%B1a+com%C3%BAn%29/23237c3a-13e0-47d7-af00-2cbcaacb3ecb?version=1.1

- *Grasses in general (narrow-leaved ragwort).* In these cases, we recommend pulling specimens one by one after rain or when the soil is wet, taking care to completely remove the roots. When possible, the removal intervention should be done at the beginning of the flowering season, when the species is obvious but still has not produced fruits or seeds. The protocol is described in detail here: http://mediambient.gencat.cat/web/.content/home/ambits_dactuacio/patrimoni_natural/especies_exotiques_medinatural/gestio_flora_invasora/miseria/Protocol_Miseria.pdf

4.5.3. Assessment of demonstrative interventions in the Congost river

The treatment of arboreal IAS was considerably efficient in the sections identified as Priority in the planning phase described in section 4.2. Successful action was also achieved in areas considered at great risk of spreading or in reduced populations, where all specimens could be removed. This is the case of *Buddleja davidii*, in sections of high torrentiality and stoniness, where the species' spreading capacity is greater. Areas with new invasive species were also detected in the Besòs basin. This was the case of chia (*Salvia hispanica*). All identified specimens were removed, making sure to completely uproot them. A similar case was the removal of moth plant (*Araujia sericifera*) from a large but isolated stand, located where the Carbonell stream flows into the Congost river. This is considered a priority control species since it is scarce in the basin and because the riverbed's high groundwater table where it was located was one of the best locations to reintroduce the alder grove. Regarding cane, which has widely spread throughout the middle course of the Congost river, selective and one-time action was taken by extracting rhizomes with a backhoe digger (Figure 54).

In the case of other target species that were specifically monitored, no specimens expected and present in the basin were detected in the work areas. This is the case of *Alternanthera philoxeroides, Fallopia baldschuanica* (=*Polygonum aubertii, Bilderdykia aubertii*), *Ludwigia spp., Myriophyllum aquaticum* and *Pennisetum* spp. Grass species that were not assessed because they were widely distributed throughout the Congost river included *Ambrosia coronopifolia, Artemisia verlotiorum, Aster squamatus, Bidens sp., Conyza sp., Cyperus eragrostis, Lippia sp., Oenothera sp., Polygonum sp., Senecio pterophorus, Stipa caudata, Stipa papposa* and *Xanthium italicum*. Although we did not conduct a specific follow-up, they were eradicated when they were located next to the target IAS, as previously mentioned.

Furthermore, some alien woody species that do not have an invasive behaviour, but that slowly spread across fluvial areas were considered. This is the case of *Acacia dealbata, Broussonetia papyrifera, Celtis australis, Gleditsia triacanthos, Koelreuteria paniculata, Ligustrum japonicum, Morus alba, Platanus x hispanica, Populus alba "pyramidalis", Prunus cerasifera, Salix babylonica* (and other hybrid willows), *Tamarix* sp. (garden varieties), etc. When they were detected within the action section, they were also eradicated. Unfortunately, these species are often still used for gardening, so it is likely that they will continue to spread in the years to come. Limiting or forbidding their use for gardening in favour of indigenous species is advisable.

After the project actions, the situation of each of the target plant species in the Congost river was assessed; results are presented below. These data are valuable to provide continuity to LIFE ALNUS actions.

- *Acer negundo.* Both in this project and in previous interventions from other initiatives, most trees were removed from the upper Congost, where it has always been scarce. Some isolated specimens remain in some sections, and it is also a species planted close to the river at several points. Given that it is an unestablished invasive plant in the Congost, comprehensively removing all detectable trees is recommended, especially female specimens.

- *Ailanthus altissima.* Interventions on this species significantly reduced its presence in the upper course of the Congost river, even if there are *Ailanthus* stands beyond this area (Figures 52 and 53). Where the Carbonell stream flows into the Congost river, all adult specimens were removed, but two years after performing the works, sprouting from the roots of the treated trees was intense. Therefore, a second action was carried out, applying herbicide to the leaves. In the stand, the herbicide treatment was 85% successful (Table 3). In a section where ailanthus formed dense shrubby structures, an alternative method was devised, consisting of pulling up stumps and the root system using machinery; the debris was moved to a controlled landfill. Resprouting was treated with herbicide. There are still some untreated stands in La Garriga and hundreds of specimens in the section of Llerona and Canovelles. All female specimens that produce seeds should be comprehensively removed to prevent them from proliferating. This includes some specimens planted on the riverside path in Canovelles, where they were only removed from the section closest to the urban centre. The town councils of Granollers and Canovelles are working together on not planting this species as an ornamental tree and replacing existing trees with non-invasive species. Ailanthus' great capacity to resprout from the root is a resilience factor that should be considered and could involve complementary treatments.

Figure 52 /

Drilling holes in ailanthus after selectively brushing and injecting herbicide. Photo: Aprèn Serveis Ambientals.

Figure 53 /

Felling works on an ailanthus after receiving treatment. View of the fallen ailanthus, before being removed. Photo: Aprèn Serveis Ambientals.

- *Araujia sericifera*. The two stands detected on the riverbanks of the Congost river in the plain section were acted upon. Resprouting was very local. It is a species that is spreading in the plain of El Vallès, where it often colonises garden fences. Given that it is an unestablished invasive species in the Congost, clearing all the detectable trees before they bear fruit is recommended.

- *Artemisia annua*. This is an annual grass species first spotted in the Congost river in 2017. In recent years, its populations have significantly increased, especially through the pebbled and open areas that emerged due to flooding from Storm Gloria (2020). Since then, it has become one of the most abundant IAS in the section between La Garriga and El Besòs. Although it was pulled from the action areas included in LIFE ALNUS, this is an invasive species that is completely out of control. Its environmental impact is significant because by growing lusciously, it has turned pebbled and open areas that had specific flora and fauna into grasslands.

- *Arundo donax.* Interventions on this species allowed a significant reduction in three sections considered a priority (Figure 54). Although in recent decades it has been removed from several sections, it is still largely abundant throughout the Congost river, especially from the town centre of La Garriga and downstream. Given the titanic effort of removing cane from the entire Congost river, focusing on completely eradicating it in sections where it is still emerging is recommended to limit its spread.

Figure 54 /

Cane stand before and during rhizome removal. Photo: Aprèn Serveis Ambientals.

- *Boussingaultia cordifolia* (= *Anredera cordifolia*). The only stand detected was cleared. Due to its capacity to transform habitats and because it is still an unestablished species in the Congost river, clearing all the specimens before they bear fruit is recommended.

- *Buddleja davidii.* Close to one hundred trees were pulled out and treated with herbicide in the upper course of Tagamanent (Figure 55). The herbicide treatment had a success rate of 98% (Table 3). A few years ago, it underwent a comprehensive intervention in Sant Martí de Centelles. There is an important stand in a garden in Aiguafreda, which acts as a dispersion area. Isolated specimens are found throughout the Congost river, especially upstream from the Tagamanent treatment plant. It should be kept under control in the upper section and all the detectable individuals downstream should be pulled out, especially in pebbled areas and shrub willow groves, the habitats most threatened by its proliferation. Based on the observations and indications of the LIFE ALNUS project, the Government of Catalonia is planning a comprehensive intervention through *Forestal Catalana* public company.

Figure 55 /

Buddleia specimen a few days after being injected. Detail of the treatment holes. Photo: Aprèn Serveis Ambientals.

- *Cortaderia selloana*. No specimens were detected within the action sections. Nevertheless, we are aware that they are present in some points of the Congost river and surrounding wasteland. Due to its capacity to transform habitats and because it is still an unestablished species, pulling out all the detectable specimens is recommended.

- *Helianthus tuberosus.* Some specimens were pulled out within the action sections. Nevertheless, it is an abundant species throughout the Congost river, which is clearly out of control. Taking measures to prevent it from proliferating in areas where works and interventions are carried out is recommended. Its spreading can be limited by encouraging bramble patches, which actively compete with it.

- *Lonicera japonica*. Interventions on this species managed to reduce it significantly in Tagamanent. No more stands were detected, but it is a species that is spreading, so the appearance of new stands cannot be ruled out. Due to its capacity to transform habitats and because it is still an unestablished species in the Congost river, clearing all the specimens before they bear fruit is recommended.

- *Parthenocissus quinquefolia*. Its presence was significantly reduced in the Vallcàrquera stream. Due to its capacity to transform habitats and because it is still an unestablished species in the Congost river, clearing all the specimens before they bear fruit is recommended.

- *Phytolacca americana*. No specimens were detected in the action sections. Nevertheless, it is abundant in some sections of the plain of Llerona, from where it could colonise black poplar groves and riparian forests. Due to its capacity to transform habitats and because it is still an unestablished species in the Congost river, clearing or uprooting all the specimens before they bear fruit is recommended.

- *Robinia pseudoacacia.* Its presence was significantly reduced in the Avencó stream, Tagamanent and Figaró. The herbicide treatment had a success rate of 72% with a single application. Resprouting was non-existent or discrete (Table 3). In some cases, felling and removing large acacias located on the fluvial slope entailed an intervention of notable technical complexity. Despite being abundant in some sections of Tagamanent and La Garriga, it does not seem to be spreading. Removing isolated specimens is recommended, always with herbicide treatment. Clearing or felling, which encourages vigorous resprouting, must be avoided.

- *Senecio inaequidens.* Hundreds of trees were pulled from pebbled areas in Tagamanent and from the section close to the Carbonell stream. In general, it is not very abundant, although it is an opportunistic species that can undergo significant population fluctuations. We recommend uprooting specimens in spring, before they bear fruit, in sections were maintenance and/or improvement interventions are performed in the fluvial area, to control their populations.

- *Tradescantia fluminensis.* The only stand detected, under the railway bridge in Les Franqueses, was removed. We are aware of its presence in other points, for example in the Malhivern stream and Font d'en Mau in La Garriga. Due to its capacity to transform habitats and because it is still an unestablished species in the Congost river, removing all the stands is recommended.

- *Ulmus pumila.* No specimens were detected, but this species is clearly spreading in the fluvial sections of the urban centres of La Garriga and Granollers, through specimens planted along the riverbanks. Due to being an invasive plant with isolated specimens, removing all stands is recommended. This species is often confused with indigenous elm (*Ulmus minor*), so it often goes unnoticed and is ignored during fluvial habitat improvement actions. On the website of the Elms Alive LIFE project (https://www.olmosvivos.es/genero_ulmus) you can find detailed information on how to distinguish this invasive alien species from native elms.

Table 3 / **Results of herbicide treatment in LIFE ALNUS stands. DC: Diameter class in cm. Source: CTFC.**

Fluvial section	Stands intervened	Species treated	Number of treated trees	Treatment type	Mortality (%)
Cànoves stream	1	*Robinia pseudoacacia*	38 (CD10-35)	Brushing	100
Avencó stream	1	*Robinia pseudoacacia*	53 (CD10-20)	Injection in large trees and brush in small trees	-
		Ailanthus altissima	2 (CD10)		-
L'Abella	2	*Buddleja davidii*	14	foliar treatment	100
La Torre	3	*Robinia pseudoacacia*	245 (CD10-20)	Injection in large trees and brush in small trees Foliar treatment	70
		Buddleja davidii	35		Foliar
Tagamanent	4	*Robinia pseudoacacia*	185 (CD10-20)	Injection in large trees and brush in small trees Foliar treatment	80
		Ailanthus altissima	23 (CD10-15)		85
		Buddleja davidii	2		100
Santa Eugènia del Congost	5	*Robinia pseudoacacia*	190 (CD10-20)	Injection in large trees and brush in small trees	30
		Ailanthus altissima	90 (CD10-15)		80
Vallcàrquera stream	6	*Ailanthus altissima*	155 (CD10-15)	Injection in large trees and brush in small trees	80
		Robinia pseudoacacia	25 (CD10-20)		70
Gallicant	7	*Ailanthus altíssima*	125 (CD10-15)	Injection in large trees and brush in small trees	80
			10 (CD10-20)		80
Granollers-Les Franqueses del Vallès-Canovelles	8	*Ailanthus altíssima*	226 (CD5-35)	Injection in large trees and brush in small trees Foliar application in sprouts	100
TOTAL		***Robinia pseudoacacia*** **(746)** ***Ailanthus altissima*** **(661)** ***Buddleja davidii*** **(51)**		**1,458 treated trees**	

Based on observations, the Besòs basin, especially in the river course of the alluvial plain, like the Congost and Mogent rivers, is really vulnerable to alien flora invasions due to several reasons:

1. Fluvial areas have been greatly transformed, both from physical and hydrological points of view and due to chemical pollution.

2. Except for headwater sections, it is a basin with a high level of anthropisation.

3. It is a region where frost is occasional and mild so, unlike colder basins in the LIFE ALNUS project, several species that are vulnerable to low temperatures can proliferate. This is the case of *Araujia sericifera*, *Boussingaultia cordifolia* or *Tradescantia fluminensis*, for example. This increases the number of flora species that can invade fluvial areas even more.

Conclusions and general recommendations for invasive flora management

After the experience gained and assessing the results of the numerous interventions on invasive flora by the LIFE ALNUS project, some key conclusions and recommendations can be established, applicable to invasive flora control plans and/or projects in riparian forests, both at basin and fluvial section level:

When planning and/or drawing up the project

1. The first step of any invasive flora control strategy or project is making a detailed inventory of alien species present in the fluvial area and evaluating their abundance and distribution. It is also desirable to have information on population trends, although it may be difficult to obtain, except for in cases where habitats are followed up in the medium term.

2. In the case that the project is limited to a specific section, the study must be extended to cover its area of influence, especially upstream, to reduce its dispersion capacity downstream.

3. Determine the primary and secondary target species, both for the entire action area and for specific sections.

4. The species indicated in current legislation (i.e. those considered invasive by the Sistema d'Informació d'Espècies Exòtiques de Catalunya - EXOCAT) must be prioritised.

5. Independently of the risk assessment results, legislation and/or available literature, it is important to consider expert field observation. A noteworthy example in this sense is the Siberian elm (Ulmus pumila) in the Congost river. This species is not considered a priority in most works, but field observations by LIFE ALNUS determined that in alluvial plain sections it has a very high invasive and habitat alteration capacity, encouraged by the fact that, during the last decades of the 20th century, it was planted on a large scale in the Congost river area below La Garriga.

6. For greater efficiency controlling IAS, prioritising isolated species present in the basin and/or with emerging colonisation stands is recommended (especially if they are tree specimens of a considerable size), which are feasible to eradicate locally. It is also more efficient to act on trees or groups of invasive species in areas where indigenous riparian vegetation is dominant. Treatments are more successful when the tree and/or shrub cover is dense enough to reduce the resilience of invasive species. Indigenous vegetation can cover released areas through crowns growing vertically and laterally, and through sexual or vegetative regeneration. Therefore, it prevents the area from being recolonised by alien vegetation, especially heliophilous species, such as black locust.

7. If resources are available, restoring the area released from alien species with indigenous vegetation that is suitable for the ecological site and saplings and stakes from seeds from the same section or basin is advisable.

8. For widely distributed species, apply confinement strategies, removing isolated clusters and/or sources of spreading.

9. Prioritise the species that entail a greater risk to the target habitats of the project, taking into account their vital form and ecological characteristics. In the case of alder groves and riparian forests in general, it has been determined that the biological form with the greatest potential to transform habitats are vines, given that they are largely unaffected by the competition of indigenous woody species and can colonise well-preserved habitat stands. In second place are shade-tolerant creeping grass species. However, riparian forest glades can be easily colonised by heliophilous species, like ailanthus and black locust.

10. Prioritise interventions in Natural Fluvial Reservoirs and/or sections of conservation interest, especially those where an administration or institution is committed to an invasive flora control project. Keep in

mind that one-time actions against invasive flora often achieve partial results and these species invade the area again in a short period of time. Long-term maintenance actions are therefore necessary.

11. Prioritise headwater sections, given that many invasive species find it easier to propagate downstream. Removing headwater stands minimises the risk of reinvasion in sections where they have been eradicated.

12. For those species not included in the lists in the previous section, but that are suspicious of being invasive, performing a risk assessment is recommended following the alien species risk analysis for plants, terrestrial animals and aquatic animals, i.e. *Manual per a l'Anàlisi de Riscos d'espècies exòtiques per a plantes, animals terrestres i animals aquàtics* (Rotchés-Ribalta & Pino, 2021). For those stands where intervention is doubtful, applying the invasive alien species management action prioritisation and assessment manual, i.e. *Manual de Valoració i Priorització d'Actuacions de Gestió d'Espècies Exòtiques Invasores* (Rotchés-Ribalta et al., 2021) is recommended.

13. When writing documentation, it is important to indicate all the synonymous names of alien species to avoid confusion or misunderstanding. Keep in mind that some cases present significantly complex nomenclature. One example is the Bukhara fleeceflower, which can be named *Fallopia baldschuanica, Polygonum aubertii* and *Bilderdykia aubertii.*

When selecting the intervention method

14. Depending on the vital form and characteristics of each species, the most suitable control method must be selected. Broadly, we can distinguish between the following plant types: *woody species that sprout from the roots (ailanthus, acacia, mimosa, etc.); woody or tall grass species that only sprout from the stump (box elder, London plane, eucalyptus, buddleia, pokeweed, etc.); vines and creepers; canes and other tall rhizomatous grasses (bamboo, etc.); grasses in general (narrow-leaved ragwort); always distinguishing between annual and perennial species.*

15. A comprehensive list of control methods depending on each species and biological type can be found at the following selected websites:

https://mediambient.gencat.cat/ca/05_ambits_dactuacio/patrimoni_natural/especies_exotiques_invasores/llista-especies/

https://www.ddgi.cat/web/servei/5977/-protocols-de-gestio-de-la-flora-exotica-invasora

https://www.biobserva.com/stopinvasoras/content/protocolos

https://www.invasoras.pt

16. For species that resprout from the root, especially in the case of *Robinia pseudoacacia*, the application of herbicide through injection treatment is only effective when there is competition with other tree and/or shrub species, or when there are only adult specimens in the stand. In shrub areas with small sprouts, the less expensive procedure is to first clear all specimens completely, while respecting the competing indigenous species, and apply foliar herbicide to the sprouts. Nevertheless, wherever possible, try to minimise the use of herbicides.

17. The girdling technique requires qualified staff, both for marking and for executing the treatment.

18. The double thin girdle technique, despite maintaining sprouts, is a simple and practical technique to generate standing dead wood. Works that require certain care in felling and treatment actions in fluvial areas are expensive.

19. Girdling provides light to the system, which can encourage the growth of interesting species that compete with the girdled tree or in its lower layer. Nevertheless, it can also encourage the regeneration of alien species, so follow-up is necessary.

When executing the works

20. Take particular care to respect indigenous species that can compete with invasive species. For this reason, the effect on the vegetation and soil must be minimised in the areas of intervention, both in the case of mechanical works and herbicide application. In this sense, the plant community that we are most interested in maintaining is bramble (Rubus ulmifolius and others), which can contain the proliferation of grass species (for example, it is one of the only way to limit Jerusalem artichoke, Helianthus tuberosus). There are many examples of fluvial sections where invasive alien flora has proliferated, if the “riverbank maintenance works” have cleared the brambles.

21. It is advisable for the females of species with male and female specimens that disseminate particularly through seeds (Acer negundo and Ailanthus altissima) to die standing, especially when they are part of large stands that are expensive to remove. Selectively removing the females also makes it harder for them to resprout, given that the area remains dominated by male specimens which have been respected.

22. Maintenance works must contemplate at least two interventions during the first year after the works have been performed.

Riverbank with black locust (*Robinia pseudoacacia*) in the edge of a forest, where the greater insolation allows them to proliferate. Ter River (Torelló) / Photo: Jordi Bas.

Restoration of sediment transport and lateral flooding with the removal of the canalization and an obsolete dam (Congost River in Granollers, Besòs basin) / Photo: Aprèn Serveis Ambientals

5 /

RESTORATION OF FLUVIAL AREAS IN URBAN SETTINGS: THE CONGOST RIVER IN GRANOLLERS

5 / RESTORATION OF FLUVIAL AREAS IN URBAN SETTINGS: THE CONGOST RIVER IN GRANOLLERS

Xavier Romero

Granollers City Council

5.1. Introduction

The city of Granollers, with 62,475 inhabitants (2021), stands on the fluvial terrace of the Congost River (Besòs river basin) and is the capital of the county of Vallès Oriental in Catalonia (Figure 56). The municipality forms a conurbation with Canovelles, Les Franqueses del Vallès and La Roca del Vallès, with a total of almost 110,000 inhabitants. Its outstanding location, just 30 kilometres north of Barcelona, has facilitated the creation of a major communications hub and a powerful industrial and commercial sector.

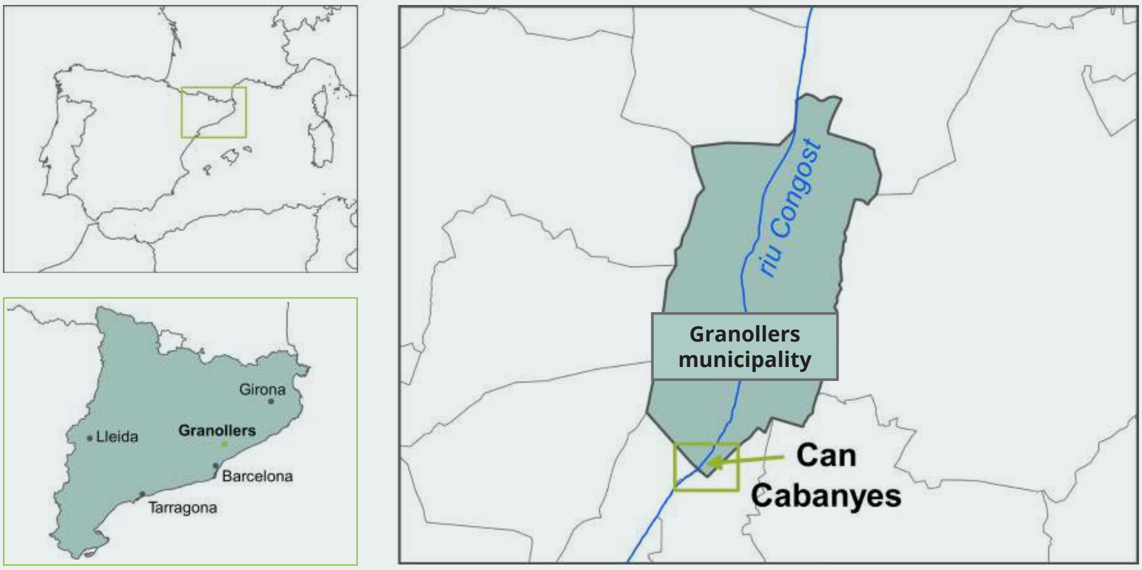

Figure 56 /

Location map of Granollers within Catalonia and the Iberian Peninsula. Photo: Granollers City Council.

Granollers is a municipality renowned for its long history of projects in environmental management and socio-ecological restoration. Its links with nature go back a long way. Indeed, the name Granollers, first mentioned in the year 944, comes from the abundance of frogs that inhabited the ponds and wetlands of the Congost River. In Old Catalan, *granolles*, from which the name of the city was derived, meant *frogs*.

The municipality had a strong agricultural and commercial tradition until the mid 20th century, at which point the population began to grow rapidly. This phenomenon generated a disorderly urban planning model that caused socio-environmental problems, including the degradation of natural environments, the progressive loss of agricultural activity and the deterioration of the city's environmental health.

The Congost River bore the brunt of this process. The degradation of the riverbed was clearly evident at the beginning of the 1980s and could only be remedied through the establishment of a new territorial governance model capable of adopting urgent measures to restore the sites deteriorated by irregular activities such as waste dumping and unregulated horticulture.

Accordingly, Granollers City Council began a major environmental restoration process in 1999 that centred on the area around the Congost River. It was the starting point of a large-scale municipal transformation that has expanded far beyond the river area.

A series of programmes for the preservation of the riverbed and its green riparian areas have been implemented year after year, leading to the creation of a first-class urban green infrastructure, with the green and social corridor of the Congost River as its focal point. These actions have been carried out thanks to municipal, regional, national and European funding.

5.2. Fluvial restoration process

5.2.1. The decay of the Congost River

The Congost is an intermittent Mediterranean river with a total length of 44 km and a basin with a surface area of 221.9 km^2. The 6.7 km stretch of the river that flows through Granollers from north to south has become the green backbone of the municipality. Just beyond Granollers, the Congost meets the Mogent River, eventually forming part of the Besòs River.

In its original morphology, the Congost flowed in a meandering pattern, splitting into shifting branches after floods. However, the first photographs of it, dating from almost a century ago, show a river that is free but already devoid of riparian trees, which is an unmistakable sign of long-standing human impact (Figure 57).

Figure 57 /

Panoramic view of the Congost River and the city of Granollers in 1924. Photo: Joan Guàrdia / Municipal Archives of Granollers.

The industrial and demographic expansion of Granollers in the 1960s and 1970s had a significant impact on its river systems. The main cause was the lack of purification of wastewater generated by human activity (housing, industry, agriculture...), which ended up eliminating all traces of life in the river, turning it into an open-air sewer.

Added to this fact was the fear of flooding. The Congost is a shallow river prone to irregular and torrential flows. Its ordinary flow rate is 0.56 m^3/second, but it can suddenly swell and flood, such as in 1943, 1944 (with continuous rain for 61 hours, almost one kilometre of alluvial plain was flooded and the estimated flood flow was 1,500 m^3/second), 1962, 1994 and 2020.

Following the 1962 floods, it was decided to canalise the Congost River. The initial containment strategy consisted of creating an embankment from demolition rubble to curb the effects of flooding. Subsequently, the General Directorate for Hydraulic Works of the Ministry of Public Works and Town Planning commissioned the construction of a concrete wall on both banks of the river between 1974 and 1979. These canalisation projects did not treat the river as a living area and no environmentally friendly practices were applied.

The canalisation project entailed reclaiming land from the river. This land was used to build new neighbourhoods, roads, industries and power line installations. In addition, the areas closest to the wall were occupied by unregulated allotments. The river landscape was radically transformed and the surface area of the riverbed was reduced from 45.03 ha to 25.34 ha.

The high degree of artificialisation of the Congost River made it impossible to restore it to its natural state. However, little by little, the idea of breathing life back into the river gained supporters, who gradually created opportunities in order to form a solid proposal for the restoration of the river.

5.2.2. Early initiatives and tentative attempts at restoration

The turning point for the restoration of the Congost fluvial area came about in 1984 with the approval of the General Urban Development Plan of Granollers (later revised in 1993). The plan brought order to urban growth and put a stop to excessive land occupation. While the previous plan envisaged the construction of two high-capacity roads next to the river walls that crossed Granollers longitudinally from north to south, the 1984 General Plan opted for the creation of a network of urban parks on the left bank. In addition to this, several areas of great natural value, such as the Palou plain and the Llevant and Ponent mountain ranges, were classified as non-development land.

In order to restore the quality of river water, the sanitation plans which the Government of Catalonia had begun to promote in 1983 were adopted, although the Granollers wastewater treatment plant did not start operating until 1992. The facility was initially equipped to carry out the primary physical-chemical treatment of wastewater. Subsequent extensions, in 1998 and 2008, equipped it with biological processes (anaerobic digestion and the recovery of nitrogen and phosphorus) with a hydraulic capacity of up to 30,000 m^3/day. The Granollers plant forms part of the Congost network of wastewater treatment plants, together with the systems in La Garriga (1992), Centelles (1993), Montornés del Vallès (1994) and Tagamanent (1996). These treatment plants are managed by the Besòs Tordera Consortium, which has been a key player in the entire restoration process of the Congost River.

The first steps towards restoring the Congost River were taken in 1994 with the greening of the stretch closest to the city centre, treating it as another urban park. In its edition of 13 June 1994, the local newspaper *El 9 Nou* reported that the goal of the action was to retrieve a recreational area for the city, away from the smoke of factories and the noise of traffic. A "River Festival" was organised, including activities for schoolchildren, the launching of a hot air balloon and concerts. Unfortunately, on 10 October 1994, after several days of rain, it is estimated that 200 litres/m^2 fell at the headwaters of the Congost, causing the most serious flooding in decades and, consequently, washing away the entire landscaped area of the Congost River in Granollers.

5.2.3. The canalisation of the Congost through the centre of Granollers

By the end of the 20th century, the proper urban planning of the fluvial area was in place, river water quality was good and some unfortunate management actions had been carried out. The foundations had been laid for the full restoration of the river, but an initiative was still to be undertaken that would affect its naturalness forever: the canalisation of the river through the city centre.

Between 1998 and 1999, the lower reaches of the Congost were canalised in order to protect against flooding and to enhance the scenic value of the fluvial area in its most heavily built-up stretch. At the time, the works were promoted as an environmental restoration initiative. However, by today's standards, this was a hydraulic engineering project with a questionable environmental contribution. The canalisation works reduced the width of the ordinary riverbed to just 20 metres along this 3.5-kilometre stretch. Once again, it was a project with no effective actions to protect the river ecosystem, consisting of the installation of two banks of buried granite breakwater and the construction of transverse concrete weirs, which crossed the course of the river every 60 metres to reduce the speed of the water and encourage sedimentation (Figure 58). The action has subsequently been assessed as good for protection against minor flooding. Unfortunately, however, it entailed the permanent canalisation of the river, and therefore the elimination of most of its fluvial dynamics, which enriched the entire habitat.

Figure 58 /

Canalisation of the Congost River through the city centre in 2013. Photo: Granollers City Council.

5.2.4. Structural support for the restoration of the fluvial area

Undoubtedly, the first proper environmental restoration intervention in the fluvial area was the sealing from the old Palou landfill site. This facility was in operation until 1985 and had become the main environmental problem in the municipality. Assessments carried out by Barcelona Provincial Council in 2000 confirmed the harmful effect of leachate seepage from the landfill site on the aquifer and on the surface waters of the Congost River. The solution consisted of building an impermeable screen of cement and bentonite around the perimeter of the landfill site to prevent the leachates generated by waste from coming into contact with alluvial waters. The works, which were executed in the 2002-2003 period, were funded by the European Union's Cohesion Fund and the Waste Board of Catalonia.

The landfill sealing project was complemented by a comprehensive infrastructure project for the social restoration of the fluvial environment, which also received funding from the Catalan Water Agency. Eight kilometres of river path from the edge of the city to the restored landfill site were prepared, including a pedestrian bridge halfway along the route and a pedestrian ford in the area of the old landfill site, allowing a circular route to be followed along both banks of the river.

The execution of this project entailed the dismantling of the unofficial allotments located along the entire river bank. This was a delicate matter, due to the social function of this type of horticulture. The solution was the creation of a municipal facility for family allotments where the evicted gardeners could continue to work on plots of 150 m^2.

5.2.5. Specific habitat restoration projects

Once the projects of a more structural nature had been implemented, proposals were made for the more specific purpose of naturalising the river and enhancing the Mediterranean riparian habitat.

The first major fluvial restoration projects were carried out in 2007 and 2008. These projects were aimed at addressing the lack of riparian vegetation, at stabilising slopes and combating invasive species. In order to recover the tree and shrub cover of the riverbank, areas for the planting of native species were created in locations close to the water table in order to reduce the amount of maintenance irrigation required. A total of 2,022 plants were planted by specialist companies, complemented by a community initiative involving 258 participants to plant some 400 additional plants. In addition, bioengineering techniques were used to accelerate natural stabilisation processes on eroded banks and to restore biodiversity in some stretches of riverbed exposed to ordinary flooding. Pilot tests were carried out using live wattles, live fascines, structured coconut fibre rolls, vegetated geogrids, structured grasslands, etc. The results of most of the techniques were satisfactory, especially the actions aimed at erosion control. However, the revegetation actions based on bioengineering techniques in highly mobile areas of the riverbed, which in later years were affected by floods, proved less successful. The last major action of this initial ecological restoration project phase was the elimination of cane species *Arundo donax*. A total of 2,250 m^2 of this exotic species were removed by means of the mechanical clearing of the aerial part of the plant and through subsoiling to a depth of 50 centimetres to collect the underground rhizomes. These operations were carried out with machinery followed by manual checking to remove rhizome remnants, which might enable the species to resprout. This technique and other similar ones made it possible to keep expansion of this invasive species under control, although no technique has yet been identified for its definitive eradication. New reed beds continue to appear from time to time, favoured by their own natural dispersal capacity or with the help of the floods that carry cane rhizomes from upstream sites to new river territories to be colonised. These initial projects were completed thanks to funding from the Catalan Water Agency, the Fundació Territori i Paisatge (Territory and Landscape Foundation), Barcelona Provincial Council and Granollers City Council.

5.2.6. Advanced river deconstruction actions and fluvial morphodynamics

River restoration actions continued year after year until the 2010-2012 period, when a new stage devoted to the restoration of river connectivity was initiated through the hydro-geomorphological restoration of the river. This involved the removal of concrete from the river in order to release it and improve its ecological connectivity. It was an extremely important and unusual undertaking that required the support of all the stakeholders involved. River engineers with expertise in biodiversity designed the projects, which were validated by the Catalan Water Agency. The projects entailed the removal of obsolete hydraulic structures but without altering the flood risk, which facilitated the acceptance of politicians and the local population after several meetings and public presentations. The longitudinal river connectivity was improved thanks to the removal of the central section of six concrete weirs that crossed the river, leaving in place the lateral connections with the wall in order for them to act as a breakwater to safeguard the riverbanks in the event of floods.

Even more innovative was the project to integrate a 601-metre stretch of the canalisation wall within a vegetated slope (Figure 59). The upper part of the wall was demolished and earth was brought in to create a green margin up to the river path that would allow the cross-connectivity of the river to the rural area of Palou, the main biological connector of the city to the Natural Park of the Catalan Coastal Range.

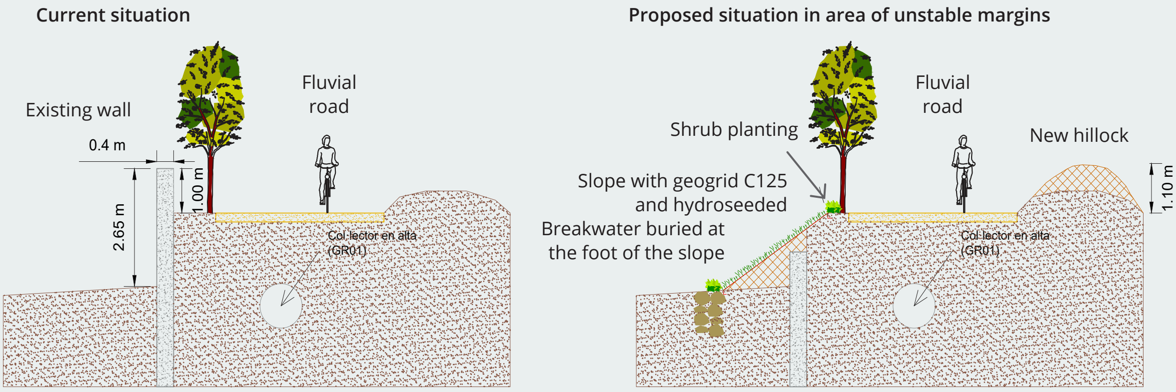

Figure 59 /

Before (left) and after (right) diagrams of the integration of the canalisation wall and connectivity restoration carried out in 2010. Photo: Granollers City Council.

A successful pilot test was also carried out with the creation of a river release zone in a highly built-up stretch of the river. The rectilinear breakwater of the low riverbed was set back in the form of a meander to gain river width and create small river microhabitats. All these actions were co-funded by Granollers City Council and entities such as the Biodiversity Foundation, the Spanish Federation of Municipalities and Provinces, the Consortium for the Protection of the Besòs River Basin and the Catalan Water Agency.

In the years following these actions, the flooding of the Congost River caused minor damage that affected concrete walls and some sections of the restored riverbank. Despite this, the ecological restoration actions have generally proved to be very effective, even reducing possible damage in episodes of river flooding. The buried breakwaters vegetated with *Salicaceae* species have been particularly noteworthy in this regard, both protecting the banks of the meanders and creating small riparian copses (Figure 60).

Figure 60 /

Meanders with buried breakwaters to prevent the erosion of banks and to improve the riparian vegetation of the Palou area (Granollers) in 2018. Photo: Granollers City Council.

5.2.7. The LIFE ALNUS demonstration project in the stretch of the Congost River that passes through Granollers

The latest phase of restoration projects is focusing even more on fluvial deconstruction processes, largely thanks to the LIFE ALNUS project.

The Congost River has benefitted from a project implemented between 2018 and 2020 that aims to demonstrate that effective and appropriate measures can be taken to reintroduce the riparian habitat in river courses where the habitat is extinct or severely altered.

The project has consisted of the following actions:

- Removal of invasive plant species.
- Fluvial release and improvement of longitudinal ecological connectivity.
- Restoration of the habitat with the planting of plant species typical of alder forests.

Removal of invasive plant species

The removal of invasive plant species consisted mainly of the elimination of different stands of cane (*Arundo donax*) in various stretches of the Congost River in Granollers over an area of approximately 1,500 m^2.

This action was complemented by another action of the LIFE ALNUS project for the eradication of invasive species in the Congost sub-basin, which was implemented in a 21.15 ha area stretching from the Avencó Stream to Granollers, mainly eradicating the species with the largest presence, such as *Ailanthus altissima*, *Robinia pseudoacacia, Acer negundo* and *Arundo donax*. However, the intervention also encompassed secondary invasive species such as *Araujia sericifera*, *Budleia davidii* or *Senecio inaequidens*, among others. The chapter on the treatment of exotic invasive species provides a definition of the types of intervention carried out during the eradication process.

Fluvial release

In two stretches of the Congost River, the low-water breakwater has been moved 10-12 metres outwards in order for the river to lose its rectilinear character and be released to meander within new, wider limits. The goal is for these meanders to diversify the river morphology and create microhabitats that will increase biological diversity.

The two stretches in which action has been taken are (Figure 61):

- Lledoner Park. 185 metres of the left-bank breakwater have been moved.

- Firal Park. A total of 276.5 metres of breakwater from both banks have been moved.

Figure 61 /

Before (top) and after (bottom) plans of the fluvial release action that has widened the low-water riverbed in the built-up area. Photo: Granollers City Council.

Also within the framework of the LIFE ALNUS project in Granollers, new demolitions of river weirs were carried out in the Firal Park area, continuing on from the Palou stretch where the first weirs were removed some years ago, and in the stretch of the Congost where it passes through the large Lledoner Park. To date, 14 obstacles in the form of weirs have already been removed, most of them structures that were either in disuse or that were providing surplus protection. It is planned to remove more of them in the near future (Figure 62).

Figure 62 /

Works carried out in 2019 for the partial removal of the central section of the concrete transverse weirs to improve the longitudinal connectivity of the Congost River in the stretch where it passes through Firal Park. Photo: Granollers City Council.

The removal of these barriers facilitates the movement of aquatic fauna, especially the fish community. In censuses conducted by the Centre for Mediterranean River Studies in various stretches of the Congost River between 2018 and 2020, it was concluded that the fish community is represented by seven species with a good population density along the entire length of the Congost River. At the Congost river station in Granollers, the growing evolution of fish biomass stands out, with maximums of up to 130,000 grams/hectare in 2020, which is an excellent figure for a river located in such a highly built-up environment. This wealth of fish is proving decisive for the return of the otter (*Lutra lutra*), a mammal that has high trophic requirements in order to satisfy its habits of making long daily journeys. The otter became extinct in the Congost during the second half of the 20th century and was not detected again until 2004, when it was spotted by technicians from the Ministry of the Environment of the Government of Catalonia in Granollers. Subsequently, it was again sporadically spotted in the neighbouring municipality of Montmeló in 2007 and, later, upstream in La Garriga in 2014. In 2018, Barcelona Zoo, the Institute of Environmental Science and Technology of the Autonomous University of Barcelona (ICTA-UAB) and the Besòs-Tordera Consortium launched an otter monitoring programme in the Besòs and Tordera river basins. This is where the Congost sub-basin is incorporated, and is where the otter can still be found on a permanent basis. Indeed, the stretch of the Congost river where it passes through Granollers is one of the areas where the species is most active, which is an indicator of the quality and degree of restoration of rivers.

In addition to the benefits for fauna, the removal of the transverse structures has given the Congost River improved fluvial dynamics; that is, the river has recovered its capacity to create geomorphological forms such as bars, rapids and shallows. Studies by the University of Barcelona, underway during 2022, have shown that the river is laterally mobile and changes shape during floods by stirring up sedimentary deposits. This restoration of river dynamics fosters an increase in river habitats and a diversification of the number of communities in the areas where the transverse weirs are still in place, although this will also entail lateral erosion and incision in the riverbed due to the lateral limitations of the Congost.

Figure 63 /

Alder planted during the restoration of the riparian forest on the Congost river next to Lledoner Park (Granollers) / Photo: Jordi Bas.

Restoration of the alder forest habitat

The LIFE ALNUS demonstration project in Granollers carried out a total of 448 plantations in order to create nuclei for the reconnection of the riparian forest habitat in the stretch of the Congost River where it passes through Granollers.

All the plantings were of indigenous trees and shrubs from local nurseries that produce varieties of plants that are native to the Besòs basin (Figure 63). The planted species were *Alnus glutinosa, Salix cinerea, Salix alba, Cornus sanguinea, Sambucus nigra, Carex pendula, Arum italicum, Aquilejia vulgaris* and *Lysimachia vulgaris*. Of the total number of plantations, 110 units of *Salix cinerea* and *Salix alba* were planted with stakes, while 263 of the remaining 348 units were planted in containers of between 2.5 and 4 litres, and 85 were planted in forest alveolus. Harvesting was carried out by the public company Forestal Catalana from seeds and cuttings collected two years earlier in the basin itself. Plant production was carried out in the company's nurseries in Breda.

These plantations were badly damaged by the Gloria storm in January 2020 and 304 riparian plants were replaced with new ones at the end of 2020.

This riparian vegetation restoration project in Granollers was complemented with the actions of the LIFE ALNUS project to restore the continuity of the riparian habitat throughout the Besòs river basin. These actions were based on the *Besòs river basin conservation and restoration plan* drawn up by the LIFE ALNUS project, designed for short- and long-term strategic actions. To this end, additional riparian reconnection nuclei were planted in ten municipalities in the basin. In total, 9,532 plant units were planted, of which 1,406 were planted in three-litre containers and 8,126 were planted in forest alveolus.

5.3. The urban river management model and its future

A new management model has now been consolidated for the Congost River where it passes through Granollers. Its key criterion is to devote the riverbed exclusively to the preservation of biodiversity. Adjacent riparian areas are regulated for the recreational use of the natural area, provided that such uses are compatible with the environmental values of the river.

The overall project for the environmental and social restoration of the Congost River has received wide technical and political recognition as a restoration programme that successfully promotes environmental, civic, health and educational values. The actions have also earned the recognition of institutions such as the United Nations, through its Habitats programme in the 2004 Good Practices Competition, or the Biodiversity Foundation (Ministry for Ecological Transition, Spanish Government), through which Granollers was awarded the title of “Biodiversity Capital” in the category of cities with 30,000 to 200,000 inhabitants in the 2011 edition.

In short, the restoration of the Congost River is bringing great eco-systemic benefits to Granollers, which has already embarked on new challenges, such as the mega-project Connect Congost Nature 2025 (CoCoNat25). This project aims to multiply the urban green infrastructure of the Congost River through the improvement of the Congost riverbed in its most built-up area, the renaturalisation of the adjacent urban park and the implementation of urban connectors in various streets of the neighbourhoods next to the river (Figure 64). This project, which is due to be completed in 2025, has been awarded a grant by the Biodiversity Foundation for the promotion of actions aimed at the renaturalisation and resilience of Spanish cities, within the framework of the Restoration, Transformation and Resilience Plan in the 2021 call for proposals.

Figure 64 /

Infographic of the CoCoNat25 project, showing the naturalisation planned for the Congost River and its vicinity. Source: Granollers City Council.

Ashy willow stake (*Salix atrocinerea*) sprouting in the ecological restoration of the Congost River, in Granollers / Photo: Jordi Bas.

Recovery of flows in a minor arm of the river Ter, thanks to the restoration of the hydromorphological dynamics of sediments. Island of Les Gambires (Torelló, Osona county) / Photo: Jordi Camprodon.

6 /

THE HYDROMORPHOLOGICAL RESTORATION OF FLUVIAL SYSTEMS. THE RIVER ISLANDS OF THE MIDDLE BASIN OF THE TER RIVER

6/ THE HYDROMORPHOLOGICAL RESTORATION OF FLUVIAL SYSTEMS. THE RIVER ISLANDS OF THE MIDDLE BASIN OF THE TER RIVER

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6.1. Hydromorphological conditions of rivers

Rivers are dynamic natural systems with the primary function of transporting water, sediments, nutrients and biota, making them extremely valuable corridors from a bioclimate, ecological and landscape perspective. Their other functions include self-regulation of extreme runoff, self-purification, regulation of bank erosion and regulation of fishing productivity. River courses (including rivers, ravines, brooks and streams) are also very valuable as they provide ecosystemic services that can only take place if active dynamics are maintained with well-preserved transport, sediment and erosion processes (Ollero, 2007). In other words, these services are only possible if the hydromorphological quality is good.

Hydromorphological quality is determined by the flow regime, the longitudinal and lateral connectivity of the river course, its morphology and quality of its banks. The assessment of this quality forms part of the river's ecological status, alongside its biological and physicochemical quality, as stipulated by the Water Framework Directive (WFD).

In many countries, hydromorphological quality assessment systems have been developed, with notable examples being the River Habitat Survey implemented in the United Kingdom in 1993 (Raven et al., 1998) and the French SEQ-Physique system (Agences de l'Eau & Ministère de l'Environnement, 1998). In the Spanish state, in 2006, the Catalan Water Agency (ACA) established the HIDRI protocol. In 2008, Ollero et al. developed a hydrogeomorphological index (IHG) to evaluate the ecological status of fluvial systems. Recently, the Ministry of Ecological Transition has created the Hydromorphological Quality Assessment Protocol (MITERD, 2019), which is currently being implemented to river water bodies in interregional river basins in order to align the assessment of their ecological status. In most cases, these indices assess similar parameters: riverbed geometry, longitudinal profile, transversal profile, grain size distribution of the river bed, structure and composition of the riparian vegetation, erosion and sedimentation elements, flow regime, longitudinal continuity, uses of the surrounding land, degree of lateral dynamic and connectivity of the river with the flood plain.

6.2. The importance of connectivity, morphology and riverbanks

Natural fluvial systems are in a state of dynamic balance or permanent adjustment achieved through a series of hydromorphological processes that take place longitudinally, laterally, and vertically over the course of the river. These processes act as regulating mechanisms of the liquid and solid flows circulating at any given time (Werritty, 1997). In terms of hydromorphological quality, the correct functioning (without any disturbances) of these processes results in good connectivity in all three directions (lateral, longitudinal, and vertical).

The riverbed is a geomorphological element formed by the river itself as the result of efficiently transporting the liquid (water) and solid (sediment) discharge, adjusting excess energy between its banks with different fluvial forms. As such, Mediterranean river courses are the processes that, during episodes of large magnitude (extraordinary floods), control the fluvial forms. Meanwhile, in times of low and medium flows, the fluvial forms control the processes (Graf, 1988). From this starting point, the longitudinal profile is formed by a succession of riffles and pools, as an automatic mechanism that regulates transportation and gives the system unity and continuity.

The flood plain is a space that dissipates the excess energy overflowing from the riverbed, creating a laminating effect that results in the reduction of the peak discharge downstream. It is also a site for sedimentation, responsible for the vertical accretion of the deposits and the fertility of the matter carried in suspension by the water flow (Strahler & Strahler, 1994). Moreover, the flood plain stores water that recharges the alluvial aquifer, beneath the alluvial plain, and ensures a high-water table.

Within the flood plain, a riparian corridor develops, with a mosaic of terrains defined by both the different types of sediment and the height with respect to the water table, where riparian species are adapted to the erosion and sedimentation processes, meaning that their regeneration generally requires ordinary flooding that respects the reproduction cycles of living organisms.

Therefore, the geomorphological fluvial dynamic is the driving force of an ecological dynamic that, through flooding, with a liquid and solid flow with different pulses, rhythms and fluctuations, guarantees the richness and diversity of these natural systems (Malavoi et al., 1998). Moreover, within this dynamic, the morphology of the river system determines a great variety of habitats that are highly changeable in terms of both time and space, enhancing the biodiversity and productivity of aquatic and riparian ecosystems (Gonzàlez del Tánago & Garcia de Jalón, 2007).

6.3. Main pressures and impacts

Rivers and riparian corridors are the most altered and endangered ecosystems in Europe (Tockner & Stanford, 2002), including valuable fluvial types such as braided rivers, which are on the verge of disappearing completely (Figure 65).

The main cause of the hydromorphological alterations of European rivers is its own socioeconomic development, entailing activities that consume land (river area), water (conveyance and diversions) and sediments (economic resource), as well as social demands for safety (from flooding), stability (with respect to the natural dynamics) and urban trends and models (in terms of the naturalness of the ecological system). This consolidated and growing reality is compounded by the fact that fluvial geomorphology is not valued at all, which is clearly demonstrated by the legal shortcomings, the lack of socio-educational awareness and professional stagnation, among other factors.

Figure 65 /

El Sorral island, in the foreground, and Les Gambires island, in the background, on the Ter River as it passes through the quaternary plain in Osona county. The islands have been the focus of one of the most important hydromorphological restoration projects undertaken in Catalonia to date (image from 2021, before the restoration). They are an example of a braided river with secondary branches, in the middle of an alluvial plain subject to the multiple typical anthropic uses found across Europe: agriculture, livestock, hydroelectric plants, sediment mining, public use, etc. However, they conserve a considerable degree of naturalness. Photo: Jordi Bas.

All these factors involve multiple pressures and impacts on the river system, both directly on the riverbed and flood plain and indirectly on the river basins and valley slopes, sometimes delayed in time, which alter the geomorphological functioning of the system, both in terms of the processes and the fluvial forms.

Alterations are often recorded in longitudinal geomorphological processes, due to interruptions to the continuity of the systems and direct actions on the riverbed. As a result, the longitudinal dynamics are modified and, consequently, so are the riverbed topography, step and pool sequence, grain size distribution and particle morphometry, local geomorphological processes, plant colonization patterns, etc. For instance, small dams constitute an interruption to the slope and the river's longitudinal profile that alters both the processes, leading to incision at the base of the dam, and the fluvial forms. Bridges and fords have similar effects on the fluvial dynamics, albeit not as strong.

Gravel dredging, extractions or removal of vegetation from the riverbed also alter fluvial dynamics through the way they affect the elements and processes.

Gravel dredging involves the excavation of lateral gravel deposits from the riverbed, as well as the elimination of river islands, including the removal of the vegetation that has colonized it, all with the aim of increasing the drainage capacity. Mining sand and gravel has similar geomorphological effects to dredging (Kondolf, 1997; Kondolf et al., 2002). It has a very significant impact on vertical dynamics, modifying the natural processes of accretion and incision, the sequence of riffle and pools and the sediment transport mechanisms by accelerating the flow velocity and causing significant incision and upstream erosion problems. It should be emphasized that many rivers still display the geomorphological effects of such practices many decades after the activity ceased. There are often stability problems on bridges and weirs due to upstream erosion cause by mining along other stretches of the river basin.

In general, constraining the lateral dynamics leads to increased longitudinal and vertical erosion, with incision effects (narrowing) on the riverbed.

Another way to quantify the impacts and pressures on water bodies is through the analysis conducted in every hydrological planning cycle in accordance with the criteria of the Water Framework Directive (WFD), as shown in the IMPRESS report, with an impact and pressure analysis and a risk assessment of failing to meet objectives of the WFD.

The impacts and pressures related to hydromorphological quality are water extraction and flow diversion, morphological and hydrological alterations (water collection, reservoirs and dams, unnatural land use along the riverbanks, river channelization, infrastructures and services on the riverbed, creation of man-made landscapes in the river basin, etc.), sediment mining and other pressures such as invasive species, sailing and recreational fishing.

6.4. General principles of hydromorphological restoration

Restoration involves reconstituting the natural processes of the river system, re-establishing the river's own functions of transport, dynamics and mobility, and facilitating the recovery of sediments, water and riverbanks that generate a structure as complex as an ecosystem. Restoring the fluvial dynamics enables the river system to recover, and in order to endure over time, action is required to deal with the causes of degradation (pressures and impacts), for instance, by eliminating pressures such as transversal and lateral structures.

Rivers have the capacity to re-establish their morphology, correct themselves and readapt to physical factors, as long as human-made impact elements are removed, with the river itself doing much of the required work for recovery (Williams, 2001; Downs & Gregory, 2004). Therefore, restoration can be seen within a river system as a dynamic component of a landscape in a continuous state of evolution, rather than as a stable, definitive entity or, in other words, as a final target snapshot. Therefore, it is important to prioritize passive, sustainable restoration, taking advantage of the fluvial dynamics themselves, their constructive power and capacity to maintain and generate the diversity of river habitats.

6.5. Implementation of environmental flows

The pulses, rhythms or fluctuations of the flow of a river regulate the ecological exchanges between the different aquatic and land units of the fluvial hydrosystem. As such, they are essential for the survival of riparian corridors (Junk et al., 1989; Tockner et al., 2000). Floods with an abundant liquid and solid flow are the driving force behind fluvial dynamics.

Over the course of the 20th century, particularly in the last few decades, very significant changes took place in the hydro-sedimentary dynamics in most of our rivers because of human intervention. One of the main factors behind these disturbances was the construction of large dams and reservoirs. These river infrastructures alter the natural flow regime of the river and the sediment dynamics, interrupting the sediment transport continuity. For this reason, in recent years, channel forming discharges are being implemented, by generating artificial floods from dams with the aim of reproducing the ordinary flood that would occur under natural conditions (without the presence of the structure), mobilizing the sediment and defining the river bed and the fluvial habitat. Channel forming discharges are one of the components that make up the environmental or ecological flow regime, which is also formed by the minimum flows to be maintained.

In the Catalan Basin District, the channel forming discharge is released at least once a year, as long as water reserves in the reservoirs are sufficient to guarantee all demands, being defined as the most probable maximum annual flood in natural regime (in the period 1940-2000This manoeuvre takes 24 hours in total (from the start to end of the released flood), with a gradual controlled increase of the discharge. In 2019 and 2020, , sediment input pilot tests were carried out at the Sau and Susqueda reservoirs to evaluate the transport capacity of the channel forming discharge and assess the effects in the river morphology (ACA, 2021).

Another specific case is the implementation, since 2011, of a minimal environmental flow regime to the Gaià River from the Catllar reservoir, accompanied by the release of the channel forming discharge, within the framework of the agreement between Repsol and the Catalan Water Agency, using a system of set points depending on the water level in the reservoir. Since the implementation of the environmental flow regime, the hydromorphological functioning of the Gaia River has improved from the town of Catllar to the river mouth (Bardina et al., 2019) enabling d the river to reach the sea for the first time since the 1970s.

6.6. Improving the longitudinal river connectivity

The term longitudinal continuity refers to the capacity of the river to transport water and sediments from the headwater to the mouth, as well as the fact that rivers are systems that enable the connection and mobility (for reproduction and/ or feeding) of biological communities, such as fish. In general, river courses are considered biological corridors as they are transit zones or areas highly frequented by living organisms. Therefore, many of them are considered sites of special interest or protected areas under initiatives such as the Natura 2000 Network.

This capacity to transport or connect water, sediment and biota may be affected by the presence of transversal obstacles, such as dams, weirs, fords and crossings, among other structures, which have significant consequences for the hydromorphology and ecology of the river.

From a hydromorphological perspective, these transversal obstacles modify both the river channel geometry and the flow hydraulics (for instance, accelerating or reducing the water velocity) and alter the hydro-sedimentary dynamics of the river by interfering, for instance, the sediment transport continuity.

From an ecological perspective, these obstacles interfere the natural movement of organic matter, nutrients, aquatic species, and plant propagules. At the end, the river is fragmented, facilitating the (localized) emergence of a new habitat that is often occupied by non-native species (some of which may be invasive) in detriment of the local species. Also fish populations are isolated, disabling its movement up and down, threatening their life cycle (reproduction and migration) and avoiding access to spawn or feeding areas being considered one of the main causes of the decline of many continental fish species, particularly, for those that need to migrate to complete their biological cycle (Latham et al. 2008; Vörösmarty et al. 2010). In short, these transversal obstacles create a barrier in the river ecosystem.

The removal of the transversal obstacles is the most efficient solution to restore the longitudinal continuity of the river course, as it allows the recovery of the hydromorphological dynamics and the restoration of interchanges and crossings in the river corridor (Figure 66). However, when obstacles cannot be completely eliminated, the optimum alternatives are the partial removal or, as a last option, the construction of a fluvial connector such as fish ramps.

Figure 66 /

State of the river before (a) and after (b) the demolition of the dam at the Molló hydroelectric plant on the Ritort River (Ter River basin). Photos: ACA.

Prior to the elimination or demolition of a transversal obstacle, one of the key points is to prevent the potential effects over the riverbed and channel morphology as well as the fluvial ecosystem because, in some cases, impacts can be largely severe. Therefore, before remove the transversal obstacle, it is necessary to gather a set of guidelines that will help to decide the most suitable way to eliminate it (i.e., in phases or all at once), as well as identify if it can be partially or eliminated. In addition, information should be gathered to ascertain if there are conditioning factors (hydromorphological or biological) that may prevent the demolition of the obstacle. Hence, a set of basic studies is required and, depending on the risk and type of impact anticipated, complementary studies may also be needed.

Basic studies include: i) hydrological characterization of the river course, ii) grain size analysis of both the riverbed and sediment retained by the obstacle, iii) estimation of the total volume of sediment retained behind the obstacle, iv) presence of contaminants into the sediment, v) river-aquifer dynamics; and vi) analysis of alternatives to remove the obstacle.

Complementary studies may include: i) analysis of changes in the aquifer system (water table recharge) in the influence area of the obstacle, ii) environmental impact (distribution of habitats and mesohabitats, presence of aquatic key species and other relevant elements) in the surrounding area and upstream and downstream of the obstacle, iii) estimation of the sediment transport capacity and expected evolution of the longitudinal profile (upstream and downstream) of the transversal obstacle.

Nowadays, there is not any standardized practice to manage the deposit of sediment retained behind a transversal obstacle when this is removed. Otherwise, there is a wide variety of options, which range from leaving the sediments at place, so that the river itself naturally redistributes them downstream, to dredge partial or totally the sediment stored. This is because there are many factors involved in the demolition of the obstacle: quantity, type, and potential movement of the sediment trapped behind the obstacle, the hydrological regime of the river, geometry of the obstacle, etc. Therefore, for each obstacle, it is necessary to evaluate individually which approach should be taken to manage the sediment. This must be incorporated in any demolition project, always under the premise that the best option is leave in place the sediment (or extract the minimum) and not be treated as waste.

It must be considered that both sediment and sediment transport dynamics are key aspects for the correct functioning of the biological communities and the river biodiversity (morphological and ecological). Sediment is the basis of the river's structure generating geomorphological diversity and, therefore, habitats. Thus, it is crucial that these elements should be largely respected.

Accordingly, sediment dredging is supposed to be the last option to consider. It should only be proposed in cases in which, for instance, the sediment is expected to have a severe impact (persistent over time and space) on both people's health and the fluvial ecosystem (for example, due to the presence of pollutants, sediment anoxic, high content of fine fractions (silts and clays) that cause strong and sustained episodes of turbidity in the water, etc.); or due to the impact on hydraulic infrastructures because a massive release of sediment onto the river bed.

In case that sediment dredging is planned, the minimum quantity must be removed, and it will be necessary to clarify, specify and quantify how the sediment dredged will be managed and how and where it will be located again in the river bed or in the river basin.

6.7. Restoration of the fluvial area or lateral connectivity

The connection between the lateral areas of the riverbed forms a fundamental part of the functioning of the river system. Accordingly, these connections must be as natural as possible, allowing the lateral processes such as erosion, deposition, nutrient retention, infiltration and energy dissipation. A correct lateral connection enables the flood pulses (overflow and return to the riverbed or lamination) to make exchanges of nutrients and organic matter between the riverbed and the alluvial plain, thereby enriching both (Figure 67).

The main problems are narrowing of the river due to channelization or lateral protections with walls, riprap and earthen berms, among other structures, that cause an increase of the flow velocity and, in general, riverbed incision or localized scour that can worsen the lateral disconnection. Consequently, river bends could be cut or secondary branches disconnected creating a single channel and exacerbating the disconnection between the river and flood plain or lateral areas.

To give back space to the river it is necessary to promote de-channelling actions especially where lateral flood defences are not need (Figure 68), such as, for instance, the elimination of artificial structures (i.e., earthen berms or other protections) or the reconnection of secondary branches, whenever possible, as incision processes generate height differences between the riverbed of the main channel and the secondary branches, making it difficult to connect them and becoming a problem that is often technically insurmountable.

Figure 67 /

The natural processes of erosion and sedimentation are well observed in this section of the Segre River in La Cerdanya county. The fall of trees in the riverbed is therefore part of the fluvial dynamics / Photo: Jordi Bas.

Figure 68 /

Elimination of the earthen berm between the Segre River and the Gallissà ponds (Bellver de Cerdanya) within the framework of the LIFE ALNUS project. Photo: Catalunya La Pedrera Foundation.

One of the measures taken within the framework of the LIFE ALNUS project was the hydromorphological restoration of Les Gambires island (Ter River basin, in the town of Les Masies de Voltregà) where a secondary branch was reconnected to the main channel, increasing the height of the riverbed by means of the construction of an stable ramp of gravel and pebbles (Figures 69 and 70).

Figure 69 /

Construction of the gravel and pebbles ramp in Les Gambires island (Ter River, Torelló). Photos: Enghydra.

Figure 70 /

Connection to the secondary branch in the hydromorphological restoration of Les Gambires island (Ter River, Torelló). Photo: Enghydra.

6.8. Recovery of former fluvial landforms

Beyond the riverbed and adjacent banks lies the fluvial area or territory, concept that was stablished by agreement within the framework of the National River Restoration Strategy (2008), being one of the most interesting solutions for river restoration. This term, nowadays, can be considered as consolidated. The fluvial territory can be defined as the land, area or landscape dominated by a river system, including the riverbed, the riparian corridor and all or part of the flood plain. That space must be claimed since socioeconomic interests are confronted to the fluvial network needs. It entails a geomorphologically and ecological active facet, of the utmost efficiency and complexity, with secondary branches, seasonal ponds that may be inundated in times of flooding, branches that are disconnected laterally but connected vertically, islands and other fluvial landforms that form a mosaic of habitats linked to the water environment. This fluvial territory must be as broad as possible, continuous, floodable, erodible, connected to the alveolar phreatic aquifer, without any lateral constriction and protected from development, and with precise borders (depending on the fluvial impact) that should not be statics, immovable, but rather adapt to the fluvial mobility. Depending on the river geomorphology it must be, in each case, a feature of land-use planning, adapted to fluvial dynamics (Ollero et al., 2010).

In this way, extremely interesting projects have been carried out at a Catalan and Spanish level, such as the initiatives developed within the framework of the LIFE Mink Territory Project were cut off secondary branches, straightened meanders and lateral lagunas have been restored in the Arga and Aragon rivers.

The following section presents a practical case conducted within the framework of the LIFE ALNUS project in which, among other objectives, a secondary river branch, disconnected by incision processes, is reconnected to the main river channel.

6.9. The hydromorphological restoration of Les Gambires and El Sorral islands

Les Gambires, El Sorral and Gallifa islands and meanders are located on the Ter River between the towns of Les Masies de Voltregà and Torelló (Osona). The transport of sediments and the morphology of the river favour the creation of meanders and islands in the river. Because of erosion and sedimentation processes, the course, length and position of the meanders and the morphology of the islands change constantly over time. The islands are highly valuable natural areas because of their biodiversity. As they are inaccessible, they provide shelter for many species of plants and animals. For instance, closely to these islands, there is a large colony of nesting herons being one of the most important in Catalonia, including the black-crowned night heron, grey heron, little egret and cattle egret (see chapter 8b). Many of these birds, as well as other species of flora and fauna, find along this stretch of the river a peaceful haven and essential food sources.

However, the Ter River has been subject to many impacts and pressures associated with human activities and with the livestock and industrial sectors. In relation to promoting conservation and restoration of the Ter River and the need for cooperation and funding, the "Ter Riverbanks project", based of different river stewardship agreements, (https://www.museudelter.cat/riberes-del-ter) has played a key role. The project started in 2009 by the Centre for the Study of Mediterranean Rivers (initially linked to the Ter Museum and, since 2016, also to the University of Vic - Central University of Catalonia), in collaboration with the Town and City Councils of Torelló, Les Masies de Voltregà, Manlleu, Sant Vicenç de Torelló, Vic and Sant Julià de Vilatorta, and the Department of Climate Action, Food and Rural Affairs or the Catalan Government. The project provides a joint platform to ensure the good conservation status of the river, including riparian areas, predominantly, through river stewardship agreements, which are based of written or verbal agreements with owners and managers to preserve riparian areas for periods of 10 to 30 years, on a renewable basis. In 2022, the Ter Riverbanks project covered a total area of 88.5 hectares. This framework agreement has facilitated fundraising to carry out restoration and environmental education projects, mostly in collaboration with the Forest Science and Technology Centre of Catalonia (CFTC), such as the SUDOE RICOVER project (2009-2012) and, more recently, the LIFE ALNUS project (2017-22), alongside other valuable partners and collaborators.

The middle section of the Ter River suffers from a chronic sediment deficit that has deteriorated its morphological and sedimentary activity. The construction of dams, as well as other more localized impacts (mining activity), have altered longitudinal and lateral connectivity, leaving disconnected flood plains in some cases, with direct effects on riparian vegetation. Many of the dams were built in the late 19^{th} and early 20^{th} centuries, which means that the river has gradually adjusted its morphology to the sedimentary imbalance caused by dams for over a century. These changes have been gradual and, in some sectors, have led to exacerbated incision processes and a complete loss of active morpho-sedimentary units. This has occurred to such an extent that, in some stretches, the river flows solely over rocky substrate, as the main morpho-sedimentary unit and lateral and central bars have eventually disappeared.

This situation led to the gradual degradation of the morpho-sedimentary state of the area studied from the mid-20^{th} century onwards. In the 1980s, when gravel extraction led Les Gambires secondary partially disconnected from the main channel from flows below, 32 m^3/s, which is the case on only 20% of the days of the year.

Consequently, the project proposed the hydromorphological and hydrodynamic restoration and reestablishment of the fluvial connectivity of two river islands of around 8 hectares each, with heavily modified riparian habitats. Main actions were demonstrative and experimental. They are listed below, with the specific objectives of each of them:

- Filling the northern part of the main channel of the Ter River in Les Gambires island. Objective: reversing the incision of the channel, increasing the lateral hydraulic connectivity and the height of the piezometric level.

- Sediment extraction on Les Gambires island. Objective: obtaining sediment to fill the channel and increase lateral frequent flows, as well as reducing the distance between the water table and the land surface.

- Recovering secondary channels upstream of Les Gambires island. Objective: increase lateral frequent flow to reduce incision processes, as well as increase hydraulic complexity of the system and the height of the water table.

- Restoring the hydromorphological dynamics of El Sorral island, interrupted by a concrete ford built to connect to a mining activity.

Figure 71 shows an orthophotograph of the area of rehabilitation and a ground map of the main actions undertaken between December 2021 and June 2022.

LES GAMBIRES AREA

- Clearing, pickling, lowering
- Clearing, lowering
- Recess and gravel extraction area
- Spreading of screened gravels
- Dam with breakwater
- Existing power line

EL SORRAL AREA

- Decompaction, leveling
- Walkway demolition

Figure 71 /

Area of hydromorphological restoration between Les Gambires island and El Sorral island (Ter River between Les Masies de Voltregà and Torelló, Osona County) 2022. Source: Catalan Water Agency orthophotograph of the ICGC.

6.10. Hydromorphological restoration of Les Gambires island

As a preliminary phase before the restoration work was undertaken, a series of studies were conducted to diagnose the morphological status and sedimentary dynamics of the Ter River along the stretch around Les Gambires island. These studies revealed a chronic structural sediment deficit that has caused a morphological change characterized by the incision and contraction of the main river channel, the loss of channel sinuosity and a reduction in the connectivity between the river bed and floodable areas, as well as an increase in stability conditions (armoured riverbed and plant colonization of old active sedimentary units). All this has led to a deterioration of ecological conditions and the death of the alder community along the left bank due to the water table drop (Figure 72).

Figure 72 /

Secondary branch around Les Gambires island before restoration, with a close-up of the degree of armouring of the river bed. Photos: ACA.

Moreover, during the execution of the LIFE ALNUS project, various sensors were fitted to ensure the continuous measurement of the river water level (Figure 73) and the aquifer piezometric levels at Les Gambires (Figure 74) and El Sorral islands, in order to obtain basic information to monitor water resources, fluvial dynamics, aquifer dynamics and the relationship between the river (flow) and the aquifer (piezometric level). Water level measurement was taken by two hydrometric stations, one south of Lacambra factory (Figure 73), and the other downstream of the Gallifa dam, south of El Sorral island. The level readings were translated into flow rate using a drainage curve that correlates water level with flow. These sensors remain active throughout the monitoring and evaluation phase of the project to enable a better analysis.

Figure 73 /

Hydrometric gauging section located 100 metres downstream of Farga Lacambra factory. The station comprises a pressure sensor that takes continuous measurements of water level and temperature. Photo: David Estany.

Figure 74 /

Transferring data from the pressure sensor installed on the piezometer on Les Gambires island. Photo: Jordi Camprodon.

To reverse these conditions, therefore, it was necessary to raise the level of the riverbed and connect main channel to the secondary one. To prevent loss in the channel capacity and an increase of erosion capacity and then ensure morpho-sedimentary stability, gravel up to 64 mm was unloaded onto the river bed. In addition, the main channel was widened along the left side of the work area, just upstream of Les Gambires island, to reduce water flow rate and erosive capacity thereby replenishing extracted sediments previously in the area affected by the work.

So, in the central part of Les Gambires island, excavations were made and the resulting material was sifted to separate the fraction bigger than 64 mm from the rest. The larger gravel was unloaded onto the river bed and the fractions of smaller matter were put back into the excavated areas on the island.

6.11. Elimination of the non-indigenous flora on the northern half of Les Gambires island

Les Gambires island displayed a great proliferation of invasive alien species that had colonised the open areas in the inner part of the island, primarily black locust (*Robinia pseudoacacia*), followed by box elder (*Acer negundo*). Taking advantage of the earthwork required to obtain gravel, invasive flora was cleared and removed from the part of the island affected by the work (Figure 75).

Figure 75 /

Population of false acacias on Les Gambires island before the restoration works. Photo: Enghydra.

6.12. Elimination of the ford that crossed the river at El Sorral island

At the El Sorral island, a ford has given access to a mining activity on the left bank on the river, which caused disruption of the hydro-sedimentary dynamic. After the public notification for the expiration of its use the ford was demolished (Figure 76). the principle of passive restoration was mainly followed, although certain actions were developed to accelerate the restoration process (elimination of invasive woody species and reinforcement of plantations).

Figure 76 /

Ford built with authorization for mining activities, which crossed the river at El Sorral island. Photo: Enghydra.

6.13. Developed works

The following overview gives a summary of the conducted tasks and the constructive processes involved.

a. Preparation of the land

The first phase consisted of clearing the land on Les Gambires island (Torelló), where the excavations would subsequently take place. The undertaken work included the following tasks:

- Manual clearing of false acacias with chainsaws (Figure 77)..

Figure 77 /

Felling of non-indigenous species on Les Gambires island in 2022. Photos: Enghydra.

- Bring down trees with chainsaws, predominantly poplars from old plantations, in areas where the river bed needed to be widened (Figure 78).

Figure 78 /

Felling trees close to the river bed on Les Gambires island. Photos: Enghydra.

- Topsoil stripping with a tractor and earth scoop (Figure 79). The top layer (approx. 20 cm) was removed from the project area as it may has contained non-native seeds. The following 20-cm layer of soil (i.e., from a depth of 20 cm to 40 cm) was also removed but was left to one side of the island to be put back in place later.

Figure 79 /

Topsoil stripping on Les Gambires island. Photos: Enghydra.

b. Excavations

Subsequently, the following earthworks were carried out:

- Excavation to widen the river bed of the Ter River, upstream the connection with the secondary river arm (Figure 80). This action enabled a reduction of flow velocity, thereby decreasing the risk of erosion of the gravel unloaded onto the river bed. These tasks were carried out with a track hoe and earth-moving trucks.

Figure 80 /

Excavations to widen the river bed on Les Gambires island. Photos: Enghydra.

- Excavation to remove and sift gravel. In the central part of Les Gambires island, excavation was carried out to remove gravel over size of 64 mm, which was later used to fill the river bed. The following machinery was used for these tasks:
    - o Excavation and inputting the excavated material into the sifter using the track hoe (Figure 81).
    - o Excavated material was sieved using a mobile sifter, which allowed to speed up the process. The sifter separated a pile of gravel over size of 64 mm from the rest of the fractions, which were put directly back into the excavated pit (Figure 82).

Figure 81 /

Excavations to obtain gravel on Les Gambires island. Photos: Enghydra.

Figure 82 /

Sifting the excavated material to obtain gravel over size of 64 mm on Les Gambires island. Photos: Enghydra.

- Adaptation of secondary channels to the connection with the main river bed.

The entrances to the secondary arms around Les Gambires island and small islands upstream were adapted to the connection with the main river bed (Figure 83). These arms had previously been functional and had generate heterogeneity and complexity of the river system, which, in turn, boosts biodiversity.

Figure 83 /

Adapting the entrances to the secondary channel around Les Gambires island. Photos: Enghydra.

c. Relleno del lecho principal del río

Esta fase se ejecutó paralelamente a la fase de las excavaciones. Los trabajos que se desarrollaron fueron los siguientes:

- Carga de las gravas de más de 64 mm con pala cargadora en el camión articulado (Figure 84).

Figure 84 /

Loading gravel with a front-end loader on Les Gambires island. Photos: Enghydra.

- Transportation of gravel and unloading it on the river bed using an off-road articulated truck (Figure 85).

Figure 85 /

Transportation of gravel and unloading it on the river bed using an off-road articulated truck on Les Gambires island. Photos: Enghydra.

- Spreading and reshaping gravel with a track hoe (Figure 86).

Figure 86 /

Spreading and reshaping gravels with a track hoe on Les Gambires island. Photos: Enghydra.

- Formation of a rubble-mound breakwater embedded with a front-end loader (Figure 87).

Figure 87 /

Formation of a permeable rubble-mound breakwater on the Ter River to the north of Les Gambires island. Photos: Enghydra.

As a result of these actions, water flow was reestablished on secondary arms around Les Gambires islands and the small islands upstream (Figures 88 and 89).

Figure 88 /

Circulating water along secondary arms of the Ter River to the north of Les Gambires island. Photos: Enghydra.

Figure 89 /

Secondary channels of Les Gambires Island completely naturalized, just finished the works in the sector. May 2022. Photos: Jordi Camprodon.

d. Repositioning of soils

Alongside the previous phases, the following tasks were undertaken:

- Restoration of soil cover with fractions up to 64 mm which was not used to fill the river bed, using the track hoe and trucks (Figure 90).
- Spreading the layer of topsoil left on one side of excavations on top of the replaced soil overusing the backhoe and truck (Figure 90).

Figure 90 /

Restoration of soil cover with fractions up to 64 mm in the previous excavated areas on Les Gambires island. Photos: Enghydra.

e. Plantations on Les Gambires island

Once the excavated soil had been put back in place and the topsoil had been spread, trees were planted manually, opening a hole and creating a small pit planting the sapling with a small wooden stake next to it to be able to locate it when the grass grows (Figure 91). Protectors were later placed around the plants to prevent animals from eating them. Lastly, they were watered, also manually.

The plantations were done with plants grown from seed (in the case of alder and ash) and from stem cuttings of different species of *Salix sp*., collected from the same area as the project (upper and middle stretches of the Ter River) and produced in the nursery of Forestal Catalana in Breda (Figure 91). The composition of this plantation is shown in the following table:

Species	Number of planted trees
Alnus glutinosa	764
Fraxinus excelsior	765
Salix alba	380
Salix elaeagnos	290
Salix purpurea	180
Salix atrocinerea	371

Figure 91 /

Plantations of woody species along the riverbank on Les Gambires island. Photos: Enghydra.

f. Removal of the El Sorral island ford

In this case, the concrete ford that spanned the river bed at the level of the left bank of El Sorral island was demolished and removed. The ford had been built decades earlier and regularly repaired after damage from various floods by two mining companies that used the ford to get vehicles and heavy machine across to their operations in the nearby alluvial terraces to extract sediments. To facilitate the environmental recovery of this island within the framework of the LIFE ALNUS project, the authorization to use the ford was eventually withdrawn by the Catalan Water Agency, enabling the ford to be demolished, within the same project, in May 2022. The demolition and removal were carried out by one trackhoe with a jackhammer and another with a bucket (Figure 92). The rubble was transported by earth-moving trucks.

Over the course of the 25 years that the ford existed, it was used as a crossing for pedestrians, cyclists and motor vehicles. The reasons for the removal of the ford and the recovery of the natural state of the space were explained to the town and city councils. Despite the custom of crossing the ford being well established, the justification for its demolition was clear: a) it was a temporary structure for industrial use; b) its removal would restore the fluvial dynamics and increase the protection of the island; c) its removal would eliminate the risk to people's safety in periods of flooding. At the beginning some users complained but soon there was a general consensus to undertake these actions for the benefit of nature, while also improving the safety and tranquillity of pedestrians and local residents by stopping the transit of vehicles.

Figure 92 /

Elimination of the El Sorral island ford in May 2022. Photos: Jordi Camprodon.

g. Plantations on El Sorral island

Once the ford had been eliminated, the soil of the El Sorral island path was decompacted and some plantations were made manually (Figure 93), in the same way as on Les Gambires island.

Figure 93 /

Plantations after the removal of the El Sorral island ford in June 2022. Photos: Enghydra.

CONCLUSIONS

1. The hydromorphological restoration of the Les Gambires and El Sorral islands constitutes a restoration, as it has improved the hydromorphological quality in terms of both longitudinal and lateral connectivity, as well as improving and diversifying the aquatic and riparian habitats.

2. Undertaking certain actions, such as eliminating the false acacias, and sifting and repositioning gravel and pebbles on the main river bed (an unprecedented action in Catalonia), caused misalignments that required readjusting with changes to the technical conditions for their execution in order to achieve greater economic and technical efficiency. The lessons learned in this respect may be useful in similar projects in the future.

3. The demolition of the ford, like most demolitions of structures on the river bed, has been evaluated as efficient based on its cost-benefit ratio.

4. The maintenance stipulated for the guarantee period is crucial for monitoring plantations, as some of the trees have died, which is to be expected in view of the climatological conditions (an extremely hot, dry year), and failed plants had to be replaced (275 units).

5. Monitoring the evolution of this restoration project over the next few years is considered extremely useful to evaluate initial objectives and results and evolution regarding fluvial dynamics. In fact, the monitoring that has been carried out within the framework of the LIFE ALNUS project and for the coming years (post-LIFE monitoring) already highlights the positive changes observed in relation to aquatic macroinvertebrates, fish, birds, mammals and fluvial habitats

Basses de Gallissà, rafts dug in the alluvial plain of the Segre River and connected to the river. Bellver de Cerdanya / Photo: Jordi Bas.

7 /

UPPER SEGRE. LIFE ALNUS ACTIONS FOR THE RESTORATION OF RIPARIAN FOREST AREAS

7/ UPPER SEGRE. LIFE ALNUS ACTIONS FOR THE RESTORATION OF RIPARIAN FOREST AREAS

Miquel Rafa, Josep Maria Fabra

Catalunya La Pedrera Foundation

The region of Cerdanya in Catalonia is well known for its unique landscape, with a plain composed of fields and rows of trees, framed by two mountain ranges: the Axial Pyrenees and the inland Pre-Pyrenees (Cadí-Moixeró, Tossa d'Alp, etc.). The Segre River and the riparian forests that border it are part of this picture-postcard image, but unfortunately, they have not received the attention they deserve, both for their intrinsic natural values and for the potential they offer in terms of recreational activities and responsible tourism. The riparian forest of the Segre is the best example of alluvial woodland in Catalonia, according to the cartographic studies carried out by the LIFE ALNUS project.

The Segre River has undergone several channelling works in order to prevent the type of flooding that has affected the area in the past or in order to repair the damage caused by flooding. However, these actions have also altered the natural dynamics of the river, preventing it from periodically overflowing its banks and flooding the adjacent areas of riparian forest, which is consequently starved of the water and sediments necessary for its proper ecological functioning. These measures have caused the deterioration of most of the riparian forests of the Cerdanya plain. These broad, expansive alluvial plain forests, once characteristic of most of Europe's rivers, have become relicts of the landscape (Figure 94).

Figure 94 /

Riparian alder forests in La Cerdanya county. Photo: Jordi Bas.

It is in this context that, as part of the LIFE ALNUS project, the Catalunya La Pedrera Foundation embarked on a restoration intervention in the area of the Gallissà Ponds, located 1.5 km downstream from the centre of Bellver de Cerdanya, on the left bank of the Segre just before the crossing of the strait of Gallissà Hill. A few decades ago, this area formed part of the riverbed (Figure 95). Subsequently, it became an area for the extraction of aggregates, after which it was abandoned and turned into a rubble dump (Figure 96). The foundation carried out an initial environmental restoration intervention in this area in 2002, removing much of the debris and turning the large dump into a public recreational area with a set of ponds, a river walk, signage and information panels, outdoor furniture and parking facilities, transforming the area into a mosaic of ponds, riparian forest and meadows (Figure 97).

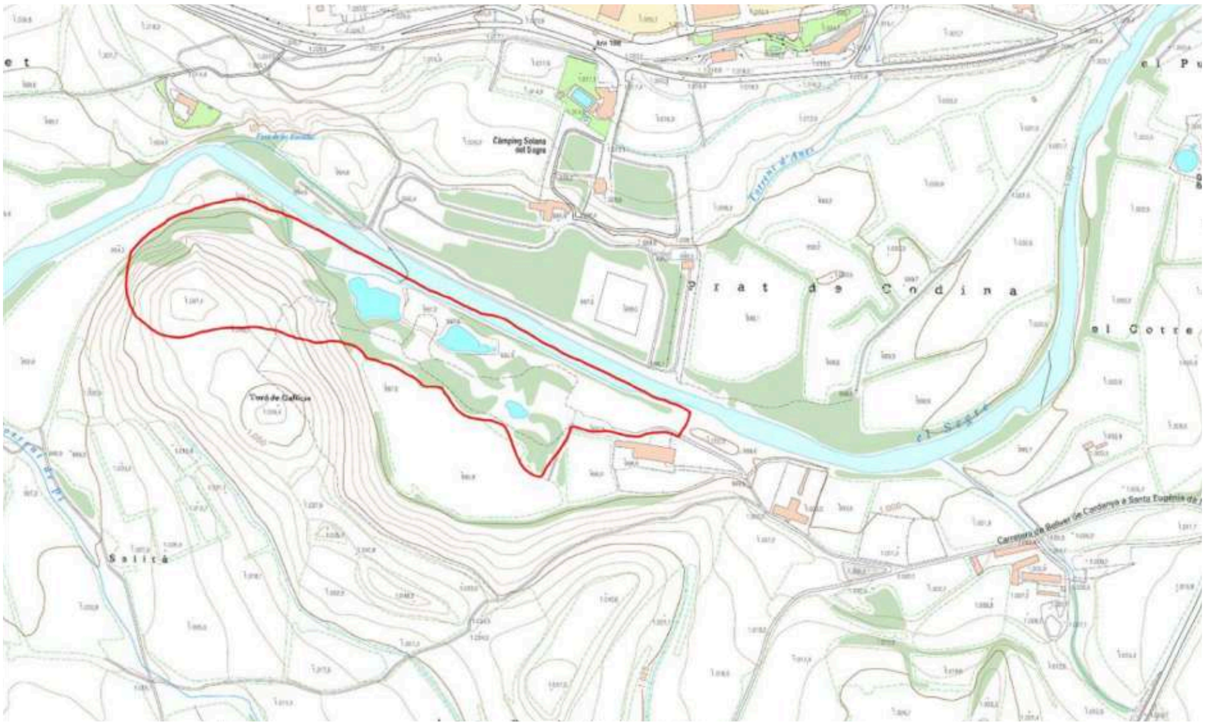


Figure 95 /

Topographic map of the Gallissà Ponds (Bellver de Cerdanya) site, with the three independent ponds. Source: Catalunya La Pedrera Foundation.

Despite this intervention, the existing riparian trees in the area tended to dry out, and there was no regeneration of new trees, except next to the ponds. Furthermore, the ponds were significantly affected by eutrophication, and although the two ponds located downstream were interconnected with each other, and temporarily with the river, the aquatic fauna observed in them was very poor, with a low level of biodiversity. The riparian forest had become disconnected from the river and lacked the ecological conditions necessary for its subsistence: occasional flooding, contribution of sediment and contact with the water table. The causes of this disconnection were the embankment that separated the river from the area of the ponds, and the incision of the riverbed as a result of the river channel being confined by embankments and rubble mound breakwaters along its course, which prevented its lateral overflow, disconnected it from its banks and accelerated its water flow, thus increasing the erosive power of this flow on the riverbed, and contributing further to the lowering of the water table.

Figure 96 /

Evolution of the Gallissà site between 1946 and 2016. In the 1946 image, one can observe the area where the ponds are now located, several intersecting channels and a wide alluvial plain covered by active sedimentary units (bars and islands without vegetation) on both banks of the river. Source: Cartographic and Geological Institute of Catalonia.

Figure 97 /

Layout of the Gallissà Ponds (Bellver de Cerdanya) before the LIFE ALNUS intervention, with the ponds, signposted routes and main landscaped elements. Source: Catalunya La Pedrera Foundation.

Pilot project to restoration of hydromorphological processes

The so-called *fluvial area* is a geomorphological and ecologically active corridor: a natural system of maximum efficiency and complexity. It should be wide, continuous, floodable and erodible. In particular, it should not have any defences or structures that break connectivity within the fluvial area. This gives the river freedom; that is, the territory it needs to naturally evolve geomorphologically and the right width for the development of its banks. In light of the foregoing, the LIFE ALNUS project aimed to recover as much of the fluvial area of the site as possible, and to enable the river to recover autonomously from negative impacts through the restoration of its hydro-morphological processes within a free territory of sufficient width, and to restore the ecological conditions necessary for the riparian forest. Accordingly, the intervention was composed of the following actions (Figure 98):

a) Interconnect the three ponds with the river on a permanent or semi-permanent basis, in order to facilitate a continuous flow of water, raise the water table and ensure the renewal of the water so as to prevent its eutrophication.

b) Remove the dividing embankment from the natural area of the Gallissà Ponds. At the entrance to the Gallissà site, there was once a ford with no embankment. However, due to the topography of the area, it was not especially functional and did not guarantee flooding when the river swelled. The aim of this action was to open up the embankment at two points in order to ensure that a swollen river could overflow and flood this side of the area, at the same time preventing the water from flooding the other side of the river, where a campsite is located.

c) Strengthen the riparian forest by replanting alders (*Alnus glutinosa*), white willows (*Salix alba*), European ashes (*Fraxinus excelsior*) and black poplars (*Populus nigra*).

d) Improve the visitor experience of the site with new information panels describing the project and a new footbridge, as well as boosting the attractiveness of the site by highlighting the values of the riparian forest.

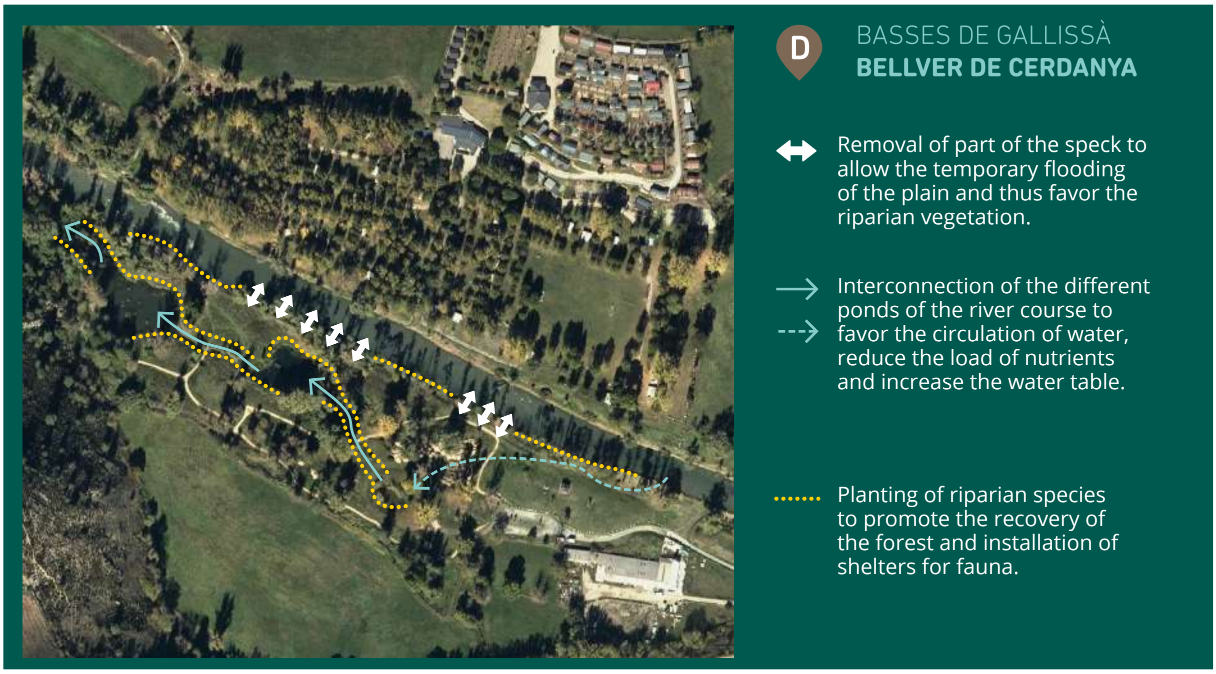


Figure 98 /

Layout of the LIFE ALNUS intervention at the Gallissà Ponds site (Bellver de Cerdanya), with the new water circulation route, the embankment openings and the replanting of riparian trees. Source: Catalunya La Pedrera Foundation.

Action 1. Interconnecting the ponds with the river

An 85-metre-long underground pipe with a 50-cm diameter was installed to connect the first pond upstream to the river. A small dam of stones was created in the river to ensure the inflow of water, and an iron grate was placed at the tube entrance to prevent any large stones from getting in that could block it, but allowing fish to swim through. A sluice gate was also installed in order to be able to cut off the water flow if necessary, or in order to carry out maintenance work.

A channel was opened and the banks were lowered, in order to connect this pond with the pond downstream from it, thus enabling the circulation of water (Figure 99). This second pond is already interconnected with the third pond. Meanwhile, the third pond has an opening through which it is temporarily connected (when the level is high enough) to a side branch of the Segre. This means that a natural circulation is established, interconnecting the three ponds, with an almost permanent flow of water, thus increasing the level of the ponds, raising the water table, ensuring the replenishment of the water and boosting the biodiversity of the site (Figure 100).

Figure 99 /

Channel between ponds 1 and 2, with newly planted trees and the new footbridge in the background. Photo: Jordi Bas.

Figure 100 /

Outlet of the tube in pond 1 just after it was installed (October 2019). Once operational, it is mostly submerged below the waterline. Photo: Jordi Bas.

Action 2. Removal of embankments

Embankments are longitudinal defences whose purpose is to prevent overflow and flooding when rivers swell. As such, they separate the secondary riverbed from the human uses that have been installed on the main riverbed or floodplain. Action 2 entailed the removal of two embankment sections, preserving the riparian trees at the site as far as possible and preventing the site from being damaged by the machinery passing through it.

The first embankment section, located upstream, was 30 metres long, between 50 centimetres and 1 metre high, and between 1 and 2 metres wide. When the river swells, this opening in the embankment is designed to offer an outlet for river water from a point where the water enters through the ford upstream, since there is a double embankment in this part of the site, next to the river and on the hill, outside the flood zone, where the barbecue facilities and seating of the picnic area are located, just before the entrance to the pond area (Figure 101).

Figure 101 /

First embankment removed and flattened. It occupied the stretch where the coarser material is visible on the ground, between the first row of trees (the river is just to their right) and the path. One can also see some of the stakes of newly planted trees and signs that the river overflowed the former embankment stretch when it burst its banks during storm Gloria (January 2020), with water entering the ponds. Photos: Catalunya La Pedrera Foundation.

The second section was about 40 metres long, between 75 centimetres and 1.5 metres high, and between 2 and 3 metres wide, separating pond 2 from the river. The goal of opening up this embankment section was to allow the overflow of river water into the ponds in the event of a flood. The second goal was to ease the pressure on the adjacent bank, where a campsite is located. Overall, the functional and visual connectivity of the pond area with the river has been improved (figures 102-104). The material removed from the two embankments (a mixture of river sediment and rubble) was sent to landfill.

Figure 102 /

Machinery removing the second embankment section. Photo: Jordi Bas.

Figure 103 /

The site just after the removal of the embankment and having been partially replanted (November 2019). Photo: Catalunya La Pedrera Foundation.

Figure 104 /

Site of the removed embankment from the other side of the interconnected pond. The stakes of the newly planted riparian trees can be observed. Moreover, visual contact has been re-established with the other bank of the Segre, where the campsite is located. Photo: Catalunya La Pedrera Foundation.

Action 3. Planting riparian trees

The areas with disturbed soil were sown with local grasses to facilitate rapid regeneration and provide stability to the slopes. Meanwhile, in the open channels, on the edges of the ponds and in the section parallel to the river, alders, white willows, European ashes and black poplars were planted to help consolidate the riparian forest that used to be in the area. The planted trees came from seeds and cuttings collected in the area and cultivated in the nurseries of the public company Forestal Catalana, S.A. (Table 4). The table below lists the planted riparian species. Most of the trees were staked. A tree pit, partly filled with topsoil, was created for each large tree (Figures 105 and 106).

Table 4 / **Tree species planted in the floodable area of the Gallissà Ponds site (Bellver de Cerdanya).**

Tree species	Size	Format	Amount
Alnus glutinosa	200-250 cm	12 l. Container	300
Alnus glutinosa	20-25 cm	seedling	500
Salix alba	20-25 cm	seedling	250
Fraxinus excelsior	20-25 cm	seedling	200
Populus nigra	20-25 cm	seedling	50

Figure 105 /

View of pond 3 and the stakes of newly planted riparian trees (March 2021). Photo: Catalunya La Pedrera Foundation.

Action 4. Environmental awareness and adaptation for public use

To inform the public of the LIFE ALNUS project and the interventions carried out at the site, panels were installed listing the planted species, together with a larger panel at the site entrance describing the LIFE ALNUS project itself. Furthermore, some damaged old panels were removed and restored, and a heather fence was taken away that had sheltered the downstream pond. There was a birdwatching area in this spot, but due to the state of the water, there was very little variety of species. The aim of the intervention was to give continuity and depth to the visual field of the site. A new footbridge was also installed over the channel connecting pond 1 to pond 2, providing the site with a new attraction (Figure 106 and subsequent).

Figure 106 /

Trees planted in the channel between pond 2 and pond 3, and around the latter. On the right side of the image, one can observe the heather fence that separated pond 3 from the rest of the site, which is to be removed. In the background, pond 3 presents significant eutrophication. Photo: Catalunya La Pedrera Foundation.

Figure 107 /

Adaptation of the new information panels on the site. Photo:Catalunya La Pedrera Foundation.

Figure 108 /

Adaptation of paths and new signs. Photo: Catalunya La Pedrera Foundation.

Figure 109 /

View from Gallissà Hill of the entire site, following the LIFE ALNUS intervention (March 2021). Photo: Catalunya La Pedrera Foundation.

Upper Segre - a forward-looking project for the riparian forests of La Cerdanya

Having completed the LIFE ALNUS restoration actions at the Gallissà Ponds site and with all the knowledge generated by the project in the analysis of alder forests in Catalonia, it was considered essential to propose and structure a forward-looking vision for the riparian forests of the upper Segre (with a current surface area of 154 ha), in light of their importance in the Iberian context and their current state of conservation, which although good in general terms can clearly be improved.

Accordingly, as an action carried out within the term of the LIFE project but with additional means and resources, the Catalunya La Pedrera Foundation commissioned a preliminary project ("Proposals for the protection, restoration and enhancement of the alluvial landscape of Cerdanya", 2019) in order to structure this forward-looking vision for the forests of the Segre. The project comprised an action strategy to be submitted for the consideration of local authorities (local councils and county council) and of the Government of Catalonia (Figure 110).

Figure 110 /

Initial document of the project submitted to local councils, the county council and the Government of Catalonia (2019).

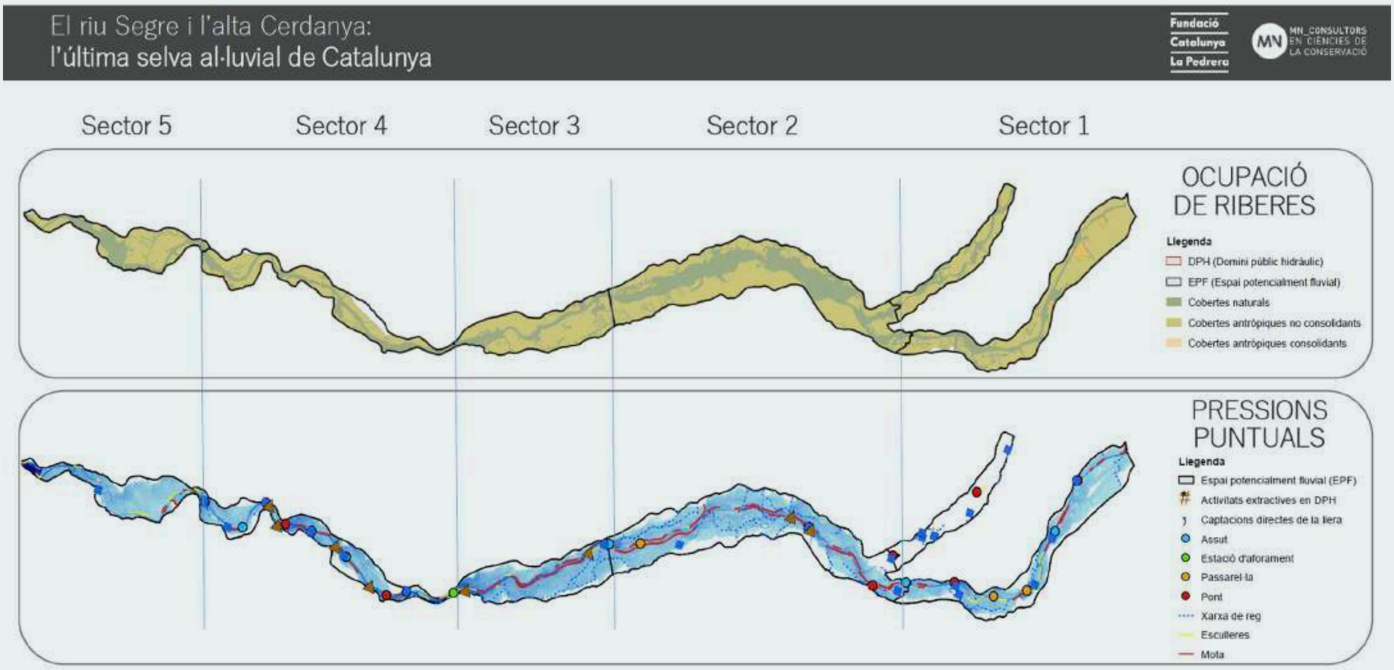
The proposal focused on two aspects:

a. Conservation and restoration of riparian areas: the restitution of the flood plain riparian forest in Cerdanya, wherever possible, with the definition of infrastructures that hinder natural dynamics and the hydrological restoration and fluvial forest actions that must be implemented.

b. Social and economic development ("River Path"): the creation of a river route between Martinet de Cerdanya and Llívia, in order to make these fluvial areas accessible to visitors, generating a tourism asset and facilitating pedestrian and non-motorized traffic between the sites of the plain, naturally respecting the areas of greatest ecological sensitivity.

The conservation and restoration of the fluvial area was entrusted to the company MN Consultants (also a partner of the LIFE ALNUS project), which had previous experience and knowledge in this aspect, gained during the analysis phase of the LIFE ALNUS project.

In this diagnosis, a detailed study was carried out of five sectors covering approximately 262 ha of riparian territory. Actions were planned for the removal of rubble mound breakwaters and embankments within the public water domain, the restitution of fluvial habitats in these sectors, the acquisition of estates and the establishment of stewardship agreements, as well as the extension of the current Segre Partial Nature Reserve. The estimated total cost of these actions is between 6.8 and 10.2 million euros (Figure 111).



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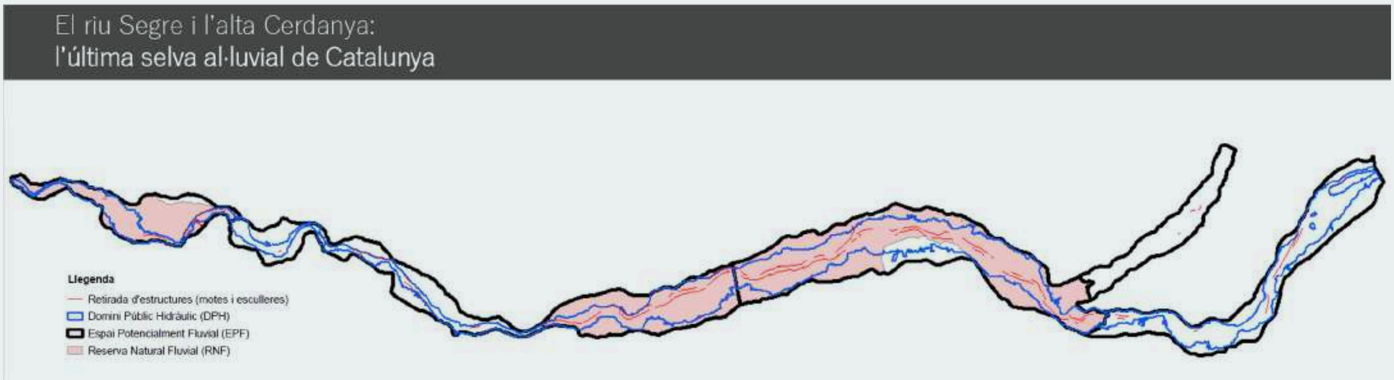

SECTOR	1) Objectius en DPH						2)Objectius fora de DPH	COST EXECUCIÓ	
	Retirada d'escculleres		Retirada de motes		Sup. Actuació (dins d'EPF)		(Ampliació RNF)	entre	
	ml	%	ml	%	ha	%	ha		
1	564.82	29%	1,631.76	72%	128.83	41%	0.00	1,040,000 €	1,560,000 €
2	320.56	100%	7,896.47	100%	210.85	55%	132.01	2,000,000 €	3,010,000 €
3	930.00	92%	3,680.33	100%	90.53	57%	67.42	2,370,000 €	3,550,000 €
4	48.87	6%	1,316.11	81%	47.87	32%	0.00	830,000 €	1,240,000 €
5	835.15	64%	956.32	100%	49.15	41%	63.32	600,000 €	900,000 €
TOTAL	2,699.40	50%	15,480.98	94%	527.23	47%	262.75	6,840,000 €	10,260,000 €

Figure 111 /

Sectors proposed for the actions of the preliminary project "Proposals for the protection, restoration and enhancement of the alluvial landscape of Cerdanya" (2019). Source: Catalunya La Pedrera Foundation.

The second aspect of the proposal, the river path, was entrusted to the ACNA company, which specializes in hiking and which had been developing the Vies Blaves (Blue Ways) of the Llobregat River for Barcelona Provincial Council. The proposed route, to be travelled exclusively on foot, is 38.4 km long, with a minimum width of 2.5 m. Seventy percent of the route follows existing paths and infrastructures (bridges) along the banks of the river. It is proposed to build up to three footbridges or suspension bridges over the river (figures 112-114). The details are set out at the following Instamaps link:

https://www.instamaps.cat/visor.html?businessid=33ea9ab7dcc3c5a0fd979deb66197f7a&3D=fal#12/42.3143/1.8279

The proposal was submitted to a Board of Mayors of the county of Cerdanya in October 2019, obtaining the initial approval of the 17 mayors and Cerdanya County Council. Subsequently, several working meetings were held with each of the municipalities involved, in order to specify the details of the proposal affecting each municipality.

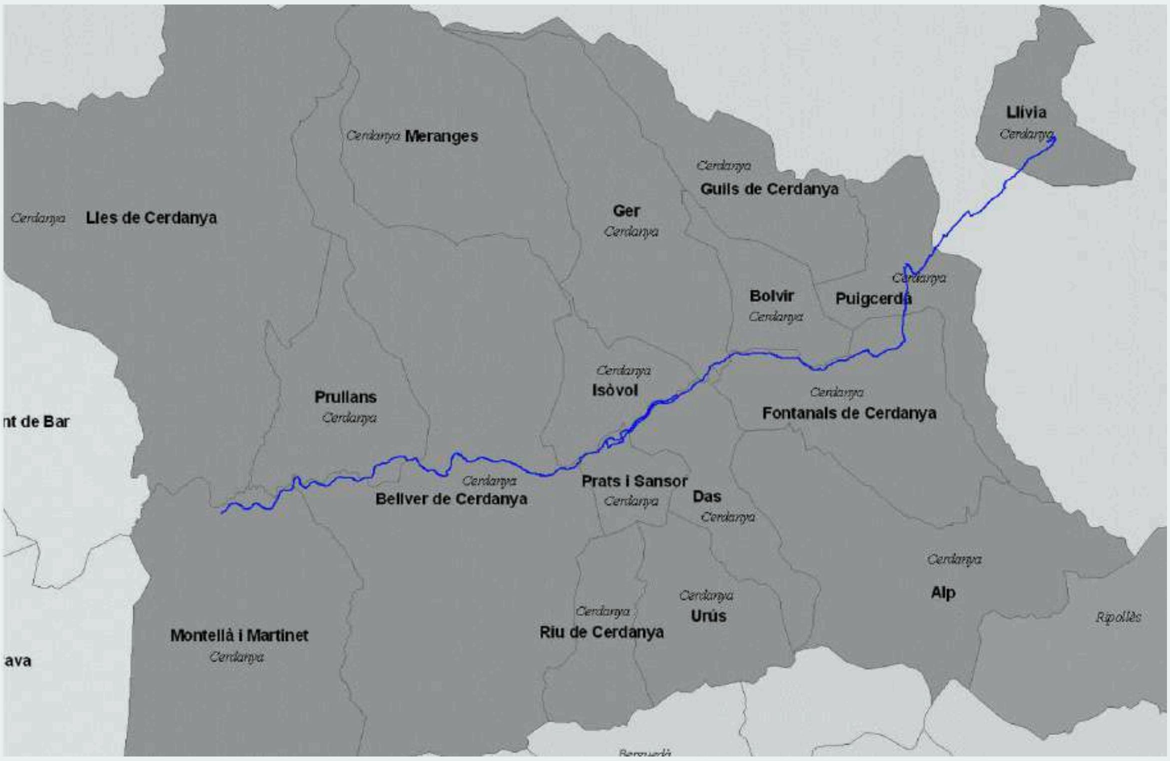

Figure 112 /

Layout of the proposed (preliminary project) Segre Path, between Martinet and Llívia. Source: Catalunya La Pedrera Foundation.

Figure 113 /

Map of the main actions planned for the Segre Path. Source: Catalunya La Pedrera Foundation.

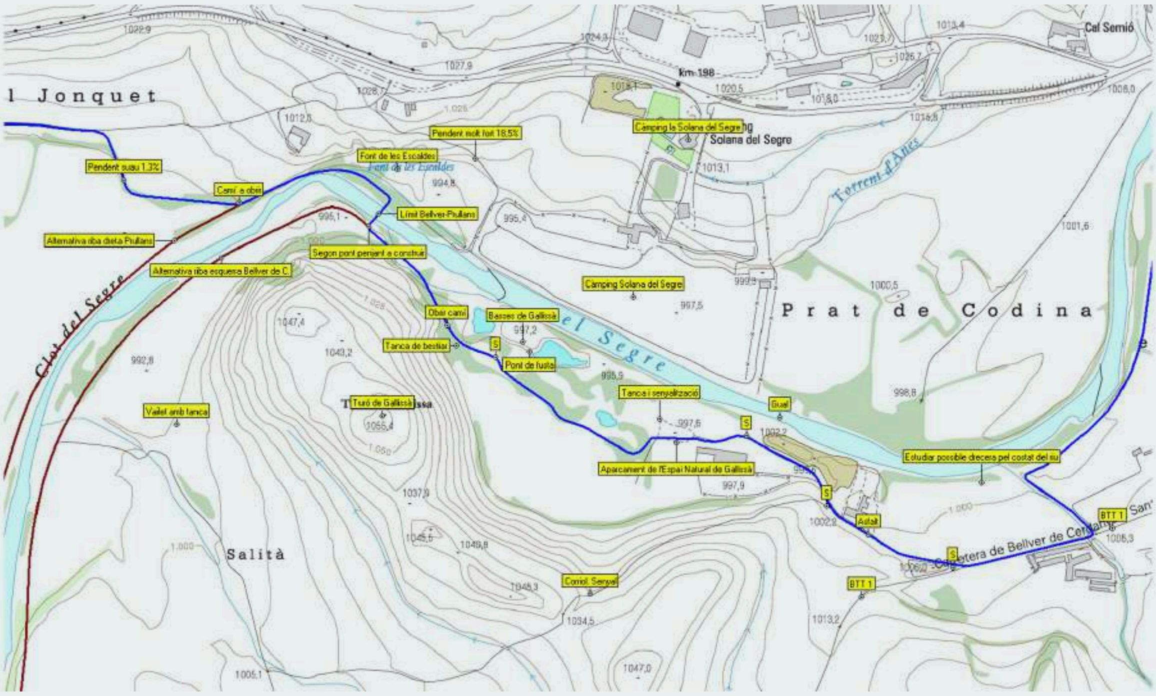

Figure 114 /

Close-up of the proposed (preliminary project) Segre Path, where it passes through the Gallissà Ponds site (Bellver de Cerdanya). Source: Catalunya La Pedrera Foundation.

Subsequently, at the end of 2019 and start of 2020, this proposal was submitted to the Government of Catalonia (Environment Secretariat and Directorate General for Environmental Policies and the Environment), which also approved its implementation, as well as agreeing to advocate it before the Ebro Hydrographic Confederation.

Despite the operational difficulties that arose during the 2020-21 pandemic, the project was also submitted to Ceretània, a local environmental association, which viewed it extremely positively.

In terms of funding, it proved possible to include the proposal in a European programme in order to opt for a Horizon2020 grant in its Green Deal call for proposals within the European "Blue Rivers" consortium. The project was proposed as an example of European river restoration in which both environmental and tourism values are promoted. Unfortunately, the project was not selected given the large number of proposals submitted in this call (a single European project was selected within the terrestrial ecosystem category from more than 200 candidates).

Nevertheless, Cerdanya County Council, with the assistance of the Catalunya La Pedrera Foundation, submitted the actions planned in the "River Path" preliminary project in the Next Generation 2021 call for proposals, within the "Naturally Lleida" programme submitted by Lleida Provincial Council, obtaining a grant of €350,000, which is expected to be tendered and executed between 2023 and 2025. It is expected that an executive project can be drawn up for the entire section, as well as various actions and infrastructures related to the path, within the province of Lleida. Furthermore, it is expected that the county council will apply for additional resources through the 2022 and 2023 calls of the Next Generation programme, also including the proposed environmental restoration measures.

With regard to environmental planning, it was considered essential to submit this proposal to the Ebro Hydrographic Confederation (CHE). This was done through a paper presented by the Catalunya La Pedrera Foundation (with the support of the Ceretània association) within the Public Information period of the Hydrological Plan of the Ebro Basin: *"Proposal for the inclusion of a stretch of the Segre River (Cerdanya, Lleida) as a new fluvial nature reserve of the Ebro Demarcation (October 2020)",* as well as in an online meeting with senior staff of the Hydrological Planning Office of the CHE. The CHE considered that it was not feasible to list the Cerdanya stretch of the Segre as a Fluvial Reserve, considering that it lacks the level of naturalness required in order to be awarded this protection status. Nonetheless, it expressed its interest in implementing the proposed hydrological and protective actions, within the new schedule of actions of the basin. It remains to be seen which specific proposals are finally accepted within the schedule of the Ebro Hydrological Plan. It is necessary to continue to emphasise the need to implement the actions for environmental reasons and to improve protection against flooding from the river.

Alder grove to natural dynamics in the Segre River Reserve of the Catalunya La Pedrera Foundation / Photo: Jordi Bas.

Sampling of riparian vegetation and aquatic macrophytes. Segre River, Bellver de Cerdanya / Photo: Jordi Bas.

8 /

MONITORING INDICATORS OF THE LIFE ALNUS PROJECT: AQUATIC HABITATS

8a / MONITORING INDICATORS OF THE LIFE ALNUS PROJECT: AQUATIC HABITATS

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8a.1. Introduction

The LIFE ALNUS project has used different monitoring indicators for aquatic environments and habitats (in relation to macroinvertebrates and fish) and riparian ecosystems (in relation to forest sites, birds, bats and other mammals).

The monitoring program had the following objectives:

1. Assessing the impact of the habitat conservation and restoration measures taken in relation to the bioindicator communities and organisms: i) establishing an environmental flow regime in the Ter River and Congost River; ii) hydromorphological restoration of the river and riparian forest in the Segre, Ter and Congost river basins (see the corresponding chapters in this manual).

2. Identifying the variables at a habitat level and for the whole set of sectors studied, which influence the richness and abundance of the taxonomic groups and aquatic and riparian bioindicators.

3. Integrating the information generated by the study of the bioindicators in the planning of the measures and actions involved in the LIFE ALNUS project and their subsequent adaptive management and replicability in other river basins.

The active habitat restoration (or rehabilitation) of the LIFE ALNUS project consisted of the following measures:

1. Silvicultural vegetation treatment. In the Ter River basin above the Sau reservoir and the Besòs river basin. For an overview of the actions taken, see chapters 3 and 4.

2. Regulation of competition from low intensity selection felling and sprout selection.

3. Treatment of invasive species.

4. Restoration of the riparian forest (habitat defragmentation or reintroduction) or reinforcement of the existing vegetation by planting native species. In the Ter River basin above the Sau reservoir, and the Besòs river basin.

5. Hydromorphological improvement. Along three stretches: on the Congost River from Granollers to Canovelles; on the Ter River from Les Masies de Voltregà to Torelló; and on the Segre River in Bellver de Cerdanya. For an overview of these measures, see chapters 5, 6 and 7.

6. Restoration of environmental flows at hydro power plants. El Mariner (Camprodon) and Gallifa (Les Masies de Voltregà) weirs. .

This chapter gives a description of the indicators associated with aquatic habitats. Samples were taken during the period 2018-2020 in all cases, except for the Ter River along the stretch that flows through the county of Osona as the sampling continued until 2022.

8a.2. Areas of study

Four sectors of three different Catalan river basins were monitored: one more urban and industrial (the Congost), the other two more rural, in an intensive (the Ter) and extensive (the Segre) farming and livestock environment. Specifically, the following aspects were tested in each of the sectors (Figure 115):

1. Ter River in Camprodon (El Ripollès county): establishment of an environmental flow regime.

2. Ter River in Les Masies de Voltregà and Torelló (Osona county): establishment of an environmental flow regime and a hydromorphological restoration of the river and the riparian forest.

3. Congost River (Besòs river basin) in La Garriga, Canovelles and Granollers (El Vallès Oriental county): establishment of an environmental flow regime and a hydromorphological restoration of the river and the riparian forest.

4. Segre River (Ebre river basin) in Bellver de Cerdanya and Prullans (La Cerdanya county): a hydromorphological restoration of the river and the riparian forest.

Pond restored in the Les Basses de Gallissà project, Segre River, Bellver de Cerdanya / Photo: Jordi Bas.

Segre River in Bellver de Cerdanya (La Cerdanya).

Ter River in Camprodon (El Ripollès).

Ter River in Les Masies de Voltregà (Osona).

Congost River in La Garriga (El Vallès Oriental).

Figure 115 /

Areas of study of the LIFE ALNUS project. Base map: Catalan Water Agency.

8a.3. Methodology

The assessment conducted used an approach based on Before-After Control-Impact (BACI) analysis, which involves sampling in at least two different periods: before and after carrying out restoration measures, comparing restored and control sectors, both before and after the potential impact. This is an effective method for evaluating the effect of natural and man-made disturbances on ecological variables. In this case, the samples were taken each year in the spring-summer period and in the autumn, to gather the desired information both before and after the summer drought.

We conducted multi-habitat quantitative sampling of aquatic macroinvertebrates (MAGRAMA, 2013; sections 1-8), which enables the calculation of different indices of the biological quality of the water: IBMWP (Alba-Tercedor & Sánchez-Ortega, 1988; Alba-Tercedor et al., 2002), FBILL (Prat et al., 2000a), IASPT (Alba-Tercedor et al., 2002), EPT (number of families belonging to the Ephemeroptera, Plecoptera and Trichoptera orders; Lenat, 1983) and OCH (number of families of the Odonata, Coleoptera and Heteroptera orders; Lenat, 1983). The ash-free dry mass (AFDM) was calculated to estimate the biomass (DW) of aquatic macroinvertebrates at each sampling point for each family/genus (Figure 116).

The fish population was assessed using electrofishing systems (taxonomic composition, individuals/100 m and biomass/ha), in accordance with the BIORI guidelines (*Protocol for the evaluation of the biological quality of rivers*) of the Catalan Water Agency (2006), as well as with the CEN UNE-EN 14011:2003 regulation (*Water Quality – Sampling of fish with electricity*; European Commission, 2003). More measurements were taken regarding water width, depth and speed every 10 metres of each sampled stretch to collect additional data on the aquatic habitat and determine the optimal site for sampling fish. Lastly, the IBICAT index (Sostoa et al., 2012) was calculated.

The sampling was complemented by the calculation of hydromorphological parameters: of the river habitat (to calculate the IHF, RBPS and RHS indices; Pardo et al., 2002; Barbour et al., 1998; Raven et al., 1997, respectively) and the quality of the riparian vegetation (to calculate the QBR index; Munné et al., 2003), in accordance with the Water Framework Directive (EU, 2000) and the criteria adopted by the Catalan Water Agency. Moreover, a detailed map was made of the mesohabitats of the river bed (in line with Vezza et al., 2011) for a geo-referenced graphical representation of the distribution of aquatic habitats and data processing, using the

Figure 116 /

Images of different samplings of aquatic environments in the areas of study of the LIFE ALNUS project. Photos: CERM-UVic-UCC.

Submerged alder roots, a magnificent example of the association between forest and water (Fornès river, Ter basin) / Photo: Jordi Bas.

MiraMon Geographic Information System (Pons, 2004). The physicochemical parameters of the water were also determined using portable probes (pH, electrical conductivity, temperature and dissolved oxygen) and the flow rate at each sampling point (using the velocity-area method; Hauer & Lamberti, 2007). In addition, within the framework of the Life Alnus project, five new gauging stations were installed and consulted regularly (which can be consulted online: https://lifealnus.eu/aca-smarty-planet): two in the Ter River in El Ripollès (upstream and downstream of the Mariner dam in Camprodon), two in the Ter River in Osona (upstream and downstream of the Gallifa dam at Les Masies de Voltregà), and one in Canovelles (downstream of the Fangar pond). Data was also taken from the Catalan Water Agency's gauging station on the Congost that was already in place in La Garriga (http://aca-web.gencat.cat/aetr/vishid).

8a.4. Results obtained

On a preliminary basis and, an improvement in the aquatic and riparian environments was observed after the measures taken, pending a more in-depth and medium-term analysis, especially in the Ter River in Osona, bearing in mind that some of the actions in this area were carried out towards the end of 2022.

8a.4.1. Upper-stretch of the Ter River (El Ripollès)

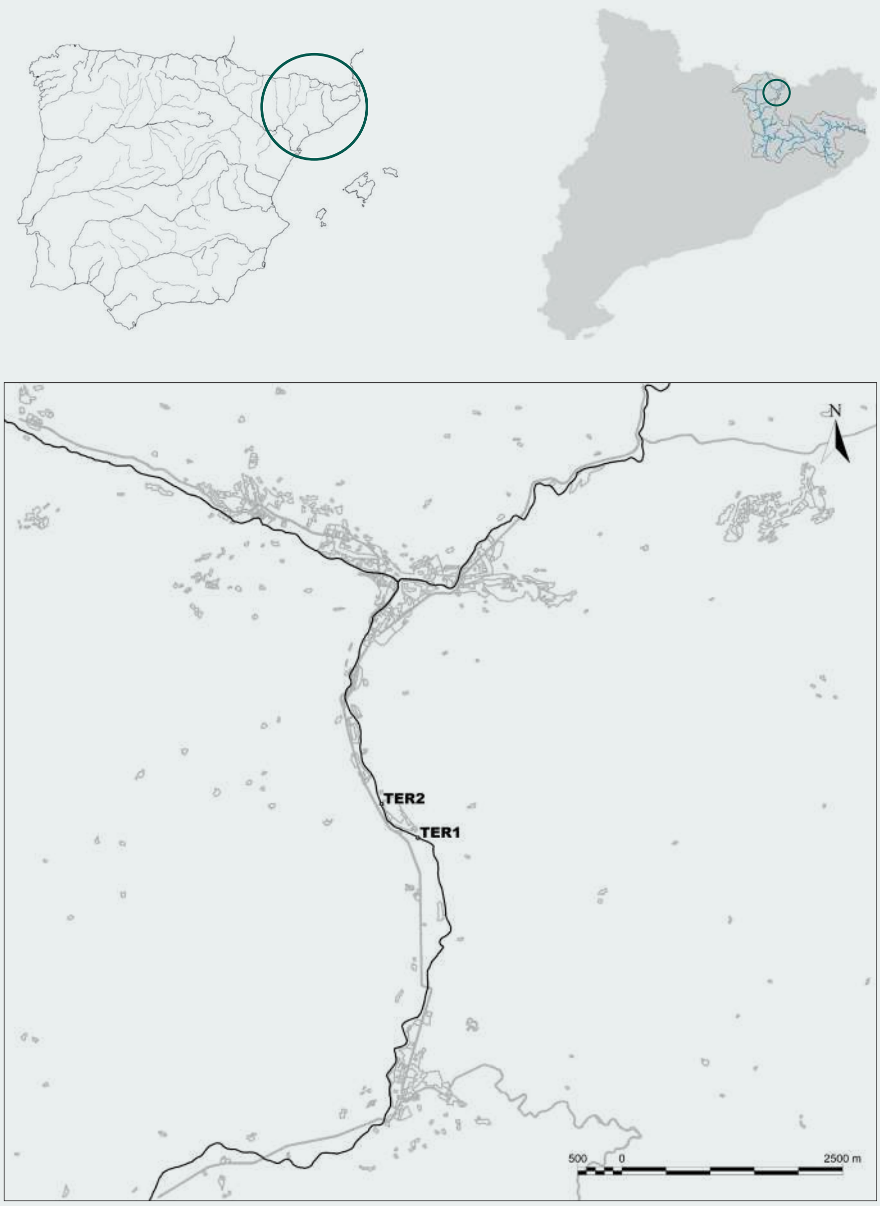


Figure 117 /

Sampling points of the LIFE ALNUS project on the Ter River in El Ripollès county in the period 2018-2020. Key: TER1: upstream of El Mariner weir (Camprodon); TER2: downstream of El Mariner weir (Camprodon).

The aim of this sampling was to evaluate the establishment of an environmental flow regime, by mutual agreement of the hydro power company Estabanell y Pahisa, SA, the Catalan Water Agency and the Centre for the Study of Mediterranean Rivers, University of Vic - Central University of Catalonia, in line with the following criteria:

- First half of 2018: ordinary operation of the hydro power plant, in the same way as to date, with an estimated maintenance flow rate of around 10% of the environmental flows specified in the Sector Plan on the Maintenance of Environmental Flows of the inland river basins (PSCM; ACA, 2005), which was 1.7 m^3/s from October to March, 1.384 m^3/in April and May, 1.73 m^3/s in June, and 2.595 m^3/s from July to September.

- Second half of 2018 (from 1/06 onwards): minimum release of 40% of the flow specified in the PSCM during the ‘critical period’, from July to December, corresponding to 2.595 m^3/s.

- 2019 onwards: minimum release of 60% of the flow specified in the PSCM during the ‘critical period’, from July to December, corresponding to 2.595 m^3/s.

Except when the river flooded, the flow of the Ter River was far higher upstream of El Mariner weir (Camprodon) than downstream (Figure 118), but the environmental flow regime established from 1st June 2018 onwards by the hydro power company Estabanell y Pahisa SA reduced this difference enormously compared to previous years. The two stretches are characterized by the predominance of high-speed flows.

The quality of the riparian forest is good, being almost natural at both sampling points. A clear disturbance was observed in the winter of 2018 caused by Storm Leslie, which reduced the plant cover on the flood plain. By the summer of 2019, however, the plant cover had returned to a phase of better quality, but the recovery was faster downstream of the weir, which gained a higher score on the Riparian Forest Quality index (QBR) than further upstream. In the period 2018-2020, the results of the River Habitat Index and the Rapid Bioassessment Protocol were, in general, optimal in terms of aquatic macroinvertebrates and fish.

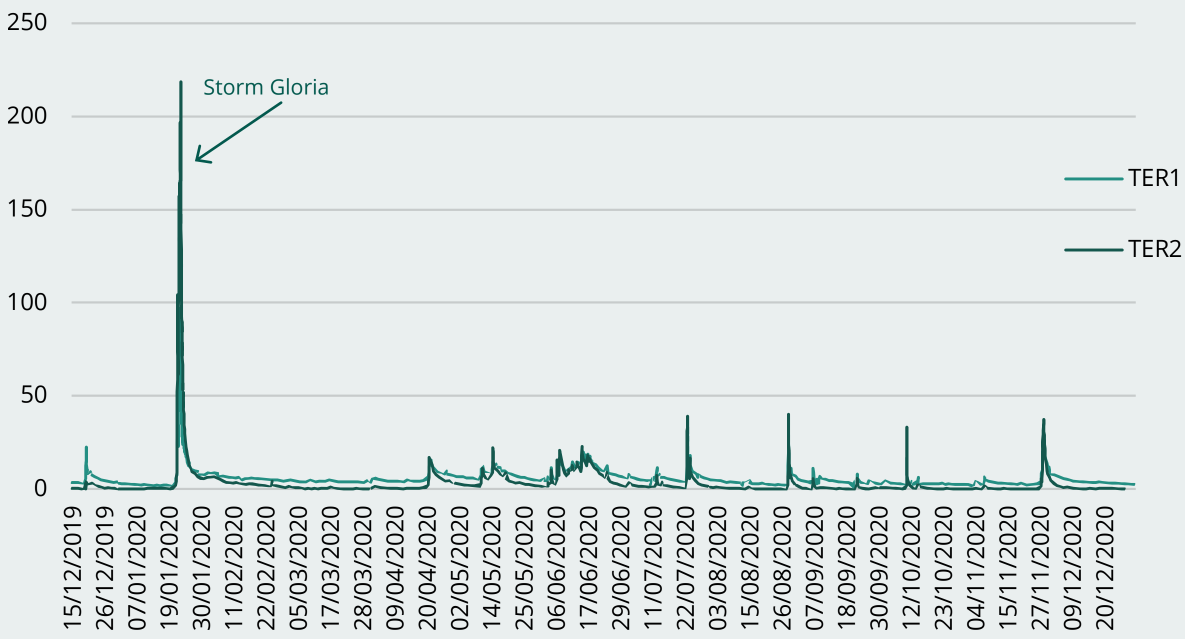


Figure118 /

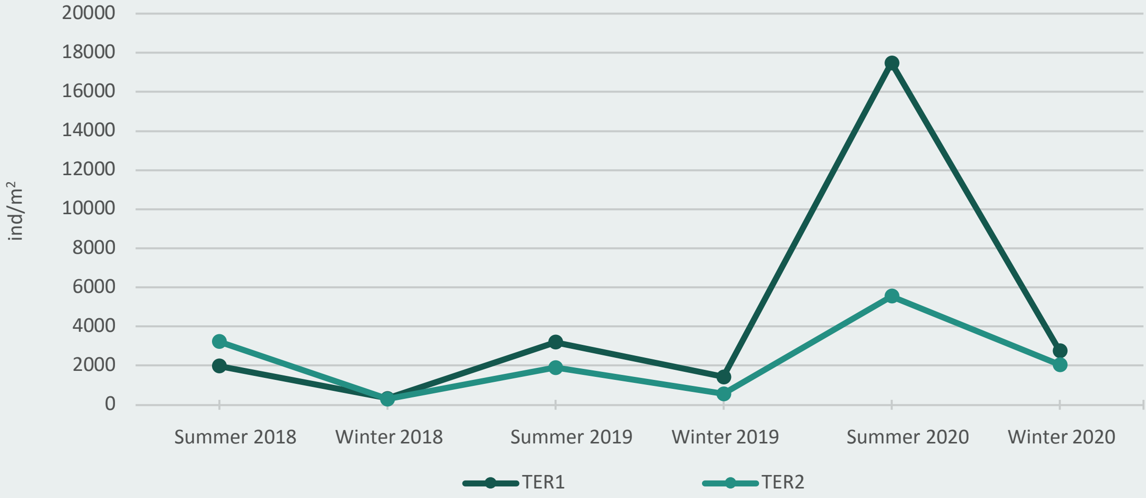
Average daily flow in the period July 2019-December 2020 obtained from the gauging stations of the LIFE ALNUS project in the Ter River in El Ripollès. Source: https://lifealnus.eu/aca-smarty-planet

River arm rehabilitated in the river Ter (Illa de les Gambires, Torelló), objective of monitoring the aquatic communities of LIFE ALNUS / Photo: Jordi Camprodon.

The density of aquatic macroinvertebrates (Figure 119) is higher in the summer, when there is far greater productivity in the rivers, including in terms of photosynthesis, than in the winter. Upstream of El Mariner weir (TER1), the density in the summer of 2018 was lower than downstream of the weir (TER2), but the opposite situation was observed in during the summers of 2019 and 2020. In the winter of 2018, the density was lower than in 2019. These low figures could be related to Storm Leslie (October 2017). In 2020, macroinvertebrate density and biomass were considerably higher than in the previous years at both sites. A detailed analysis is required to ascertain whether there was a recovery after the flooding caused by Storms Leslie and Gloria. Moreover, there were more macroinvertebrates upstream than downstream of the weir, where mesohabitats flourish with relatively high speeds, which can promote the drift of such fauna. The macroinvertebrate biomass displays the same pattern as the density, also being higher in the summer than in the winter (Figure 119).

The most abundant families of aquatic macroinvertebrates in this sector are: *Chironomidae, Leuctridae, Ephemerelidae, Hepatgeniidae, Simulidae and Hydropsychidae*. The proportion of each group changes depending on the season and year. The number of macroinvertebrate taxa tends to increase over time. In general, there are more taxa upstream of the weir than downstream and the gradual increase over the years is also more notable than downstream. The progressive increase in the environmental flows may also play a role in this respect.

The biological quality of the water based on aquatic macroinvertebrates is very high along both stretches. However, downstream of the weir, where there is far greater oxygenation and less sediment deposited over the course of the year, the quality of the water is relatively better than upstream (Figure 120).



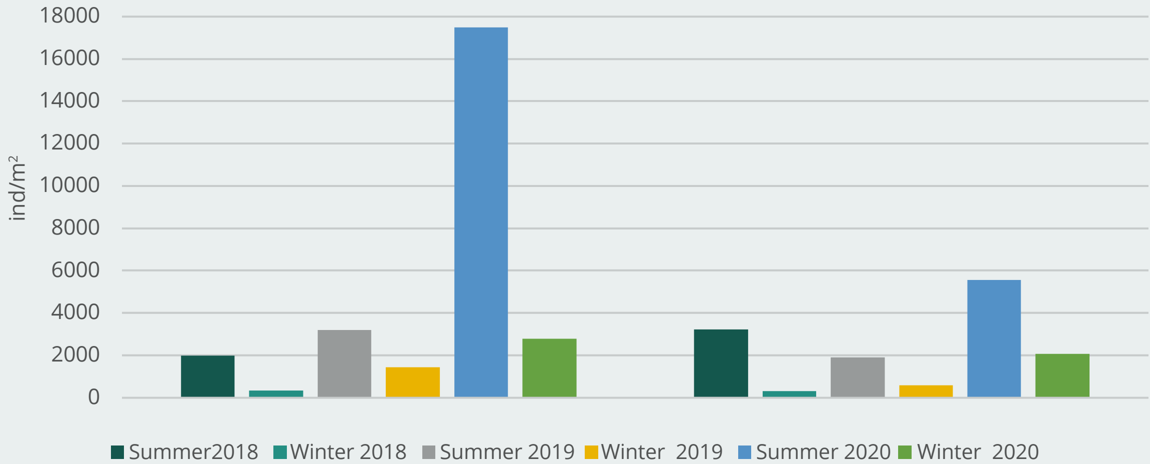


Figure119 /

Density (top) and biomass (bottom) of aquatic macroinvertebrates in during the period 2018- 2020 in the Ter River in El Ripollès. Key: TER1: upstream of El Mariner weir (Camprodon); TER2: downstream of El Mariner weir (Camprodon).

Brown trout (*Salmo trutta*) is the predominant species in the fish population of the Ter River in Camprodon, both upstream and downstream of El Mariner weir. They are accompanied by a small number of another native species, the Mediterranean barbel (*Barbus meridionalis*), and an invasive species originating from Central Europe, the stone loach (*Barbatula barbatula*) (Table 5).

Some years, differences in fish density can be detected between either side of El Mariner weir (Figure 121). The biggest change was recorded in 2020, when the fish density fell in the summer, and even further in the winter and downstream of the dam, reaching values lower than any previously detected. This change is assumed to be related to a broken wastewater sewer upstream, which unfortunately affected the whole stretch of river being studied.

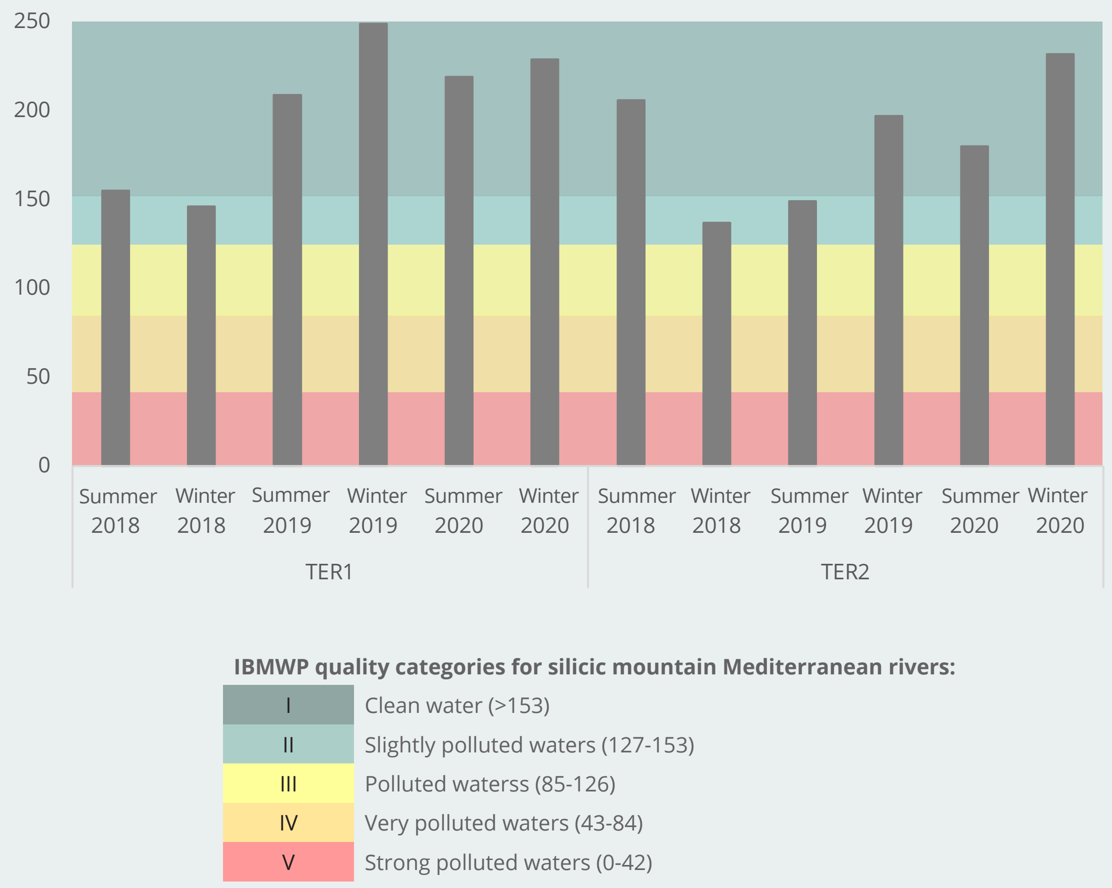


Figure120 /

IBMWP biological quality index, based on aquatic macroinvertebrates in the period 2018-2020 in the Ter River in El Ripollès county. Key: TER1: upstream of El Mariner weir (Camprodon); TER2: downstream of El Mariner weir (Camprodon).

Table 5 / **Fish population in the period 2018-2020 in the upper Ter river basin (El Ripollès county). Conservation status in Spain according to the Red List of Spanish Vertebrates; worldwide, according to the IUCN Red List. Drawings: Toni Llobet.**

Species	Conservation status	
Brown trout (*Salmo trutta*)	In Spain: Vulnerable Worldwide: Low concern	
Mediterranean barbel (*Barbus meridionalis*)	Habitats Directive 92/43/EEC, Annexes II and V. In Spain: Vulnerable Worldwide: Vulnerable	
Stone loach (*Barbatula barbatula*)	Invasive species	

Figure 121 /

Density (top) and biomass (bottom) of fish in the period 2018-2020 in the Ter River in El Ripollès. Key: TER1: upstream of El Mariner weir (Camprodon); TER2: downstream of El Mariner weir (Camprodon).

8a.4.2. Mid-stretch of the Ter River (Osona)

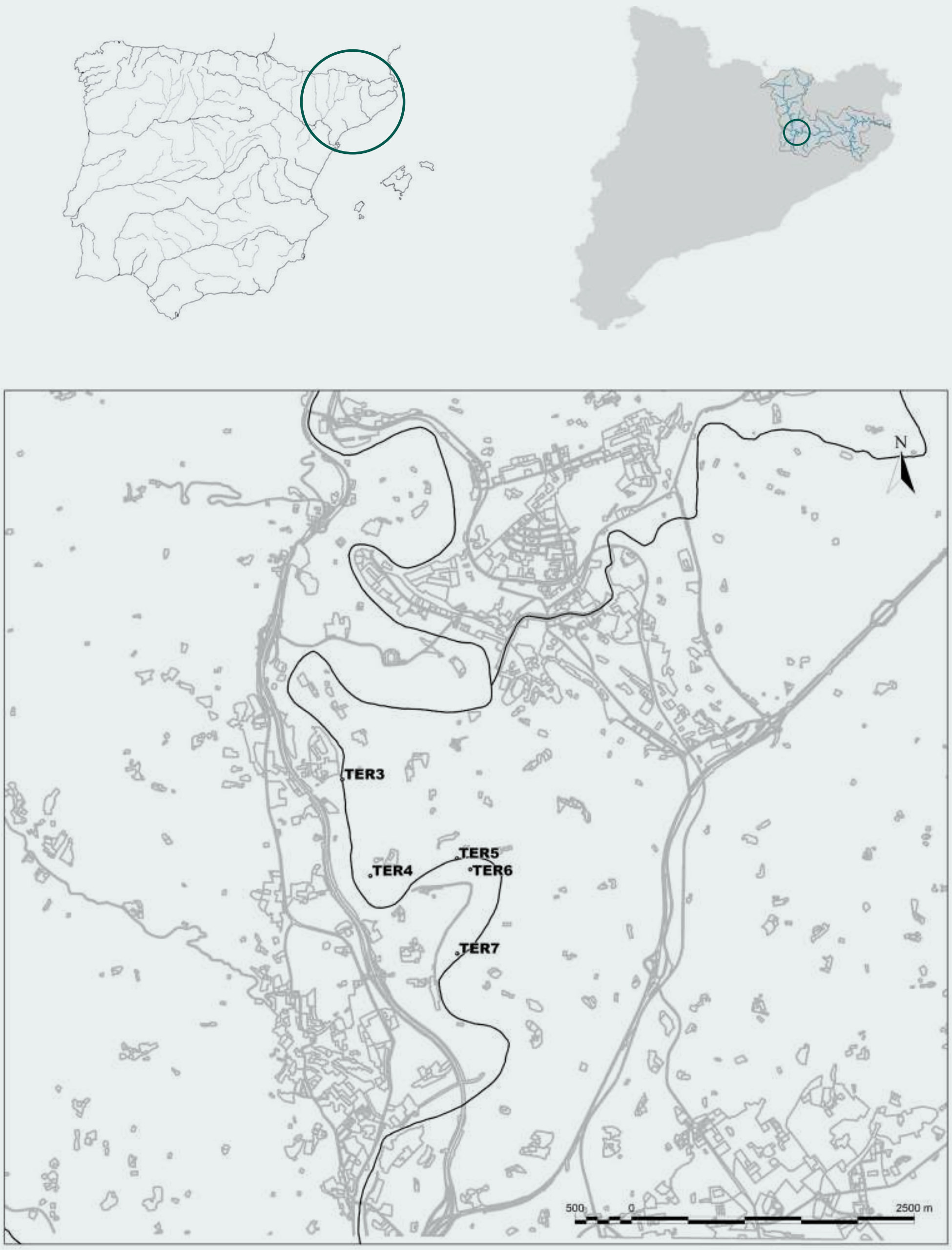


Figure 122 /

Sampling points of the LIFE ALNUS project in the Ter River in the Osona county in the period 2018-2022. Key: TER3: Ter River, upstream of Les Gambires island and Gallifa weir (Les Masies de Voltregà); TER 4: secondary branch of the Ter River at Les Gambires island, upstream of the Gallifa weir (Les Masies de Voltregà); TER 5: main branch of the Ter River at El Sorral island, downstream of the Gallifa weir and the ford (that was demolished in May 2022); TER 6: secondary branch of the Ter River at El Sorral island, downstream of the Gallifa weir and the ford (demolished in May 2022); TER7: Ter River, downstream of El Sorral island (Les Masies de Voltregà).

Another sector of the arm. of rehabilitated river in the river Ter (Illa de les Gambires, Torelló), objective of monitoring the aquatic communities of LIFE ALNUS. Photo: Jordi Camprodon.

Our objective here was to evaluate, on the one hand, the establishment of an environmental flow regime from January 2019 onwards and, on the other, the hydromorphological restoration of Les Gambires and El Sorral islands, carried out between the autumn of 2021 and May 2022.

The establishment of an environmental flow regime, by mutual agreement of the hydro power company Estabanell y Pahisa, SA, the Catalan Water Agency and the Centre for the Study of Mediterranean Rivers, University of Vic - Central University of Catalonia, was carried out in line with the following criteria:

- 2018: ordinary operation of the hydro power plant, in the same way as to date, with an estimated maintenance flow rate of around 10% of the environmental flow specified in the Sector Plan on the Maintenance of Environmental Flow of the Catalonia's inland river basins (PSCM; ACA, 2005), which was 3.5 m^3/s from October to March, 4.5 m^3/ in April and May, 3.5 m^3/s in June, and 2.8 m^3/s from July to September.

- 2019: minimum release of 30% of the flow specified in the PSCM during the 'critical period', from July to September, corresponding to 2.8 m^3/s.

- 2020 onwards: minimum release of 60% of the flow specified in the PSCM during the 'critical period', from July to September, corresponding to 2.8 m^3/s.

Before the hydromorphological restoration of Les Gambires island and the removal of El Sorral island ford (completed in May 2022), the river flow was very low or practically non-existent in the secondary river branches around Les Gambires (TER4) and El Sorral islands (TER6). After the restoration, the flow increased considerably in the secondary branch around Les Gambires island but not in the case of El Sorral island (possibly due to the existence of a groin that was not removed). In the main course of the Ter River, a reduction in the flow was observed from upstream of the Gallifa weir (TER3) to downstream (TER5, TER7), due to the bypass effect of the Gallifa weir. In drier years, reduced flows lead to even lower water speeds, with the practical disappearance of rapids, a reduction in riffles, a predominance of laminar flow and a general loss of habitat diversity (Figure 123).

The quality of the riparian forest scored highly on the Riparian Forest Quality index (QBR) on several of the stretches sampled, although there was a slight disturbance (TER3, TER4 and TER5), primarily because of the fragmentation and the narrow width of the riparian forest. Communities of invasive species (*Robinia pseudoacacia*, *Populus* sp.) were found everywhere, as well as the modification of alluvial terraces in some stretches. The results of the River Habitat Index (IHF) and Rapid Bioassessment Protocol (RBPS) show that, along the main riverbed of the Ter River (TER3, TER5 and TER7), there are optimal conditions for communities of fish and aquatic macroinvertebrates but, on the secondary branches (TER4, TER6), the quality of the habitat is suboptimal, primarily due to the predominance of slow flow patterns and an increase in deposition, particularly in the driest periods up to May 2022. From that date onwards, the conditions improved considerably in the secondary branch around Les Gambires island, which resumed its constant flow throughout the whole year, even during the extremely dry summer of 2022.

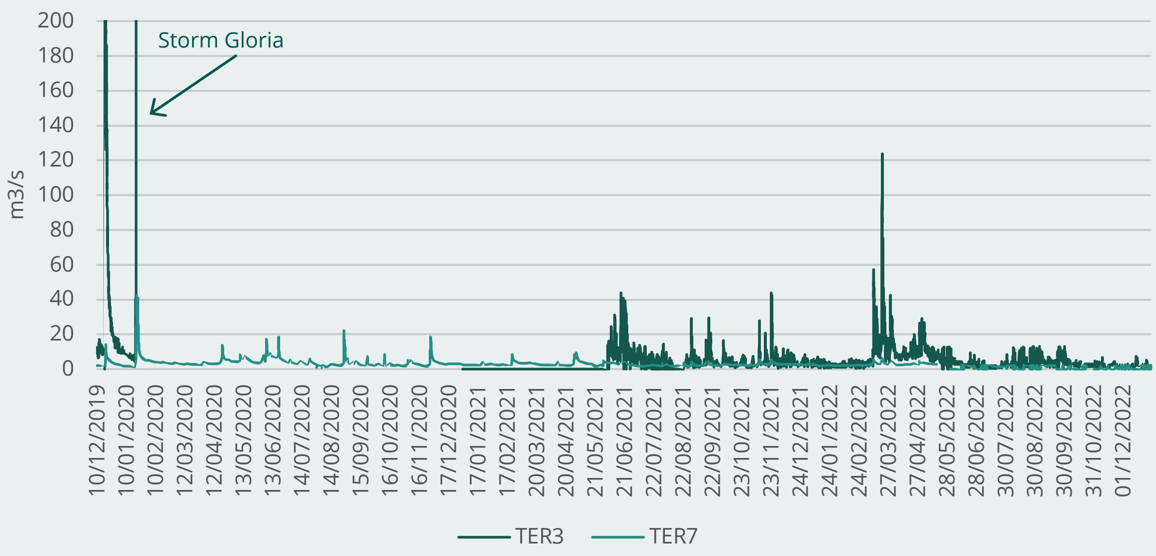


Figure 123 /

Average daily flow in the period July 2019-December 2020 obtained from the gauging stations of the LIFE ALNUS project in the mid-stretch of the Ter River in the Osona county. Key: TER3: Ter River, upstream of Les Gambires island and the Gallifa weir (Les Masies de Voltregà); TER7: Ter River, downstream of El Sorral island (Les Masies de Voltregà). Source: https://lifealnus.eu/aca-smarty-planet

In general, the aquatic macroinvertebrate density is higher in the spring than in the autumn. In the autumn of 2018, after Storm Leslie, all the sampling sites, except the one on the secondary branch around El Sorral island (TER6), experienced a significant reduction in macroinvertebrates. Since then, despite recovering in the spring of 2019, they slightly decreased at all the sampling points (Figure 124).

The most abundant families in the main branch are *Chironomidae, Hydropsychidae and Simuliidae* in the spring, and *Chironomidae, Corixidae, Caenidae, Simuliidae* and *Hydracarina* in the autumn. In the secondary branches, the predominant species are *Copepoda, Cladocera* and *Chironomidae*. The groups of Ephemeroptera, Plecoptera and Trichoptera, typical of riffles and rapids, are more abundant in the main branch than in the secondary branches. The lowest figures of all the sampling points are related to the impact of Storm Leslie, and Storm Gloria –but in the latter case, the effect was less severe than on the coast– and the lowest flows of the lateral branches, except from May 2022 onwards on the small branch around El Sorral island.

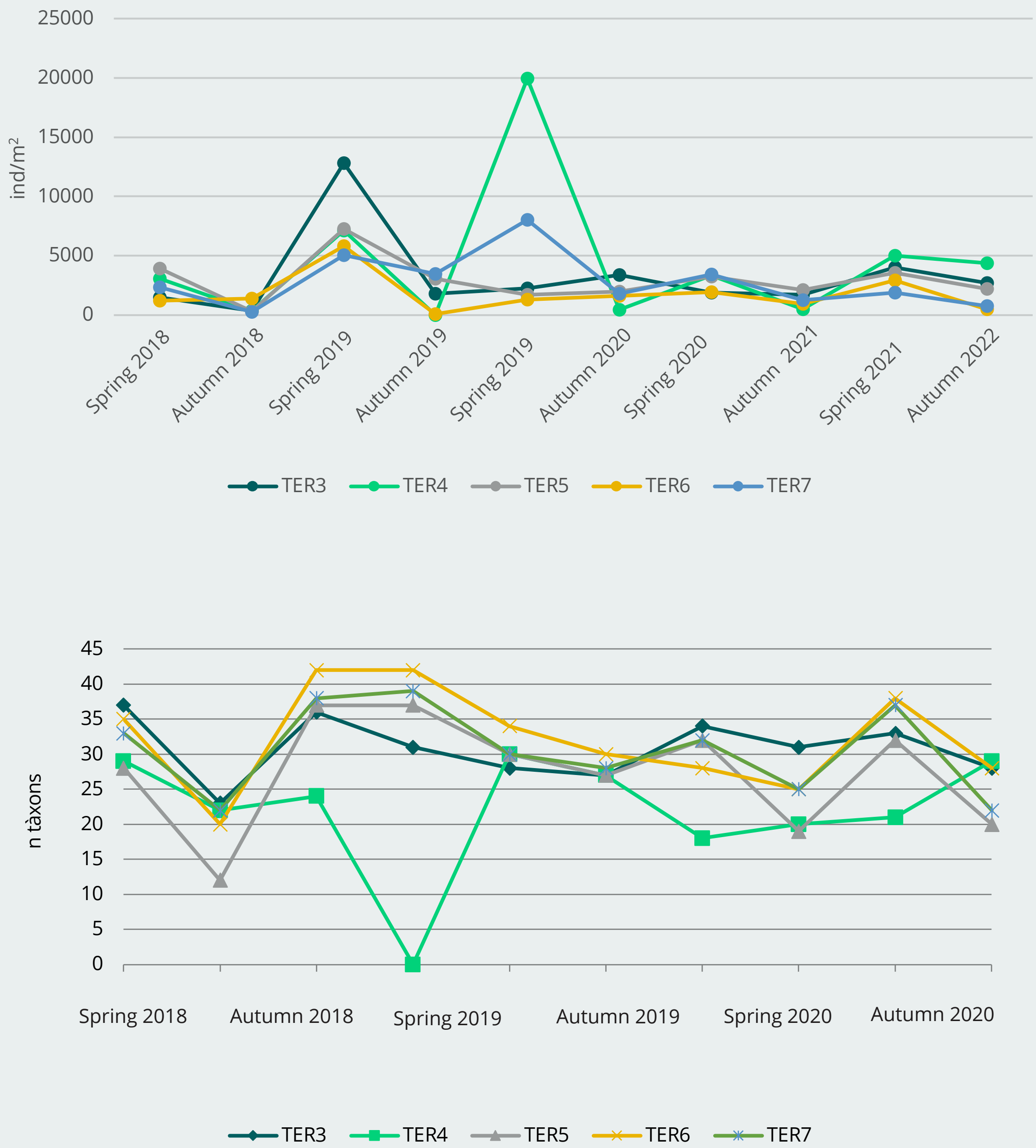
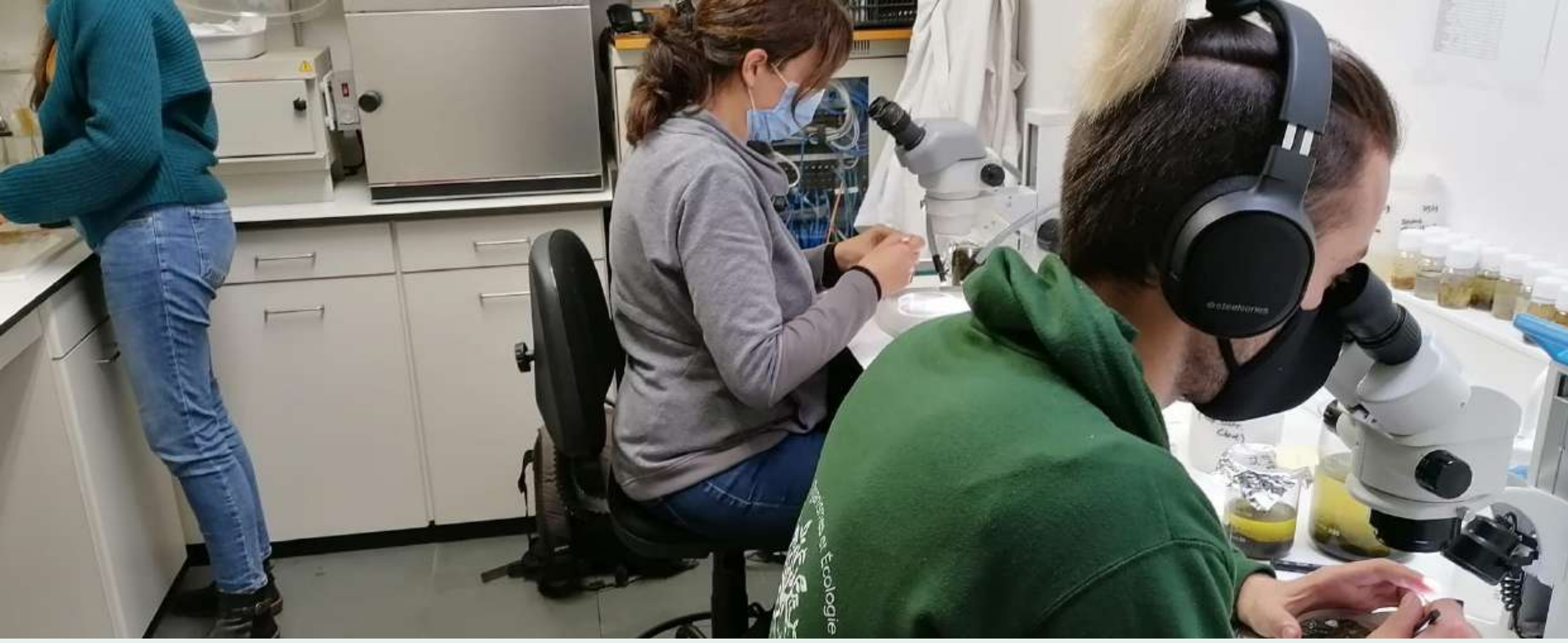


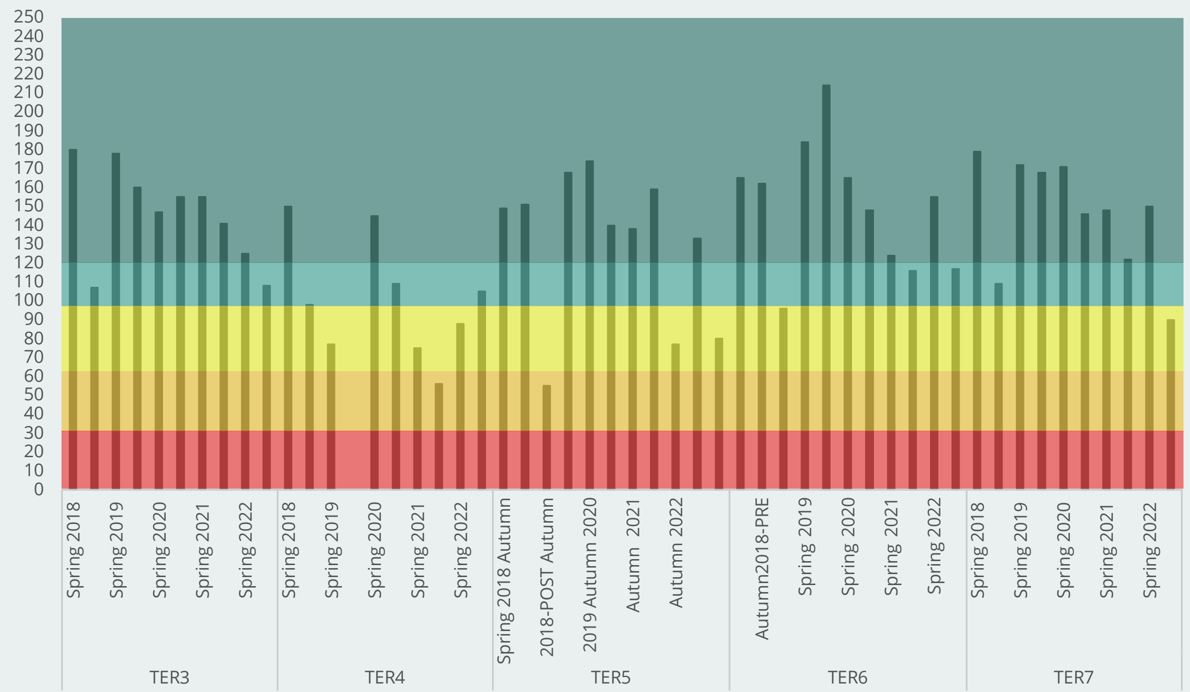
Figure 124 /

Density (top) and number of taxa (bottom) of aquatic macroinvertebrates in the period 2018-2020 in the mid-stretch of the Ter River in the Osona county.

The biological quality of the water based on aquatic macroinvertebrates is high or very high in most of the samples taken (Figure 125). The lowest values detected, indicating an intermediate level of water quality, are a consequence of the flooding that resulted from Storm Leslie. Another case of lower quality values was detected in the secondary branch around Les Gambires island (TER4) in the spring and autumn of 2019, when the flow decreased a great deal or, in the autumn, when the water stopped flowing completely.



Determination of aquatic macroinvertebrates in the CERM-UVic-UCC laboratories at the Museu del Ter. Photo: Marc Ordeix.



IBMWP quality categories for silicic wet mountain rivers:

I	Clean water (>121)
II	Slightly polluted waters (99-121)
III	Polluted waterss (66-98)
IV	Very polluted waters (34-65)
V	Strong polluted water (0-33)

Figure 125 /

IBMWP biological quality index (ALBA-TERCEDOR & SÁNCHEZ-ORTEGA, 1988; ALBA-TERCEDOR et al., 2002), based on aquatic macroinvertebrates in the period 2018-2020 in the Ter River in the Osona county.

Table 6 / **IBMWP biological quality index (ALBA-TERCEDOR & SÁNCHEZ-ORTEGA, 1988; ALBA-TERCEDOR et al., 2002), based on aquatic macroinvertebrates in the period 2018-2020 in the Ter River in the Osona county.**

Fish species	Status	
Mediterranean barbel (*Barbus meridionalis*)	Habitat Directive 92/43/EEC, Annexes II and V. In Spain: Vulnerable Worldwide: Vulnerable	
Catalan chub (*Squalius laietanus*)	In Spain: Vulnerable Worldwide: Vulnerable.	
Truita comuna (*Salmo trutta*)	A Espanya: Vulnerable Al món: Preocupació menor	
Common bleak (*Alburnus alburnus*)	Invasive species	
Black bullhead catfish (*Ameiurus melas*)	Invasive species	
Stone loach (*Barbatula* sp.)	Invasive species	
Common carp (*Cyprinus carpio*)	Invasive species	
Pumpkinseed sunfish (*Lepomis gibbosus*)	Invasive species	
Ebro barbel (*Luciobarbus graellsii*)	Invasive species	
Common minnow (*Phoxinus* sp.)	Invasive species	
Stone moroko (*Pseudorasbora parva*)	Invasive species	
Common roach (*Rutilus rutilus*)	Invasive species	

Stretch of calm waters in the river Ter (Isla de las Gambires, Torelló). Photo: Jordi Camprodon.

The fish community in the Ter River in its middle section in the Osona county is made up of at least eleven species (Table 6). Invasive species represent the largest proportion, with only two native species being found among the eleven: Mediterranean barbel (*Barbus meridionalis*) and Catalan chub (*Squalius laietanus*). The most abundant species of fish at all the sampling points and gauging stations was the common minnow (*Phoxinus* sp.), originating from Central Europe, except for the secondary branch around Les Gambires island (TER4), where, in some samples, there was a higher number of another exotic species, the stone moroko (*Pseudorasbora parva*), possibly favoured by the conditions of low water replenishment and low oxygen levels in the water. These conditions were reversed from May 2022 onwards, when the flow was reactivated and the fish population in the secondary branch around Les Gambires island became very similar to the population in the main branch of the Ter River.

In autumn 2020, the highest density was observed in the secondary branch of the Ter River around Les Gambires island, upstream of the Gallifa weir (TER4) and, after the application of an environmental flow regime, in the main branch of the Ter River at El Sorral island, downstream of the Gallifa weir and the ford (TER5). No clear pattern can be distinguished at all the stretches sampled but, on the secondary branch around Les Gambires island, where the flow progressively decreased, there was also a reduction in fish density over time (Figure 126). As mentioned earlier, this trend changed completely once the water was reactivated along this branch in May 2022.

Fish densities and biomass (Figure 126) were possibly affected by the barrier effect of the ford, in the first case, and a natural waterfall, in the other. On the bed of the main river (TER3, TER5 and TER7), the biomass is lower in the autumn than in the spring. This pattern is different on the secondary branches around the two islands (TER4 and TER6), where the fish are more scarce and smaller, and the density is practically the same in the spring and the autumn, due to the low flow rate, the sedimentation of fine materials and very low oxygen levels. This situation persists in the small branch around El Sorral island but changed in the case of the secondary branch around Les Gambires island due to the reactivation of the water flow from May 2022 onwards.

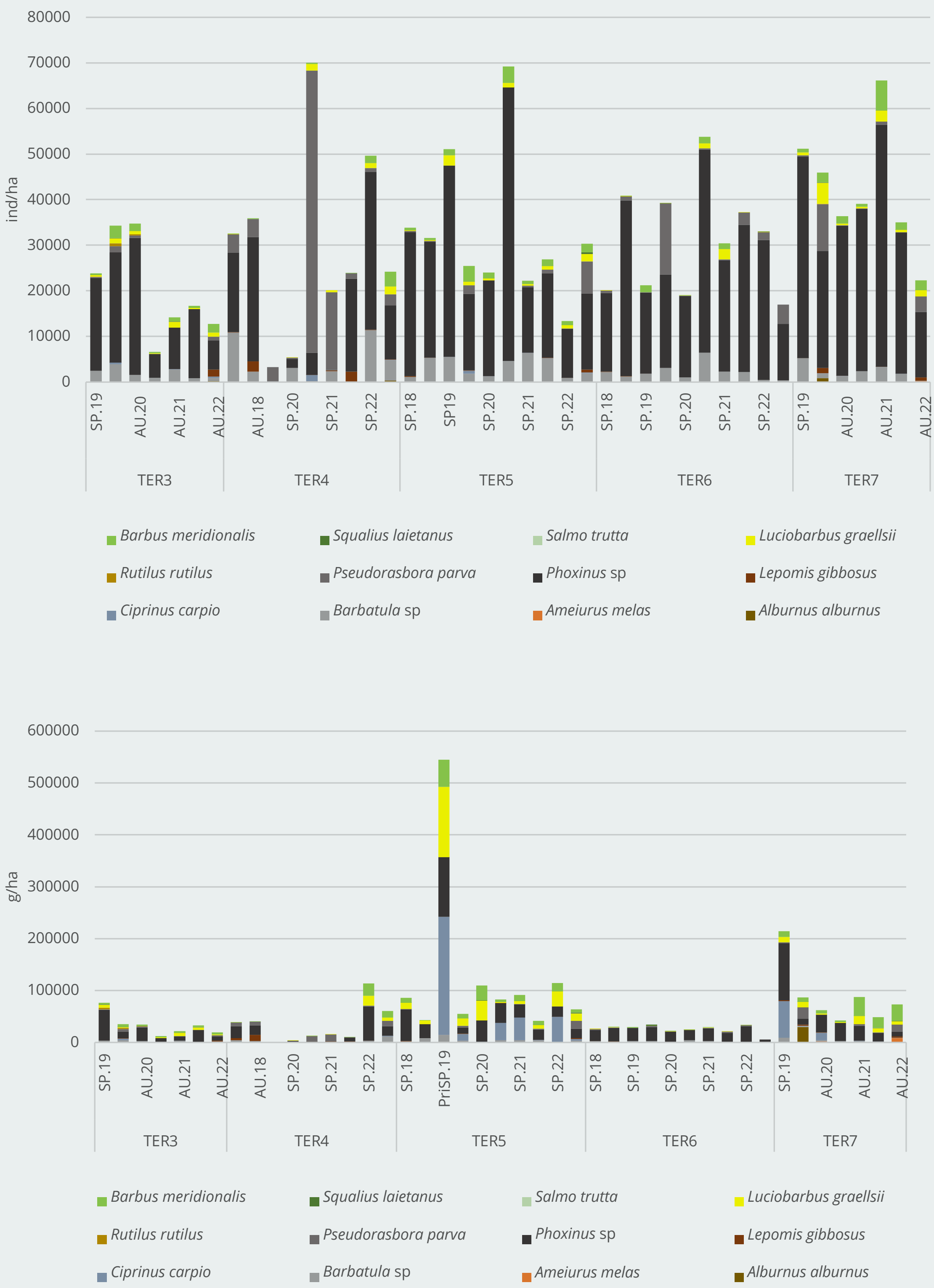


Figure 126 /

Density (top) and biomass (bottom) of fish in the period 2018- 2020 in the Ter River in the Osona county.

8a.4.3. Congost River in El Vallès Occidental

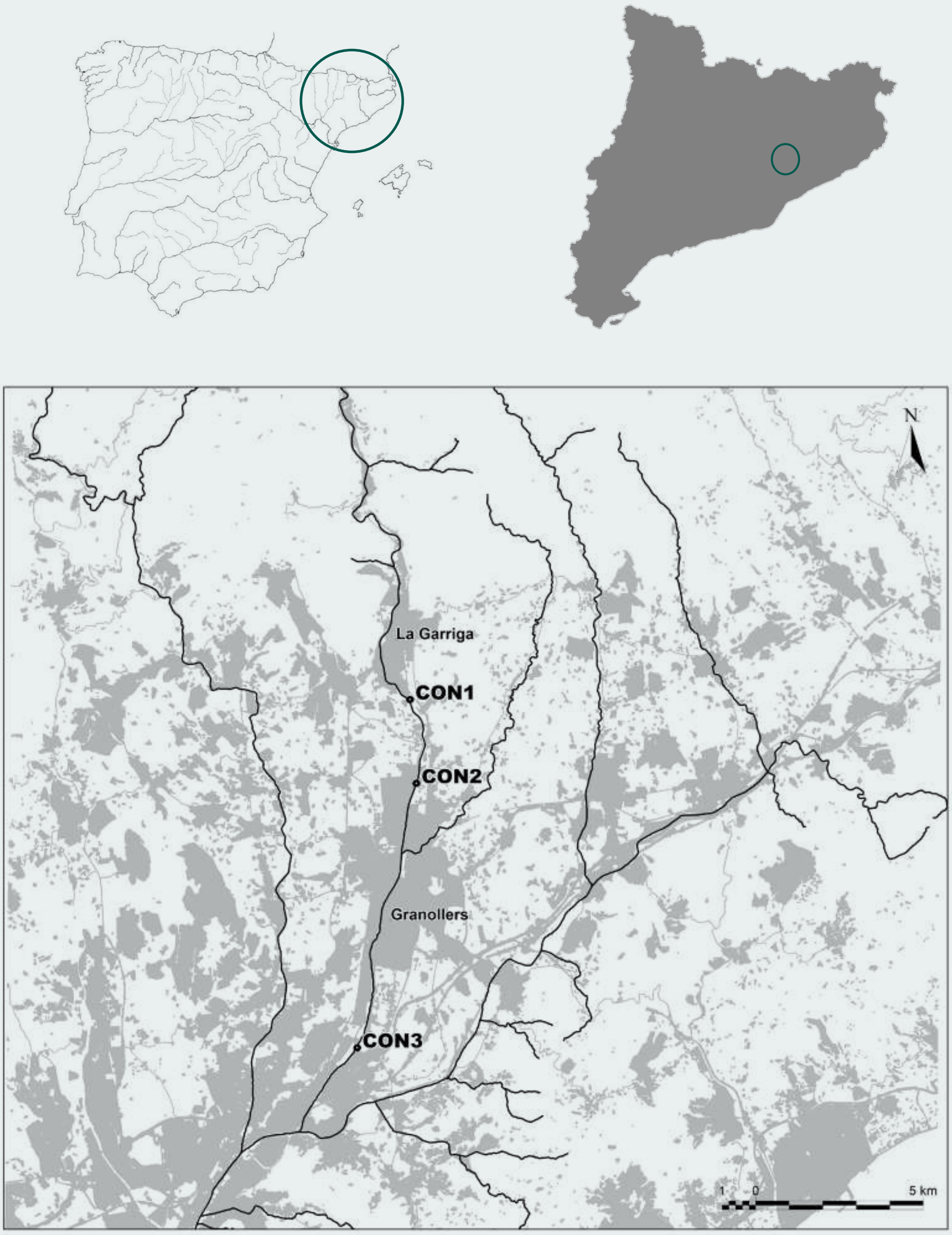


Figure 127 /

Sampling points of the LIFE ALNUS project on the Congost River in El Vallès Oriental county in the period 2018-2022. Key: CON1: Congost River, upstream of the La Garriga Wastewater Treatment Plant; CON2: Congost River, in Les Franqueses del Vallès; CON3: Congost River, in Can Cabanyes, Granollers. Base map: MiraMon, 2002.

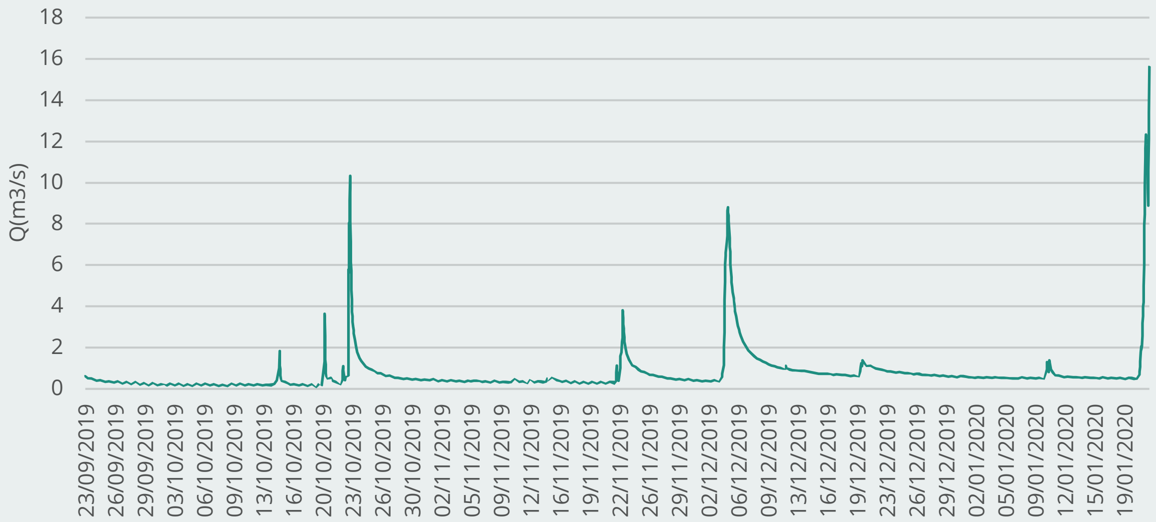
Lock on the river Congost in Granollers. One of the barriers to be eliminated by LIFE ALNUS and subject to monitoring of aquatic organisms. Photo: Jordi Camprodon.

The aim of this sampling was to evaluate the establishment of an environmental flow regime, by mutual agreement of the Catalan Water Agency and the communities of irrigators between La Garriga and Canovelles, as well as the hydromorphological improvements undertaken by the Granollers City Council and other town councils on the banks of the Congost River.

The flow of the Congost River varies a great deal over the course of the year and between years, as is usual for Mediterranean rivers (Figure 128). It gradually increases downstream, in sudden surges, because of the output from wastewater treatment plants, such as the one in La Garriga (between CON1 and CON2). Unfortunately, the flow data from the gauging station on the Congost River at Canovelles (CON2) was stemmed from January 2020 onwards, when it was put out of action by Storm Gloria.

Along all the stretches, the water speed is low but, in wetter years, such as 2018, most of the stretches were characterized by alternating between riffles and laminar flow sections. In drier years, the mesoaquatic habitats were more homogeneous, with a predominance of laminar flow at all the sampling sites.

In general, the Riparian Forest Quality index (QBR) shows signs of degradation, primarily in Can Cabanyes, in Granollers (CON3), where the strip of riparian forest is very small. In winter 2018, the flooding resulting from Storm Leslie reduced the plant cover considerably. The River Habitat index (IHF) shows an intermediate-good quality in terms of aquatic macroinvertebrates in La Garriga upstream of the wastewater treatment plant (CON1), which improves slightly downstream (CON2 and CON3), although it becomes more homogeneous, perhaps due to the increased flow (to a large extent, originating from conveyance from the Ter River). The RBPS aquatic macroinvertebrate index registered a suboptimal-optimal habitat in most of the stretches and dates, except for the autumn of 2019 in Granollers (CON3). A suboptimal habitat is characterized by having good shelter available for fish and macroinvertebrates, despite not being the most suitable habitat.



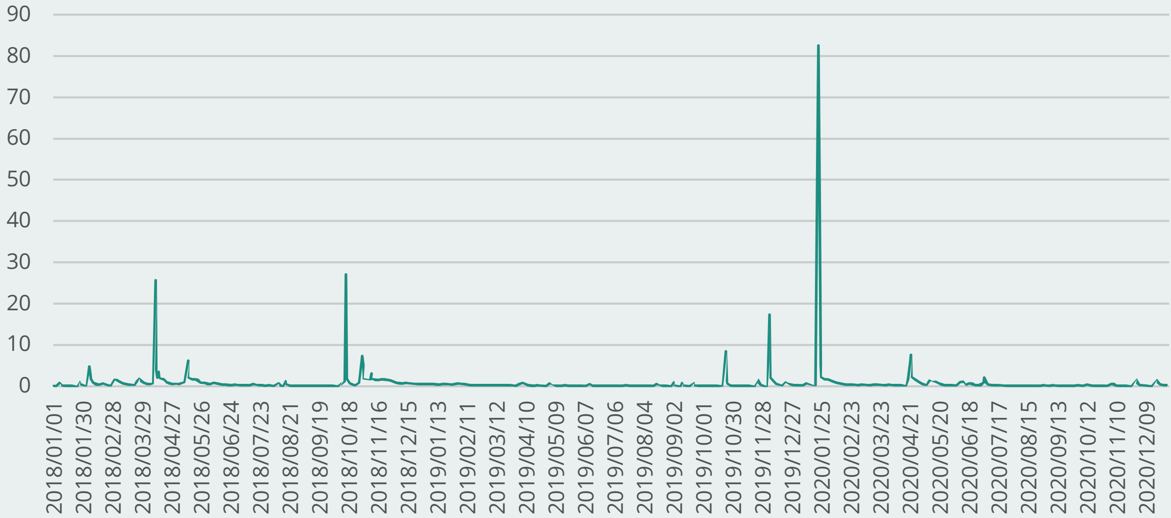


Figure 128 /

Average daily flow in the period July 2019-December 2020 obtained at the Catalan Water Agency's gauging station in La Garriga (EA 037, code 080885-001) and the LIFE ALNUS project's gauging station on the Congost River in El Vallès Oriental county. Key: CON 1: Congost River upstream of the La Garriga Wastewater Treatment Plant; CON2: Congost River at Les Franqueses del Vallès. Source: http://aca-web.gencat.cat/aetr/vishid#riverChartModal (EA 037) and https://lifealnus.eu/aca-smarty-planet (EA 19023).

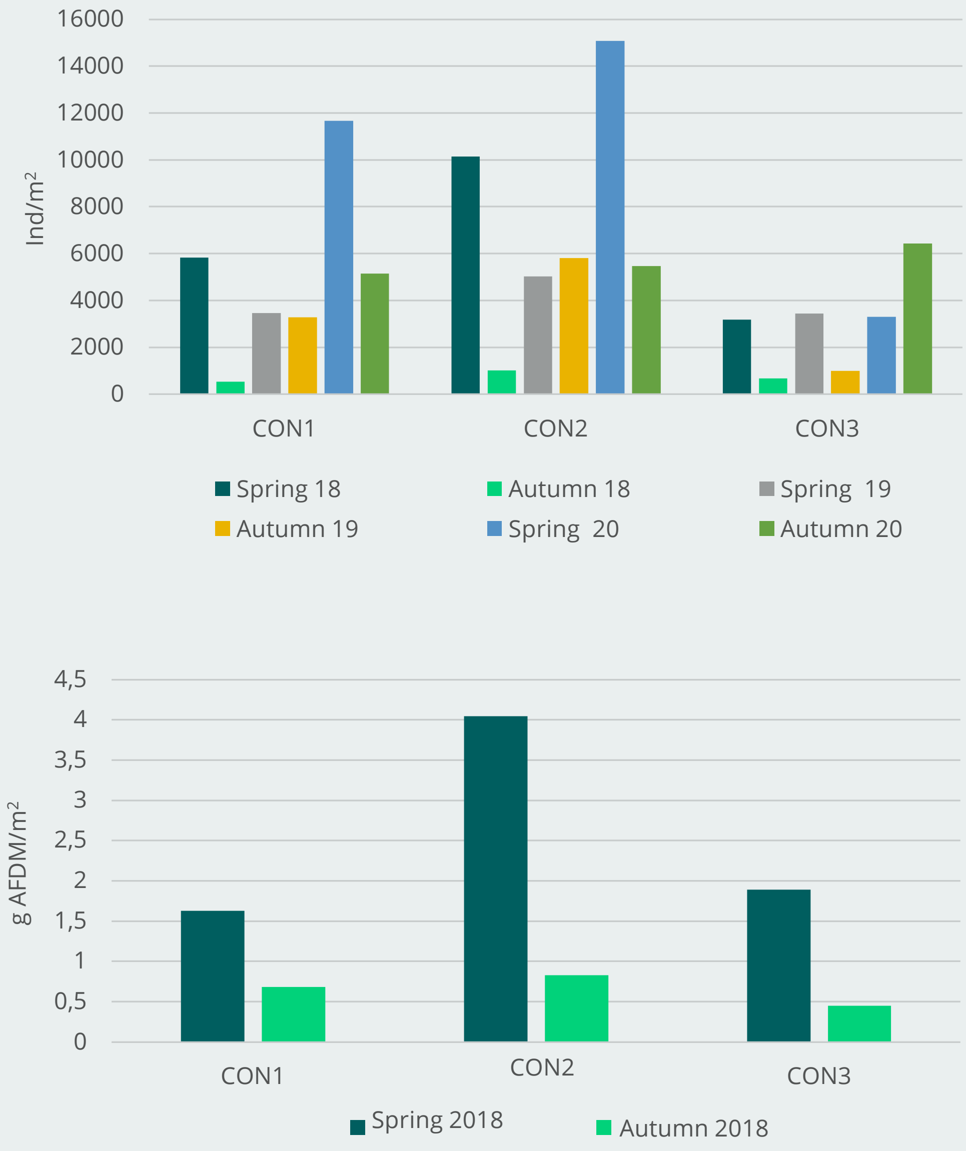


Figure 129 /

Density (top) and biomass (bottom) of aquatic macroinvertebrates in the period 2018-2020 in the Congost River in El Vallès Oriental county. Key: CON 1: Congost River upstream of the La Garriga Wastewater Treatment Plant; CON2: Congost River in Les Franqueses del Vallès.

The highest density of aquatic macroinvertebrates in the Congost River is in the spring, as is the case in many other of our rivers. The density gradually decreases downstream (Figure 129). With respect to the macroinvertebrate biomass, the same pattern as the density is observed: the biomass is highest in the spring. In the Congost River, the biomass is highest in Les Franqueses del Vallès (CON2), possibly due to an increase in the nutrients along this stretch of the riverbed, after receiving the effluent of a wastewater treatment plant and the runoff from several crop plantations.

The main families of aquatic macroinvertebrates are *Chironomidae, Baetidae, Simulidae, Caenidae, Hydropsychidae, Physidae, Corixidae, Cladocera and Oligochaeta* (in taxonomic order). The families of the Odonata, Coleoptera and Heteroptera orders, typical of calm, slow-moving waters, increased considerably in the autumn at all the sampling sites, with the exception of Can Cabanyes, Granollers (CON3), where there was a lack of calm, shallow waters in all the years sampled.

The biological quality of the water obtained using the IBMWP aquatic macroinvertebrate index (Figure 130) is intermediate-good along all the stretches sampled in the period of 2018-2020. The lowest quality figures recorded at the three sampling sites were at Can Cabanyes, Granollers (CON3) in all the seasons and years sampled. All the data indicates that the morphology of the riverbanks, modified by retaining walls, leads to significant speeds being generated when there are river floods, which facilitates the loss of invertebrates and other fauna downstream.

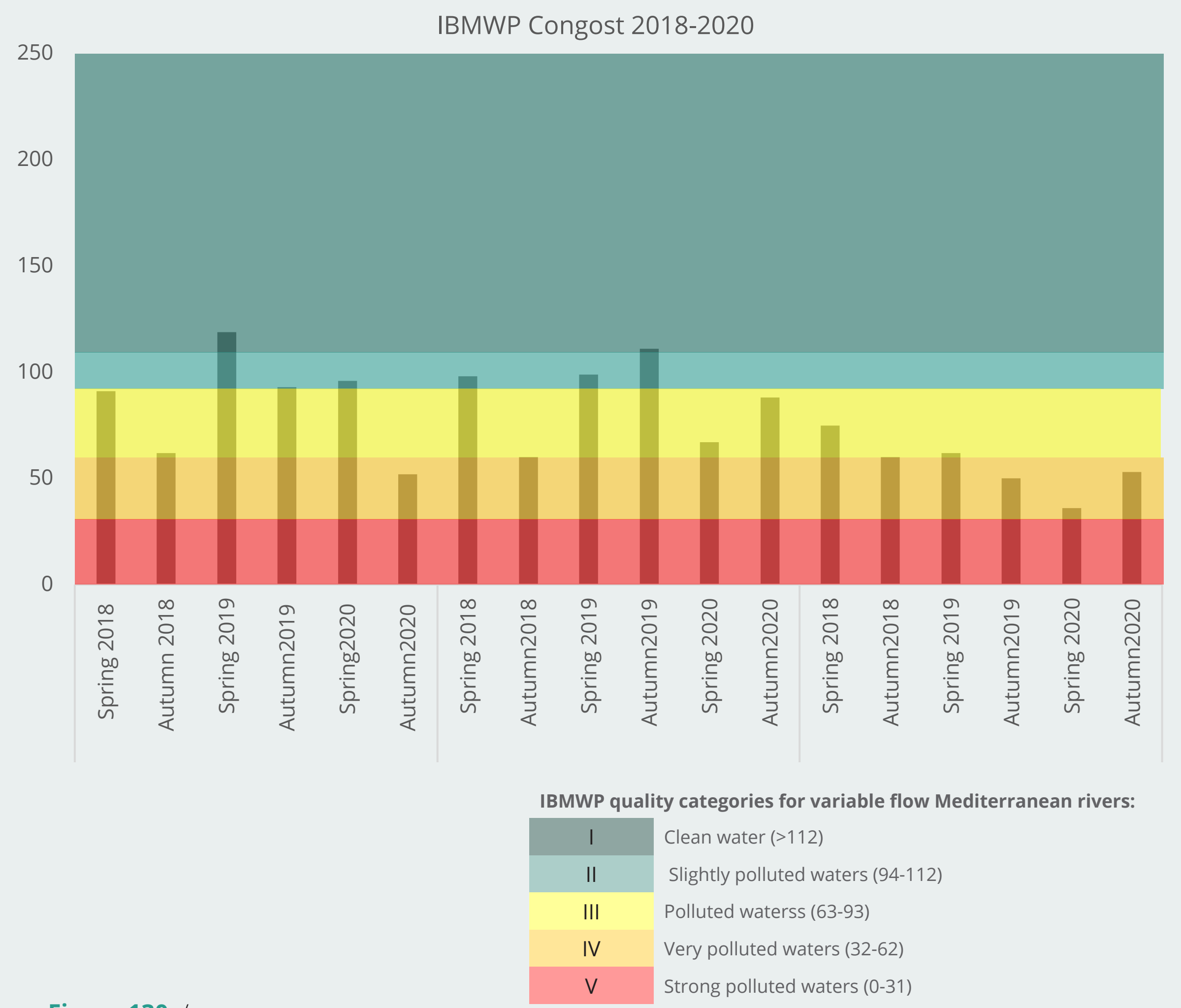


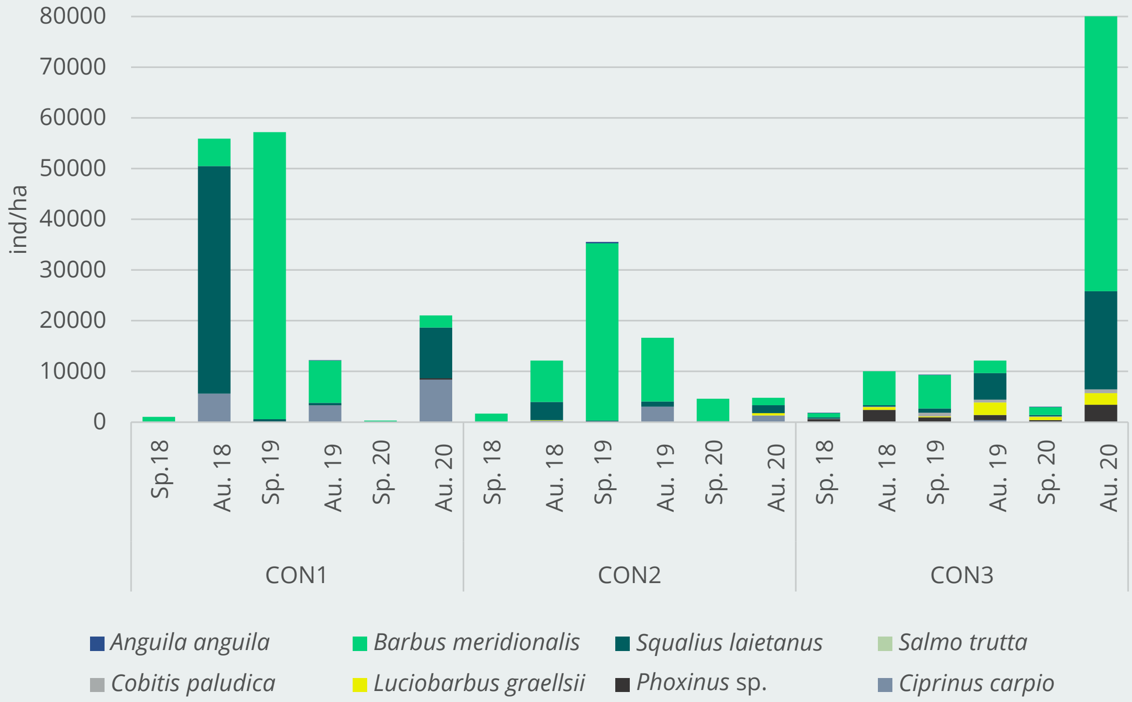
Figure 130 /

Biological quality index, based on aquatic macroinvertebrates, in the period 2018-2020 in the Congost River in El Vallès Oriental county. Key: CON 1: Congost River upstream of the La Garriga Wastewater Treatment Plant; CON2: Congost River in Les Franqueses del Vallès.

The fish community in the Congost River is made up of 7 species, of which only 3 are native (Table 7): Mediterranean barbel (Barbus meridionalis), Catalan chub (Squalius laietanus) and European eel (Anguilla anguilla). Fortunately, the Mediterranean barbel and the Catalan chub are the predominant species in all the stretches sampled, and the European eel, while predominant in the lower stretch of the river, also makes it upstream (CON1). In general, the highest fish density is recorded in the autumn. Despite the weakness associated with river floods resulting from the morphology of the river banks, which cannot dissipate but drag the fauna downstream, the fish seem to be favoured by the river flow, which is abundant throughout the year, even in extremely dry years, as a consequence of the conveyance of water from the Ter River and the output of good quality treated wastewater (Figure 131).

Table 7 / **Fish population in the period 2018-2020 in the Congost River in El Vallès Oriental county. Conservation status in Spain according to the Red List of Spanish Vertebrates; worldwide, according to the IUCN Red List. Drawings: Toni Llobet.**

Fish species	Status	
European eel (*Anguila anguila*)	Habitats Directive 1100/2007, 18 September 2007. In Spain: Vulnerable Worldwide: Under threat of extinction.	
Mediterranean barbel (*Barbus meridionalis*)	Habitats Directive 92/43/EEC Annexes II and V. In Spain: Vulnerable Worldwide: Vulnerable	
Catalan chub (*Squalius laietanus*)	In Spain: Vulnerable Worldwide: Vulnerable.	
Common carp (*Cyprinus carpio*)	Invasive species	
Ebro barbel (*Luciobarbus graellsii*)	Invasive species	
Iberian Loach (*Cobitis paludica*)	Invasive species	
Common minnow (*Phoxinus* sp.)	Invasive species	



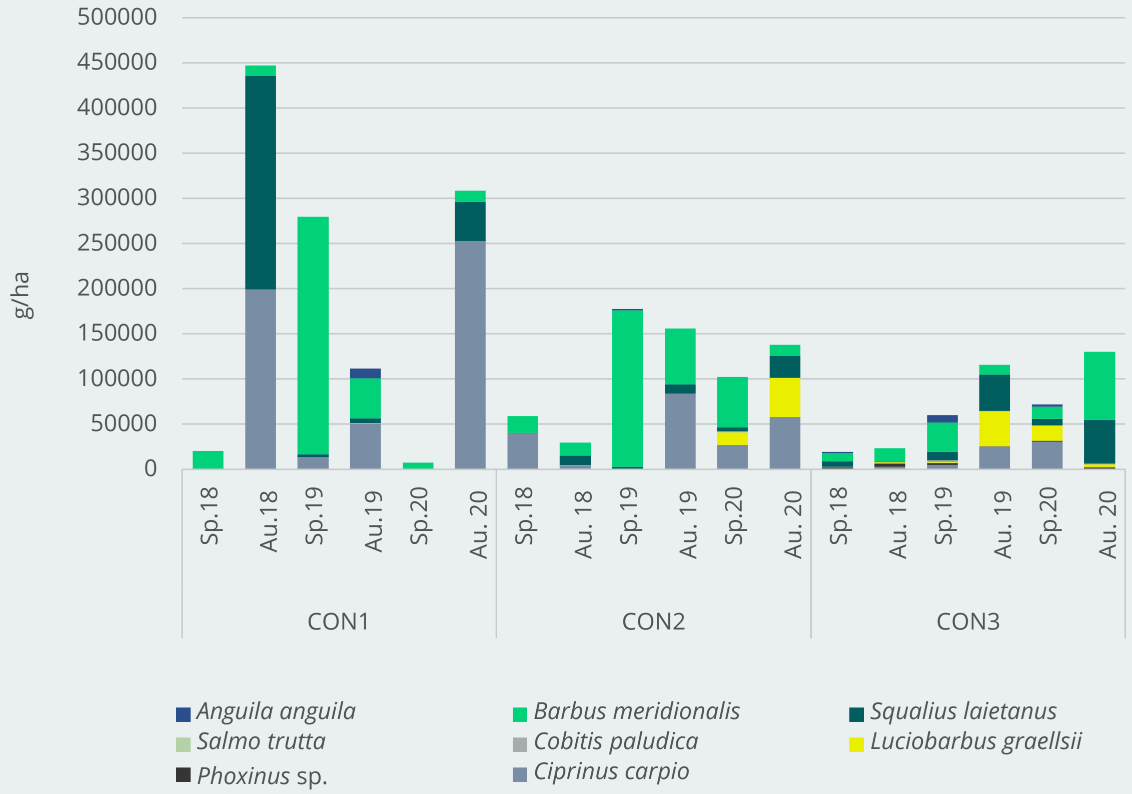


Figure 131 /

Density (top) and biomass (bottom) of fish in the period 2018-2020 in the Congost River in El Vallès Oriental county. Key: CON 1: Congost River upstream of the La Garriga Wastewater Treatment Plant; CON2: Congost River in Les Franqueses del Vallès.

8a.4.4. Segre River in La Cerdanya

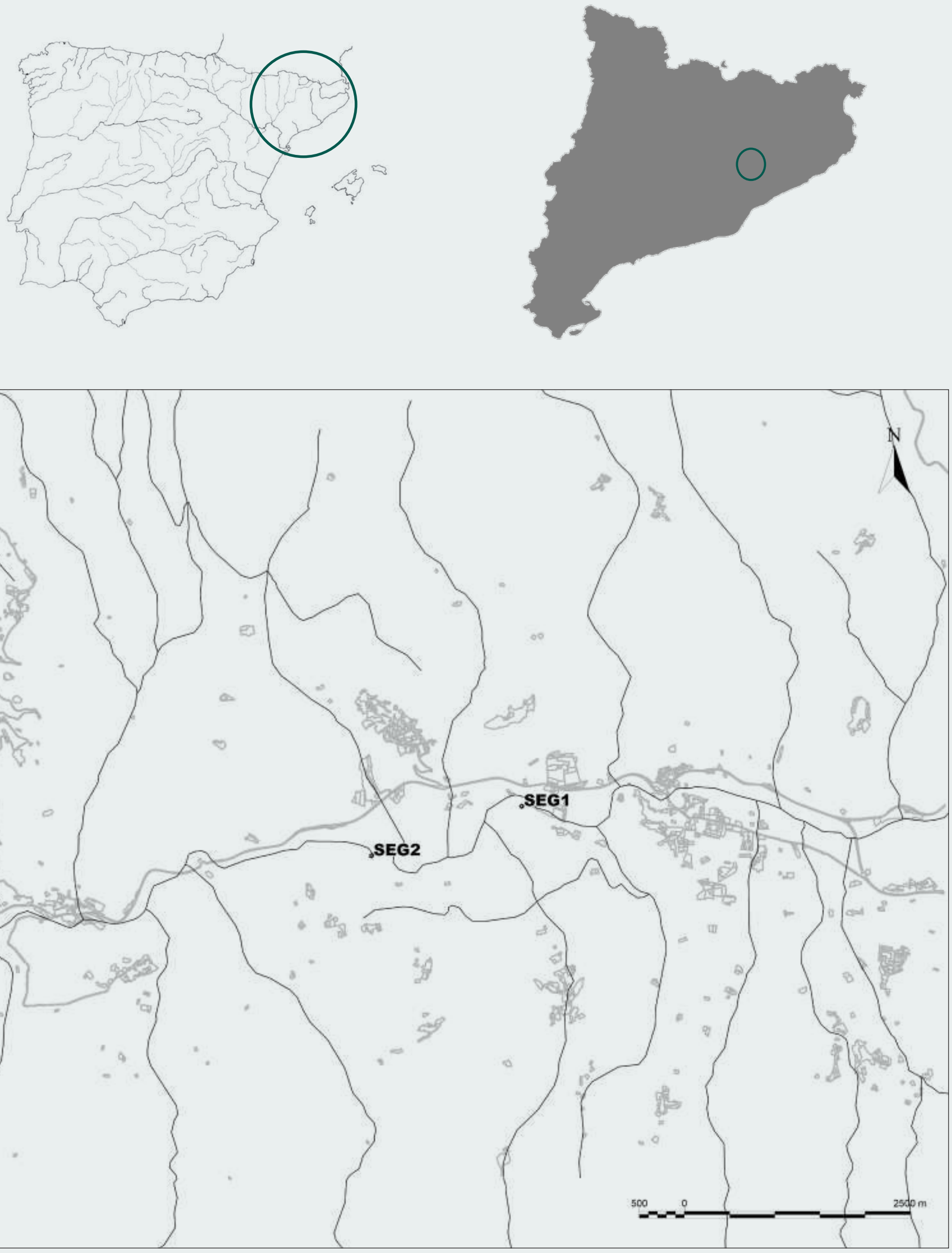


Figure 132 /

Sampling points of the LIFE ALNUS project on the Segre River in La Cerdanya county in the period 2018-2022. Key: SEG1: Outflow channel from the Gallissà ponds to the Segre, downstream of the town of Bellver de Cerdanya; SEG2: Segre River at La Prada island, downstream of the town of Prullans.

The aim of taking these samples was to evaluate the increase in environmental flows and the hydromorphological improvements undertaken by the Catalunya La Pedrera Foundation at the Segre River in the area around the Gallissà ponds (Bellver de Cerdanya), comparing them to the Segre River at La Prada island, downstream of the town of Prullans, which already had a high level of environmental quality, naturalness and diversity of habitats, and is exceptional throughout Catalonia and across the Iberian Peninsula as a whole.

The outflow channel of the Gallissà ponds to the Segre, downstream of the town of Bellver de Cerdanya (SEG1), had a very low flow rate with laminar flow (Figure 133), although a gradual improvement was observed after the measures taken in 2020. In contrast, in the Segre River at La Prada island, downstream of the town of Prullans (SEG2) there was a very heterogeneous regime of water speeds and flows, with a total of as many as seven branches active in the period of the study, with a predominance of riffles and laminar flows (at the surface and at greater depths).

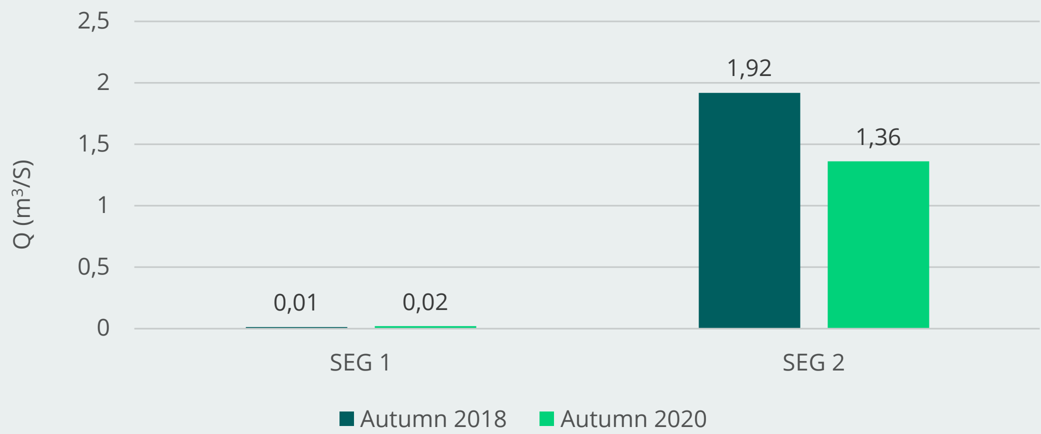


Figure 133 /

Average flow in 2018 and 2020 in La Cerdanya county. Key: SEG1: Outflow channel from the Gallissà ponds to the Segre, downstream of the town of Bellver de Cerdanya; SEG2: Segre River at La Prada island, downstream of the town of Prullans.

The Riparian Forest Quality index (QBR) is high in the Segre River at La Prada island (SEG2), where there is a highly natural riparian forest. This index is relatively lower in the outflow channel from the Gallissà ponds to the Segre (SEG1), where the riparian forest has been slightly disturbed, although it still maintains a good level of quality. At this sampling point, no significant differences were detected between 2018 and 2020, although there was certainly an improvement observed in the rest of the Gallissà ponds, where the restoration measures taken improved the plant cover on the inner part of the left bank of the Segre River, the channels connecting the ponds and their ecological status.

The River Habitat index (IHF) shows an intermediate-good quality in terms of the macroinvertebrate community in both stretches sampled. This figure is higher in the Segre River at La Prada island, downstream of the town of Prullans (SEG2), where the habitat is more heterogeneous and more suitable for macroinvertebrate communities. No significant differences were observed in this case between 2018 and 2020.

The IHF and RBPS indices find that the habitat is optimal for both macroinvertebrates and fish in the Segre River at La Prada island, downstream of the town of Prullans (SEG2), which remained stable across the two years of study (2018 and 2020). Moreover, the habitat of the outflow channel from the Gallissà ponds to the Segre (SEG1) improved its category from marginal in 2018 to suboptimal in 2020, indicating that it had more shelter available for macroinvertebrates and fish, as well as a faster flow regime

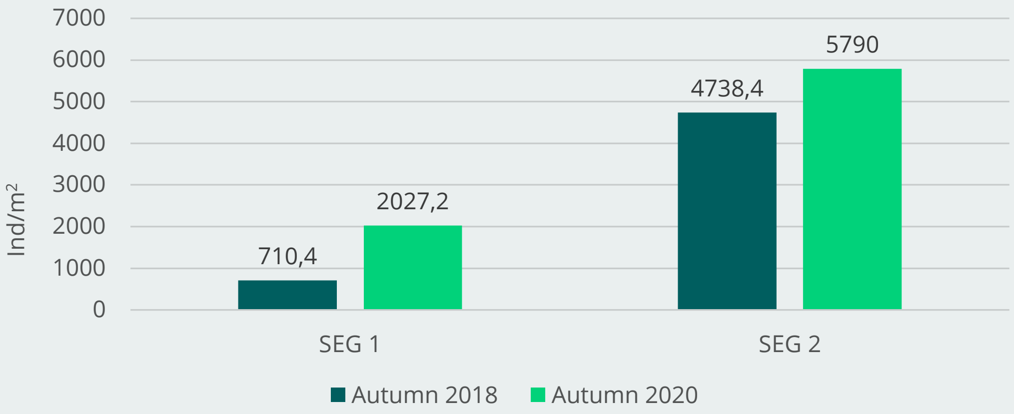


Figure 134 /

Density of aquatic macroinvertebrates in 2018 and 2020 in the Segre River in La Cerdanya county. Key: SEG1: Outflow channel from the Gallissà ponds to the Segre, downstream of the town of Bellver de Cerdanya; SEG2: Segre River at La Prada island, downstream of the town of Prullans.

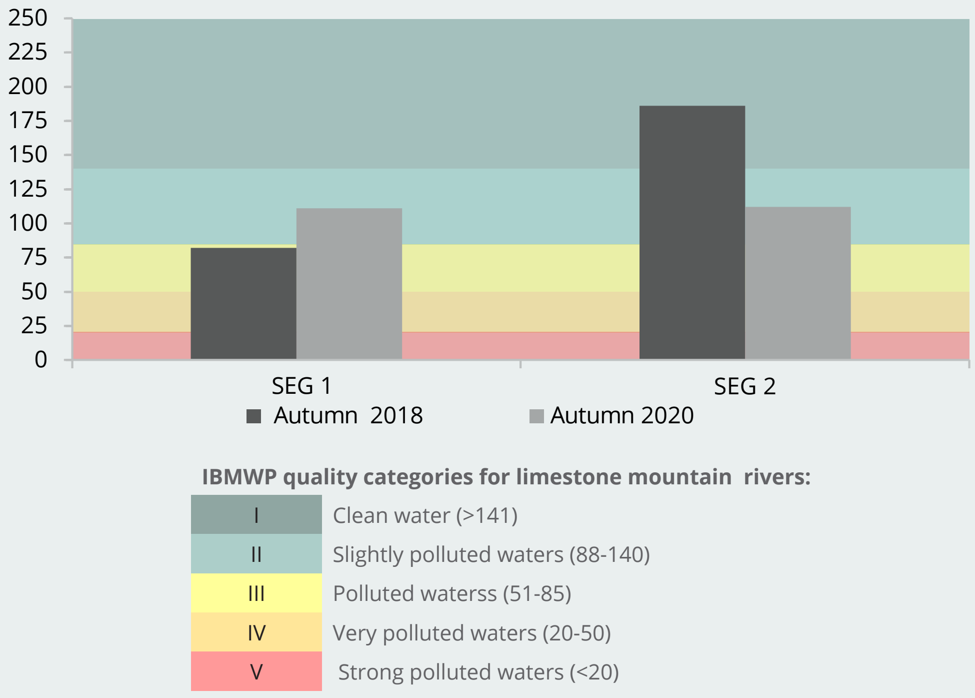


Figure 135 /

IBMWP biological quality index, based on aquatic macroinvertebrates, in 2018 and 2020 in the Segre River in La Cerdanya county. Key: SEG1: Outflow channel from the Gallissà ponds to the Segre, downstream of the town of Bellver de Cerdanya; SEG2: Segre River at La Prada island, downstream of the town of Prullans.

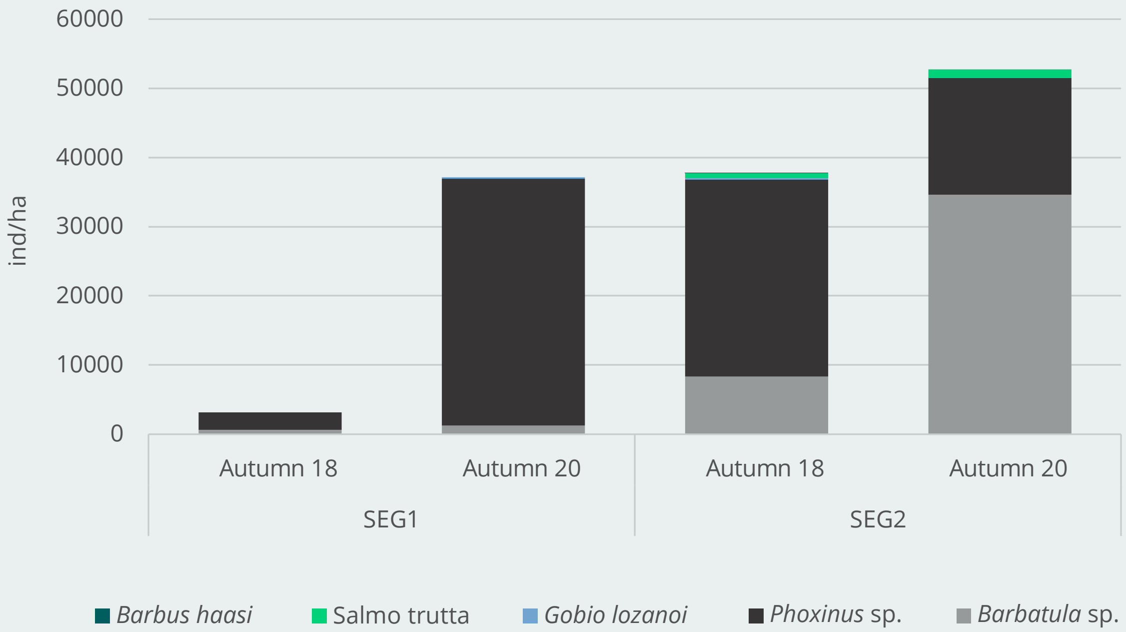
At the sampling sites (SEG1 and SEG2), the macroinvertebrate density increased significantly from 2018 to 2020 (Figure 134), although, in line with the same pattern shown in all the other indices, the densities in the Segre River at La Prada island (SEG2) tended to be higher than those from the outflow channel of the Gallissà ponds to the Segre (SEG1).

The most abundant macroinvertebrate families in the outflow channel from the Gallissà ponds to the Segre (SEG1) are *Physidae, Hydrobiidae, Chironomidae* and *Dytiscidae*. In the Segre River at La Prada island, downstream of the town of Prullans (SEG2), the predominant families change, with the typical families found in varied habitats being most abundant: *Brachycentridae, Chironomidae, Elmidae, Hydracarina* and *Hydropsychidae.*

In the outflow channel from the Gallissà ponds to the Segre (SEG1), the biological quality of the water obtained using the IBMWP macroinvertebrate index was relatively bad in 2018 but improved to intermediate in 2020 as a consequence of the increased water flow resulting from the restoration project conducted (Figure 134). In contrast, after two years of study, the water of the Segre River was of much better quality at La Prada island, downstream of the town of Prullans (SEG2).

Table 8 / Fish population in 2018 and 2020 in the Segre River in La Cerdanya county. Conservation status in Spain according to the Red List of Spanish Vertebrates; worldwide, according to the IUCN Red List. Drawings: Toni Llobet.

Espècie	Estatus de conservacó	
Brown trout (*Salmo trutta*)	In Spain: Vulnerable Worldwide: Low concern	
Catalan barbel (*Barbus haasi*)	In Spain: Vulnerable Worldwide: Vulnerable	
Stone loach (*Barbatula* sp.)	Invasive species	
Gobio ibérico (*Gobio lozanoi*)	Invasive species	
Piscardo (*Phoxinus* sp.)	Invasive species	



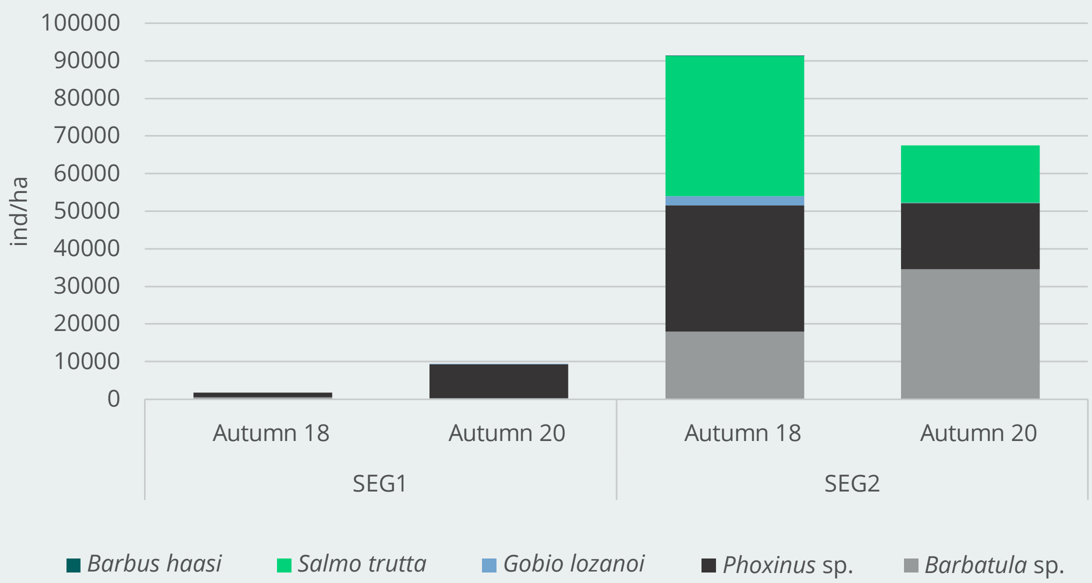


Figure 136 /

Density (top) and biomass (bottom) of fish in 2018 and 2020 in the Segre River in La Cerdanya county. Key: SEG1: Outflow channel from the Gallissà ponds to the Segre, downstream of the town of Bellver de Cerdanya; SEG2: Segre River at La Prada island, downstream of the town of Prullans.

Scientific sampling of fish using electrofishing. Photo: Pol Guardis.

The fish community is made up of five species (Table 8), only two of which are native: brown trout (*Salmo trutta*) and Catalan barbel (*Barbus haasi*). There is a clear predominance of common minnow (*Phoxinus sp.*) in both stretches, followed by the stone loach (*Barbatula barbatula*). There is greater diversity at La Prada island (SEG2) and, moreover, there is a higher proportion of native species (Figure 136). The number of fish increased between 2018 and 2020 in the outflow channel from the Gallissà ponds to the Segre River (SEG1) after the Gallissà ponds restoration project was completed. In contrast, the number of fish dropped in the Segre River at La Prada island, downstream of the town of Prullans (SEG2), apparently owing to the presence of more fine material on the river bed, due to an unknown cause, which had not been observed since 2018.

CONCLUSIONS

1. The prior trends are very positive but, due to a broken wastewater sewer that had a negative impact on the entire stretch of the river being studied, the final data from the period 2018-2020 prevent us from drawing satisfactorily firm conclusions with respect to most of the indicators on the lower stretch of the Ter River and the upper stretch above El Mariner weir (Camprodon, El Ripollès). However, it confirms the correct application of the environmental flows by the company Estabanell y Pahisa, SA.

2. The monitoring carried out in the period 2018-2020 around the Gallifa weir (Ter River, at Les Masies de Voltregà, Osona) shows a recovery in the population of aquatic macroinvertebrates and fish since the application of an environmental flow regime, particularly in terms of the number of individuals and the larger sizes of the Mediterranean barbel. Although it will be necessary to continue monitoring progress in the years to come (the recovery of fish populations and riparian vegetation is not immediate), the correct application of the environmental flows at the Gallifa hydro power plant of Estabanell y Pahisa, SA at Les Masies de Voltregà seems to have had a very positive impact, which is even more promising bearing in mind the drought suffered during the period of 2021-22. Moreover, the river also benefitted from a synergy carried out from May 2022 onwards, with the reactivation of the small branch around Les Gambires island and demolition of El Sorral island ford.

3. The monitoring carried out during the period 2018-2020 on the Congost River in the county of El Vallès Oriental, as well as the measures taken to improve the riparian vegetation and the hydromorphological improvements to the riverbed, show that the aquatic habitat indices are positively correlated to the aquatic macroinvertebrate variables. Moreover, a positive trend was detected with respect to fish and the riparian vegetation was positively correlated with the number of native Mediterranean barbels.

4. The measures taken to increase the circulating flow and restore the riparian vegetation around the Gallissà ponds in Bellver de Cerdanya appear to have facilitated an improvement in the state of the channel that connects them to the main course of the Segre River. In addition, although a reduction in the fish population was observed in the Segre River at La Prada Island, downstream of the town of Prullans, it is still a river area of a high environmental quality.

5. Therefore, the processing of the data generated over the years to come should provide valuable insight into the response of aquatic communities in these river environments that have already improved positively, becoming more natural because of the pilot measures carried out within the framework of the LIFE ALNUS project.

8b / **LIFE ALNUS PROJECT FOLLOW-UP INDICATORS: RIPARIAN HABITATS**

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8b.1. Introduction

The fluvial area consists of the aquatic environment (flooded riverbed or waterway) and the riparian environment (land influenced by the riverbed and associated groundwater table). Both environments interact where the riverbed and the riverbank intersect, an area called bankfull. The bankfull's geomorphology, water and vegetation greatly influence the distribution of aquatic and riparian organisms (Figure 137). The flood patterns of the water course and groundwater table extend the aquatic environment's influence up the riverbank, an impact that is dampened by the distance to the bankfull and translates into a distinctive distribution of the vegetation. The highly necessary soil moisture and environmental humidity is located closer to the bankfull and the riparian soils with a more superficial groundwater table. This gradient, which becomes complicated in alluvial plains with secondary river branches, dead branches and stagnant water, confers an extraordinary ecological complexity to fluvial areas, which translates into one of the greatest biological diversities of continental ecosystems.

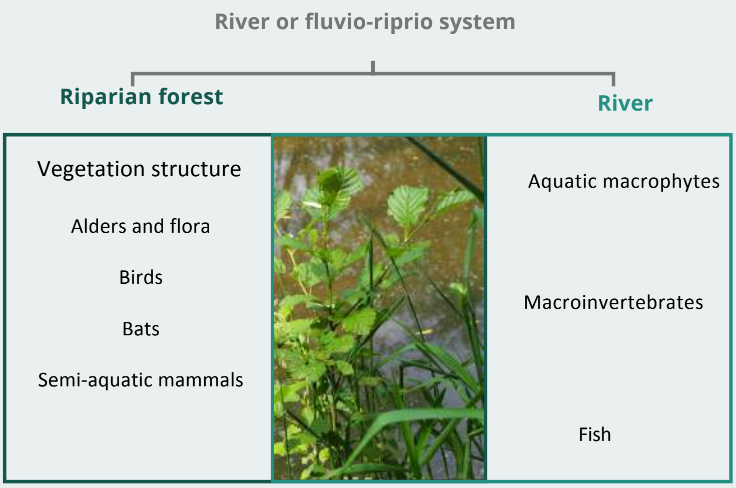

Figure 137 /

Biological indicators measured in the LIFE ALNUS project. Both ellipses represent the intersection between structural, hydromorphology and vegetation components, which connect aquatic and riparian elements.

This chapter presents the bioindicators of riparian habitats. Vascular flora and vegetation, birds, bats, terrestrial and semi-aquatic mammals have been selected. Sampling was conducted during the 2018-2020 period in the three action basins of the LIFE ALNUS project: Besòs, Upper Ter and Upper Segre.

The general objectives are included in the previous chapter on the follow-up of aquatic indicators. The specific objectives of riparian bioindicator follow-up included in this chapter are the following:

a. To discover the communities of vascular flora and different groups of vertebrates of bioindicator value in the three action basins of the LIFE ALNUS project.

b. To determine if the communities of birds and mammals, for their intrinsic value and as bioindicators, were more diverse when the fluvial area structure grew in complexity. This information is extremely useful as part of management, habitat restoration and when transferring results to environmental managers and the general public.

c. To investigate the causes of the alder decline observed in headwater sections.

d. To assess the success of plantations in restoring the riparian forest.

e. To assess the fluvial system's dead wood decomposition and movement processes.

f. To assess the impact of hydromorphology and riparian habitat restoration actions in relation to bioindicator groups.

The assessment of the effect of restoration actions is not included in this chapter. Their ending in 2022-2023 prevented post-treatment inventories from being compiled when writing this manual. Furthermore, it is common knowledge that certain organisms respond in the medium or long term, such as slow-growing organisms, like trees, or living beings with extremely specific habitat requirements or associated to advanced phases of natural succession. We expect to follow up riparian bioindicators (vascular flora and vertebrate fauna) in the different fluvial sections undergoing restorative actions in the years to come.

8b.2. Study areas

The study area corresponds to the potential range of Mediterranean (Besòs basin) and Pyrenean (Upper Ter and Upper Segre) alder groves and their transitional forms (Middle Ter), alongside other riparian structures: white willow groves and ash groves, with small occasional white poplar grove stands, mainly on alluvial substrate (for the description of biogeographical types of alder grove, see Chapter 2). These communities are typical of medium-low river sections (Lara et al. 2004). Nevertheless, from a topographical perspective, we use Upper Segre to refer to the Segre axis in Cerdanya and Alt Urgell, Upper Ter for the main Ter axis and the Freser river above Ripoll, and Middle Ter from below Ripoll to the Sau Reservoir. More specifically, follow-up has been conducted in four sectors of the three Catalan fluvial basins:

a) Besòs basin: Congost and Mogent rivers and Ardenya, Valcàrquera and Avencó streams.

b) Ter middle basin: Ter river from Roda de Ter to Ripoll.

c) Ter high basin: Ter river from Ripoll to Camprodon and Freser river from Ripoll to Ribes de Freser.

d) Segre high basin: between Puigcerdà and Organyà.

See location in Figure 138.

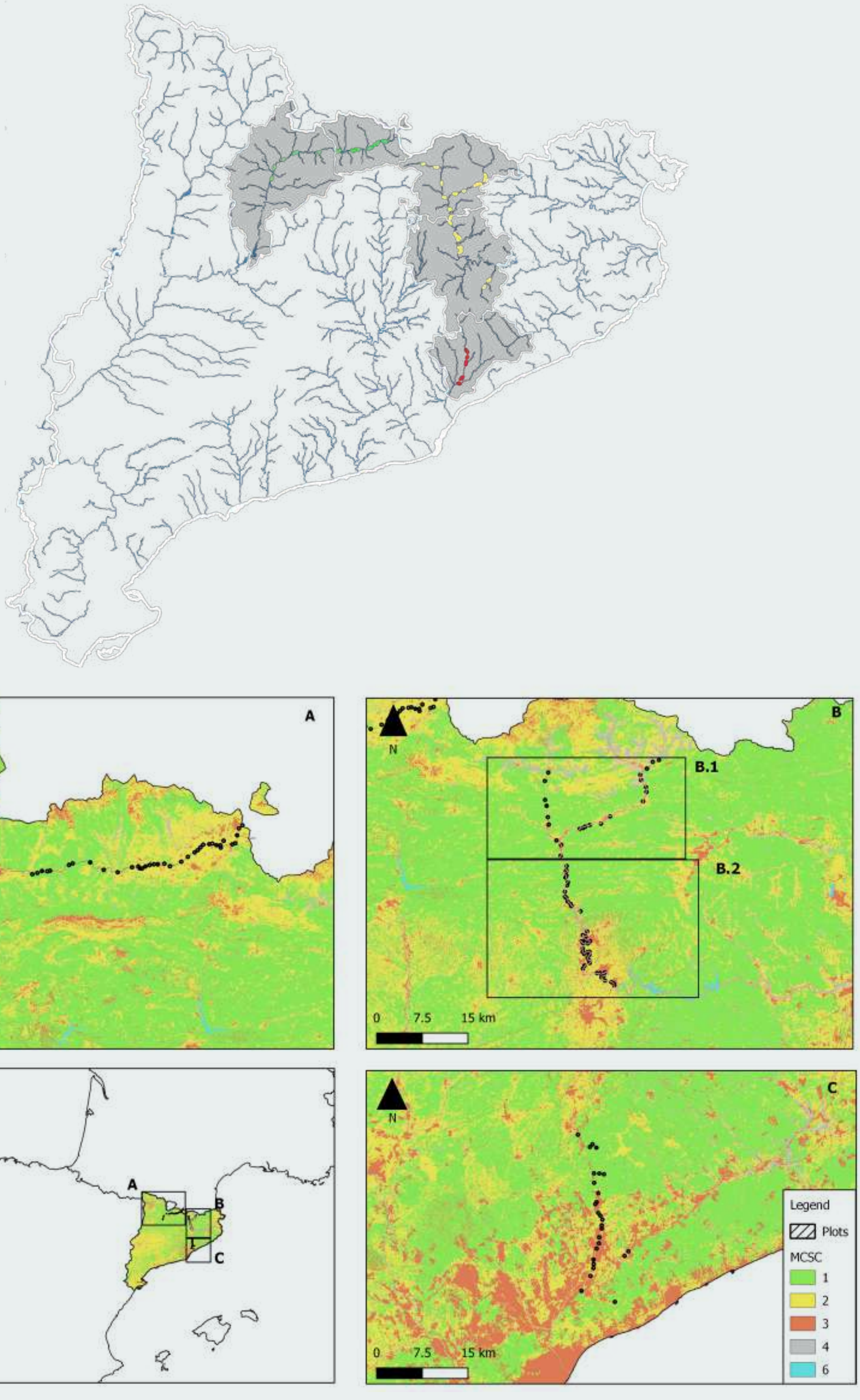

Figure 138 /

A. Location of the four fluvial basins with a map of soil uses and location of vegetation, bird and bat sites of the LIFE ALNUS project. A: Segre basin. B: Ter-Osona and Ter-Ripollès basin. B.1: Ter-Ripollès basin. B.2: Ter-Osona basin. C: Congost/Besòs basin. MCSC (Land Cover Map of Catalonia): 1- Forest, 2- Open/agricultural areas, 3- Urban/productive areas, 4- Riparian habitat, 5- Water. B. Location of mammal transects. Source: Bertrans (2019) on top of the land cover map (CREAF, 2009) and Soler (2021).

White heron (*Casmerodius albus*) in the Ter River. Photo: Jordi Bas.

8b.3. Methodology

Planning the riparian bioindicator sampling is based on two approaches: a) synchronous sampling of the impact of the riparian forest habitat structure and the landscape configuration in a gradient from more to less anthropization, with three landscape matrix scenarios: urban, agricultural and forest; b) Before-After-Control-Impact (BACI) analysis, based on sampling before and after performing restorative actions, comparing restored sections with other control sections. Actions will receive continuous follow-ups after the Life project. For more details on the methodology and results described, please see Bertrans (2019), Guardis (2019), Font & Casas (2020), Oró (2020), Soler (2021) and Valor et al., (2020), works available on the LIFE ALNUS project website (lifealnus.eu).

8b.3.1. Flora and vegetation inventories

Alder growth and decline

Dendro-chronological and stable isotope techniques were used to assess the relationship between the alder decline observed in headwater areas in ALNUS basins and drought. The study was conducted around the Comes Grans stream (Ter basin), in the municipality of Toses. For more details and results from the study, see Valor et al. (2020). The same —or similar— techniques will be used after the Life project to assess the restoration of riparian vegetation and the release of stream flows and fluvial restoration. They will be performed three or four years after the actions, once the fluvial system and vegetation are stable to a certain degree. We will measure riparian trees located above and below hydroelectric power plants that have started to release maintenance stream flows and above, below and within hydromorphology restoration actions and riparian vegetation restoration actions.

Riparian flora, vegetation, habitats and landscape

Characterising vegetation and habitats consisted of compiling phytocoenological inventories in the different habitats of four areas where riparian vegetation restorative actions were conducted (Table 9). To evaluate the conservation condition of the riparian forest, we used the Riparian Vegetation Index (RVI; Gutiérrez & Salvat, 2006), suggested by the Catalan Water Agency. It was calculated based on data from floral inventories. For the index assessment, see ACA (2006). 72 inventories were compiled during the spring and summer of 2018, before the restoration actions. Post-action inventories will be compiled during the spring-summer of 2023, once enough time has passed since the interventions. For more information, see Font & Casas (2020).

Table 9 / **List of the LIFE ALNUS project action areas and the locations where floral inventories have been compiled. It distinguishes between the number of inventories in riparian forest, flattened field and hydro-nitrophile grasslands.**

Basin	Course	Municipality	Place	Forest	Field	Grassland
Segre	Upper	Bellver de Cerdanya	Gallissà	3		
			Prat de Segre	3		
		Prullans	Potamolls y aliseda de Prullans	3		
Ter	Upper	Camprodon	La Vall	6		
			Can Beia	5		
	Middle	Torelló	Can Batista	3		
			Isla de Les Gambires	3	4	2
			Espadamala de Baix	4		
		Masies de Voltregà	Isla de Gallifa o del Sorral	5	3	1
Congost	Middle	Figaró-Montmany	Gallicant	2		
		La Garriga	Depuradora de La Garriga	2		
		Les Franqueses del Vallès	Pla de Llerona	1	1	
			El Falgar		2	2
	Lower	Granollers	Parc de Ponent		2	3
			Palou	2	2	1

Inventories of forest variables were compiled to characterise the riparian forest structure. The measured variables selected could also have certain impact on the distribution of birds and bats, according to Camprodon (2013) and Guixé & Camprodon (2018). We measured the average diameter of the 30 trees closest to the centre of the echolocation/listening point. Tree diversity was calculated based on the Shannon-Wiener Diversity Index, represented by the relative cover of each tree species (Kohn & Pielou, 1977). Out of the set of 30 trees, we estimated the density of small (diameter classes 10-20 cm), medium (25-35 cm), large (35-45 cm) and very large (>45 cm) trees, measuring the average diameter (at a height of 1.3 m on the trunk) and expressed in trees/ha (Leal et al., 2017). We calculated the sampled surface area based on the minimum convex polygon (MCP) of the outermost trees. As part of the MCP, we also measured the density of dead trees that are standing or fallen (feet/ha) with an average diameter of ≥ 7.5 cm. The standing dead trees were inspected to look for dendro-microhabitats: crack-shaped cavities and cavities hollowed out by woodpeckers that could be used as a nest or shelter by burrowing birds or bats. We measured the cover percentage of each vegetation layer distributed at different heights (0-25 cm, 25-50 cm, 50-100 cm, 1-2 m, 2-4 m, 4-8 m, 8-16 m and more than 16 m) in a 50-m transect from the centre in both directions parallel to the river according to (Prodon & Lebreton, 1981). These transects were also used to calculate the Shannon-Wiener Index of tree and shrub diversity based on the Braun-Blanquet index (Khan et al., 2012).

We calculated the land cover percentage in circular buffers of three different radiuses (100, 250 and 500 m) to capture the soil composition of the coverage in the landscape surrounding the sampled riparian forest. The different landscape matrix was obtained by reclassifying the Land Cover Map (MCSC) (CREAF, 2009) into four classes following an anthropogenic gradient: urban, agriculture/open spaces, riparian forest, climatic vegetation and bodies of water. The predominant landscape and the Shannon-Wiener Diversity Index which estimates the landscape's diversity was measured for each reclassified MCSC buffer. These variables were analysed by the ArcGIS program (ESRI Inc., 2014). For more details, see Bertrans (2019) and Oró (2020).

Figure 139 /

Sampling diagram of the LIFE ALNUS project habitat structure. Source: Bertrans (2019) on top of the land cover map (CREAF, 2009).

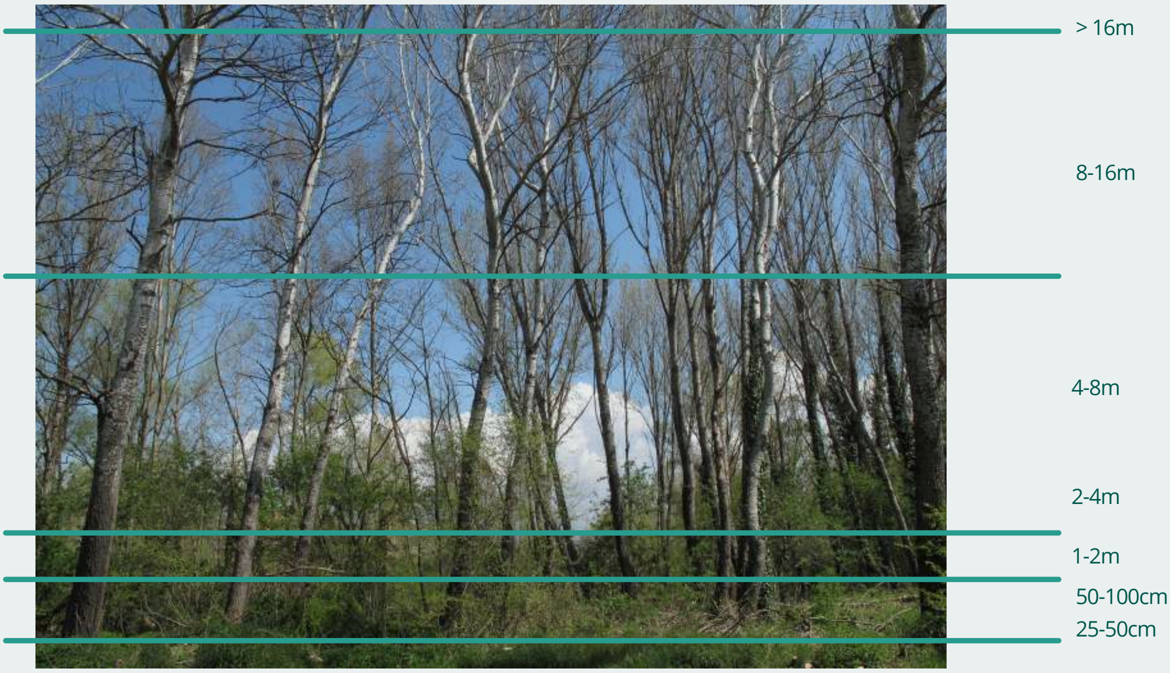

Figure 140 /

Sampling diagram of vertical vegetation coverage (according to Prodon & Lebreton, 1981). Source: Bertrans (2019).

To connect the habitat structure with the terrestrial and semi-aquatic mammals, we took several hydromorphology structure and vegetation variables along the track transects, during the spring of 2021. We made semi-circular plots with a radius of 25 m on the riverbank in contact with the riverbed every 200 m along the transect. We measured habitat variables that could impact mammal distribution. We adapted variables used in several protocols, like the QBR (Quality of the Riparian Forest) by Munné et al. (1998) or the IHG (Hydrogeomorphology Index) by Ollero et al. (2008). The land cover map allowed us to calculate the occupation percentage of six types of cover: a) water, b) bare soil, c) climatic forest, d) riparian forest, e) crops, pastures and shrubs, f) buildings and other urban areas in a 100-m buffer around each transect. The 100-m buffer included the habitat diversity in the river environment, without adding noise from the covers too far away from the focus area of our study. Landscape data was analysed using the ArcGIS program (ESRI Inc., 2014). For more details, see Soler (2021).

Dead wood

Large wood debris impacts the morphology of rivers and erosion and sediment retention processes. The debris, alongside live wood, contribute to dissipating the effects of floods by dissipating part of the water flow energy, and to retaining solids and suspended particles (Wohl et al., 2016). They are part of the fluvial system and contribute to its biodiversity by generating microhabitats, and to soil carbon fixing. Nevertheless, the accumulation of dead wood in rivers can also increase the risk of damage to infrastructures located in potential flood areas (Mao et al., 2014). During the LIFE ALNUS project, two large floods took place in inland basins in Catalonia: Storm Leslie (October 2018) and Storm Gloria (January 2020), which created a large amount of plant debris, including many medium and large trees. To assess the possible effects on the geomorphology of rivers, it is important to understand wood distribution, movements, and retention times in rivers. For these reasons, LIFE ALNUS set out to follow up on the dead wood in one of the most emblematic sections, where hydromorphology restoration actions were conducted: the islands of Les Gambires and El Sorral (Ter river, Torelló-Masies de Voltregà).

By establishing the dead wood follow-up protocol, we try to respond to several questions, such as: 1) knowing if dead wood is incorporated into the riverbed structure, creating (small scale) new spaces in the sheet of water, waterfalls, pools, shelters, etc.; 2) the capacity to move large plant debris in rivers such as the Ter, depending on if the dead wood is standing or fallen and the volume, length and location of each piece; 3) the retention time and movement distance; 4) information on the damage to infrastructures that moving dead wood can cause; 5) quantifying the dendro-microhabitats that appear in dead wood and the decomposition process.

The methodology used consisted of marking and monitoring 100 pieces of dead wood, in several sizes and species, among other concepts. They were identified according to size by painting a pattern on them using marking spray, and with a number plate for each piece. They will be followed up annually, preferably outside of the vegetative period, when the land is more accessible, and after each flood.

8b.3.2. Fauna censuses: birds and mammals

Four work hypotheses were formulated. The first consisted of verifying if riparian forests included a high ornithologic diversity and conservation interest compared to other forest habitats. The second proposed that the diversity of birds, bats and terrestrial and semi-aquatic mammals was significantly correlated to the landscape matrix: forest, agricultural, urban. The third hypothesis consisted of corroborating if the habitat's internal structural complexity and tree species composition implied greater diversity of different fauna groups.

In the three fluvial basins, we selected 131 bird listening sites (Bibby, 1992) and 48 bat echolocation sites, following the Quirohabitats protocol (2009), evenly distributed in different scenarios. The separation between sites was 500 linear metres in the case of birds and 1000 linear metres in the case of bats (Figure 141). Each listening site registered the birds seen or heard for 20 minutes between 6.30 and 9 a.m. during breeding season, between the 20th of April and the 10th of June of 2018 and 2019. Contacts within a radius of 25, 50 and 100 metres from the observer were registered. For treatments, the 50-m radius was used because it was the best suited to the riparian forest dimensions with less loss of contacts (riparian forests form small stands, which are usually narrow, often below 2.5 ha). Bird species were grouped into breeding and/ or food substrate selection ecological guilds: soil, undergrowth, crowns, occupants of tree cavities, birds that hollow out tree cavities (woodpeckers) (Camprodon 2013; Améztegui et al. 2018), as well as landscape scale preferences: forest specialist birds (found mainly in dense forests), generalist birds (they prefer forests, but are present in other habitats with trees); ubiquitous birds (present in forests but also or only in open areas) and mosaic birds (they prefer the agricultural-forest mosaic). For more details, see Bertrans (2019).

To sample the bat activity, we used Wildlife Acoustics ultrasound detectors, models Song Meter SM3 and SM4. Recordings were taken during the months of June, July and August of 2018 and 2019. The detectors recorded during seven consecutive days, obtaining daily data from half an hour before sunset to half an hour after sunrise. The recordings were analysed using Software Kaleidoscope Pro, by Wildlife Acoustics. Four nights with the greatest activity at each point were selected. We calculated the average number of bat cries per species or acoustic group and per night. Bat species were grouped into similar ecological affinity guilds: arboreal bats (which prefer to find shelter in trees), bats that usually feed in the forest, and generalist bats (which can be found in different habitats). For more details, see Oró (2020).

To sample terrestrial and semi-aquatic mammals, we performed linear track transects (tracks, excrements and other signs) along one of the river margins and 2 m of census band, the autumn of 2019. This is a non-invasive and efficient method to detect the presence of terrestrial and semi-aquatic mammals (Silveira et al., 2003). The transects were placed to have at least 5 km of sampling in each basin. In total, 36 transects were made, which largely coincided with the sites for birds and bats. Each track that was more than 20 metres from the previous one was individually noted.

The mammals were grouped into similar ecological affinity guilds (adapted from Molina-Vacas et al. 2009; Santos & Santos-Reis, 2010): semi-aquatic carnivores, consisting of the Eurasian otter (*Lutra lutra*), American mink (*Neovison vison*) and the European polecat (*Mustela putorius*); indigenous forest carnivores, consisting of the beech marten (*Martes foina*), common genet (*Genetta geneta*) and European badger (*Meles meles*); domestic carnivores, including the dog (*Canis lupus familiaris*) and cat (*Felis cattus*); large herbivores (ungulates), consisting of the wild boar (*Sus scrofa*) and roe deer (*Capreolus capreolus*); small semi-aquatic mammals, consisting of the Iberian water shrew (*Neomys* sp.) and Southwestern water vole (*Arvicola sapidus*). The red fox (*Vulpes vulpes*) did not fit into any of the aforementioned guilds since it is a generalist predator. Results were expressed in the Kilometric Abundance Index (KAI; track count/ linear kilometre). To complement this, 27 camera traps were installed to verify the presence of the European polecat (*Mustela putorius*) where likely tracks were found. For more details, see Soler (2021).

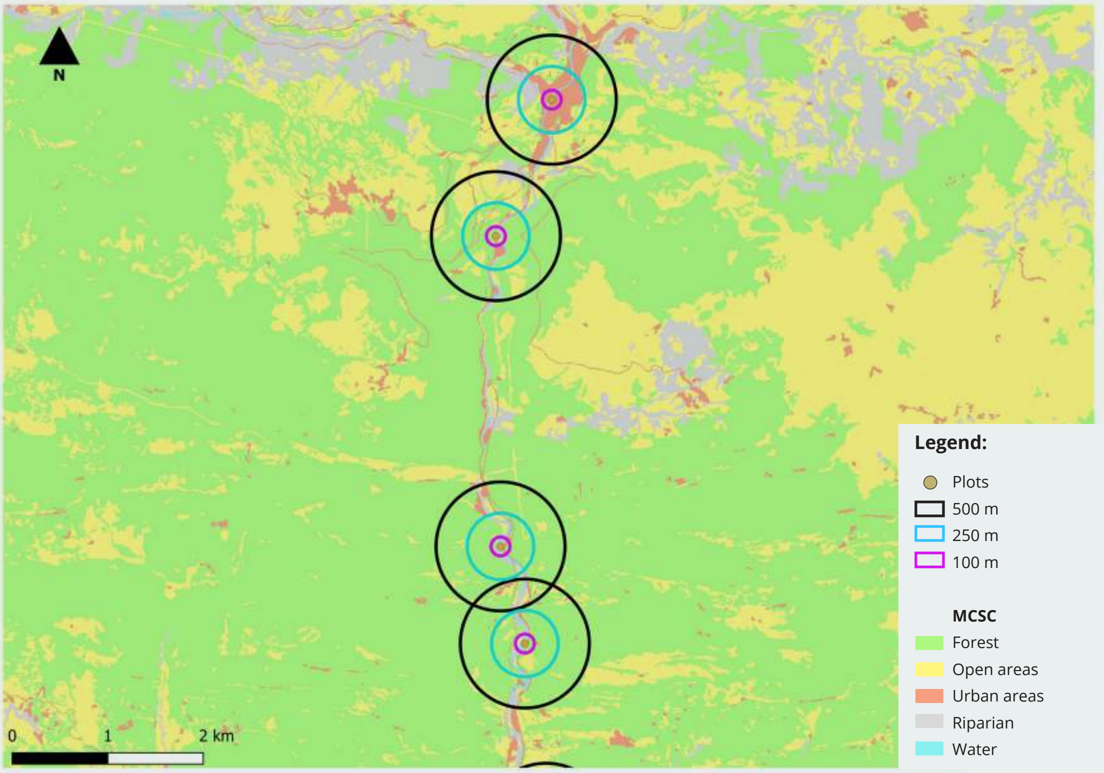

Figure 141 /

Example of the location of listening sites in the riparian forest with three census radiuses of 25, 50 and 100 m, from the LIFE ALNUS project. Source: Bertrans (2019) on top of the land cover map (CREAF, 2009).

Statistical processing

Pearson correlations were calculated between the alder residual chronologies and monthly stream flow. Alder resilience index to decline was modelled using a mixed model according to weather, vitality, geomorphic position and river characteristics.

The influence of environmental variables on bird and mammal distribution was calculated using generalised linear mixed models (GLMM). The initial set of environmental predictive variables was simplified using the redundancy discrimination analysis (RDA) for birds or the principal component analysis (PCA) for mammals. The RDA and PCA factors were used as independent variables and the wealth and abundance of ecological affinity guilds of birds, bats and terrestrial and semi-aquatic mammals, as response variables. Data were analysed using the statistical program RStudio version 1.1.463 (R Core Team, 2019).

8b.4. Results obtained and discussion

8b.4.1. Alder growth and decline according to change factors

Restoration of riparian vegetation with stream flow release and fluvial restoration

One of the actions performed by the LIFE ALNUS project consisted of experimentally releasing stream flows in two weirs with hydroelectric exploitation on the Ter river. As mentioned in the fluvial indicators chapter, over the course of the LIFE ALNUS project, uncommon flooding occurred. This random circumstance surpassed the effect of releasing stream flows. Nevertheless, as a post-Life follow-up, we are planning to compare a representative series from years before and after the actions, through the average alder growth and isotopic analysis, as a phreatophyte plant species that is more sensitive to stream flows, and other riparian trees. The comparison between alder location and the data provided by stream flow sensors should allow us to know the tree response to a seasonal increase and decrease and before/after the stream flows were released in the weirs, providing more or less water available. Droughts will be critical periods, comparing a long enough annual recurrence series. Both the response of riparian tree species and the assessment of invasive species treatment in the Ter and Besòs basins are aspects to be considered in the medium and long term.

Figure 142 /

Declining alders in an alder grove stand in the Ardenya stream, in the Catalan Pre-Coastal Range. Photo: Jordi Camprodon.

Alders: water stress measurement

A phenomenon demonstrated by the project's preliminary actions was the decline of alders located in headwater areas of the Ter and Besòs basins (Figure 142). Currently, alder decline is one of the major problems affecting the riparian ecosystem in basin headwater areas. Since 1993, a hybrid fungus belonging to the *Phytophthora* genus has spread among alder groves distributed within fluvial ecosystems, especially in central Europe. Nevertheless, in 2009, a phytopathological study performed in the headwater area of the Ter basin ruled out the activity of this pathogen, as well as other fungi. Other abiotic factors, such as continuous droughts that entail potential groundwater below the alder's water requirements, could be the causes of decline. The purpose of this study was to assess the relationship between alder decline and drought. For more details, see Valor et al. (2020).

The study confirmed that the growth of the specimens in decline was more influenced by the weather than healthy specimens. Dying specimens started to wane after the drought of 1998, the most extreme in the climate series (Figure 143). Post-Life follow-up will be performed in the short and medium term on the response of alders and other woody vegetation to silvicultural treatments to improve woodland structure and the success of alien plant species (see Chapters 3 and 4).

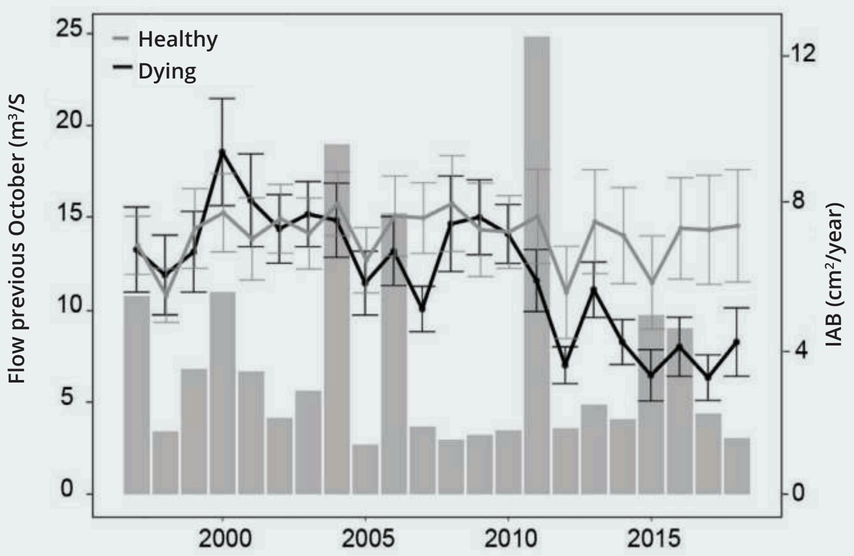

Figure 143 /

Stream flow from the previous October and BAI for the 1997-2018 period in the Ter river to Ripoll. BAI: basal area annual increases, the result of transforming the growth ring width measurements of analysed alders. Source: Valor et al. 2020.

The resilience to drought of dying specimens compared to healthy specimens diminished over time (Table 10 and Figure 144, top). Additionally, over time, the resilience of specimens further away from the river diminished compared to those that were closer (Table 9). Nevertheless, specimens further away with less growth prior to 1998 revealed greater resilience than trees with more growth (Table 10 and Figure 144, bottom). In short, the distance from the river and the growth rate negatively impacts alder growth.

Table 10 / **Summary of mixed model (estimation ± standard error), which describes the resilience of healthy and dying alder specimens alongside the drought events (1998, 2005/07 and 2012/15), in the upper Ter basin. P-values: n.s., not significant, *p < 0.05. Source: Valor et al., 2020.**

Resilience to drought	Value	Std. error	*p*
Intercept	0.35	0.56	ns
BAI (prior to 1998)	0.10	0.06	ns
Distance to the centre of the river	0.010	0.003	ns
Vitality (healthy)	-0.71	0.31	ns
Time	0.07	0.20	ns
Time X Vitality (healthy)	**0.37**	**0.16**	*****
Time X Distance to the centre of the river	**-0.002**	**0.004**	*****
BAI X Distance to the centre of the river	**-0.001**	**0.000**	*****
Marginal R	0.24		
Conditional R	0.40		

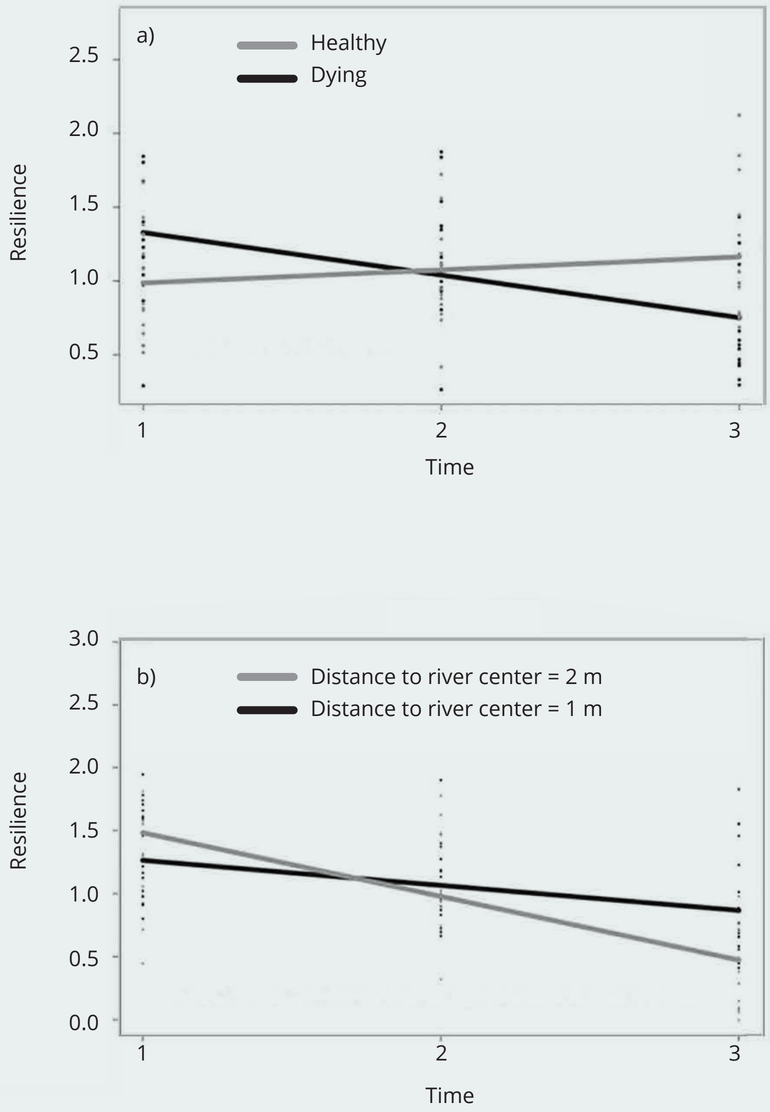

Figure 144 /

Prediction line and partial waste from the resilience model that shows the interaction between time and vitality (top), time and distance to the centre of the river (centre) and between BAI (basal area annual increases) prior to 1998 and the distance from the measured tree to the centre of the river (bottom). Source: Valor et al., 2020.

Understory of an ash tree with snow lily (*Galanthus nivalis*). Ter River. Photo: Jordi Camprodon.

8b.4.2. Riparian forest structure

The trees that appear as the most abundant on average per inventory are, in decreasing order, black poplar, alder, white willow, common ash and narrow-leaved ash (Figure 145). The occurrence of other dominant species per inventory, but that appear less frequently, is considerable. The dominance of alien species at many sampling sites is also noteworthy. Black poplar appears more dominant in the Ter river than in the Besòs. In the Ter river, indigenous black poplar converges with hybrid and commercial clones. In the Besòs river, poplar plantations are symbolic and in the Segre river, most of the black poplars can be considered indigenous and natural components of the riparian system. Alders are irrelevant in the middle course of the Ter River, whether due to riverbank deterioration or, also, because the highly calcareous substrate does not favour them. Whereas, in the Upper Ter and Segre, with less anthropogenic pressure and silicic substrate (oligotrophic soils and water currents), alders form real alder groves. White willow is abundant, especially in soils and water currents rich in (eutrophic) carbonates, as a highly adaptable species to less established substrates that are exposed to floods (Lara et al., 2004), where it forms willow groves that can become monoclonal. Alders, willows, ashes, white poplars and black poplars form mixed communities in alluvial lands, especially in mesotrophic substrates and waters with carbonates and silicic particles transported by the river (Lara et al., 2004). The dominance of other less common and alien plant species is noteworthy in the Besòs, where the riparian forest is potentially weaker, due to the more discrete water flows of the Congost and Mogent rivers. Zonal forest species appear, such as holm-oak, or they are deteriorated and dominated by alien plant species, often subspontaneous from ornamental trees, like the street elm, nettle tree and ailanthus.

The most common dominant species in the riparian forest undergrowth of the three basins are the European dewberry and the thornless blackberry (Figure 145). Cane is abundant in the Besòs river and loses strength in the Ter and Segre rivers, where it is less competitive. The variety of other dominant species is considerable depending on the sampling site, especially in the Ter river. The climate, orography, hydromorphology and anthropogenic gradients in the Ter encourage this greater variety. Ecological diversity (Shannon-Wiener Index) is high for trees, especially in the Besòs river and Upper Ter (Figure 146). In the case of the Besòs river, diversity is due to more balanced proportions between different species, including second-line species, such as the narrow-leaved ash and the elm, and zonal species (holm-oak), which mix with the first-line species, alder, white willow and white poplar. In the Upper Ter, the wealth of riparian species and humid environments, such as lime and maple, is greater than in the other basins. In the Segre river, diversity decreases, since these are larger alluvial forests, dominated by a typically riparian species such as alder, white willow or black poplar.

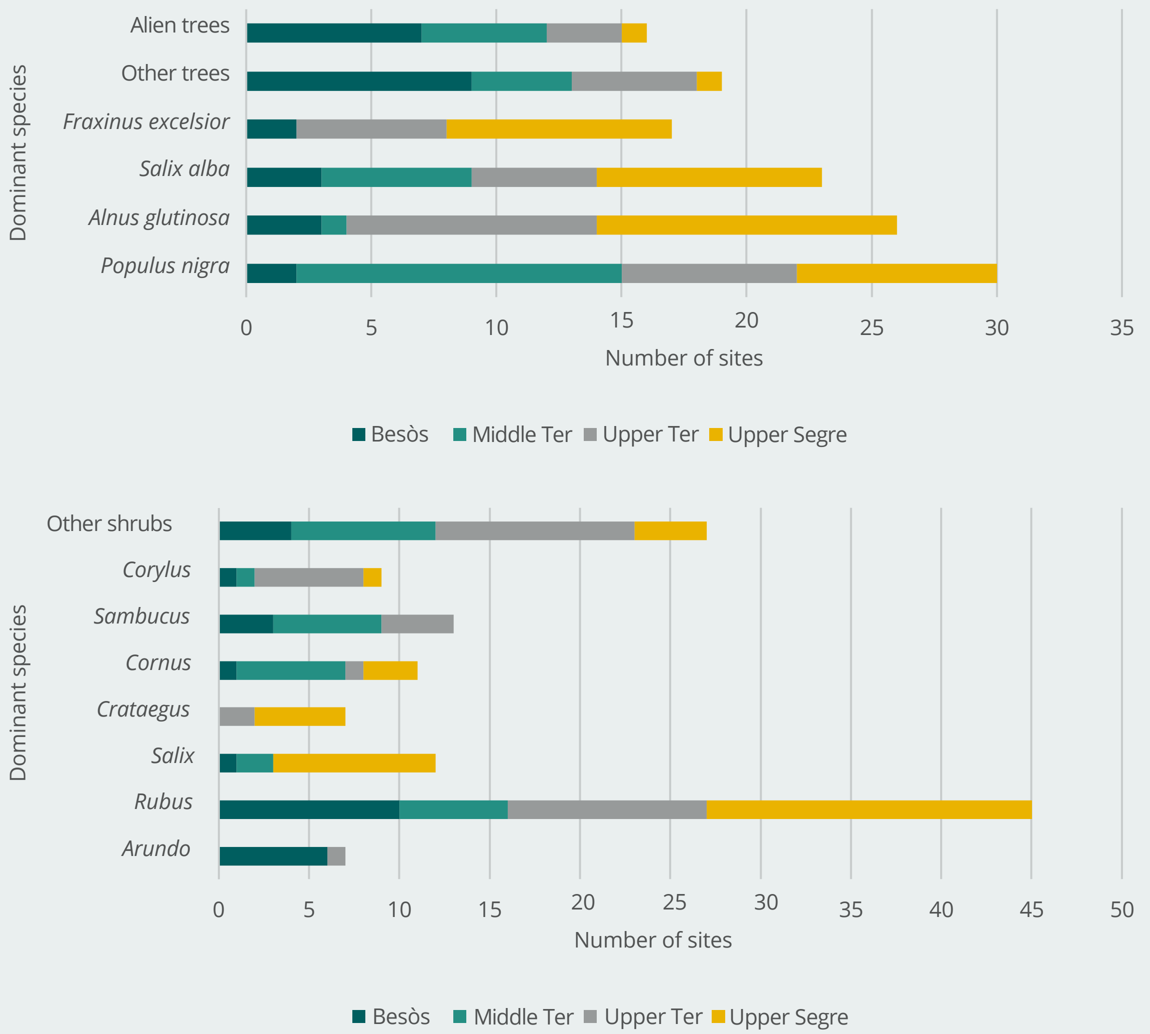

Figure 145 /

Composition of main tree and shrub species at the inventory sites of the Besòs, Ter and Upper Segre basins, expressed as the number of sites where the species is dominant.

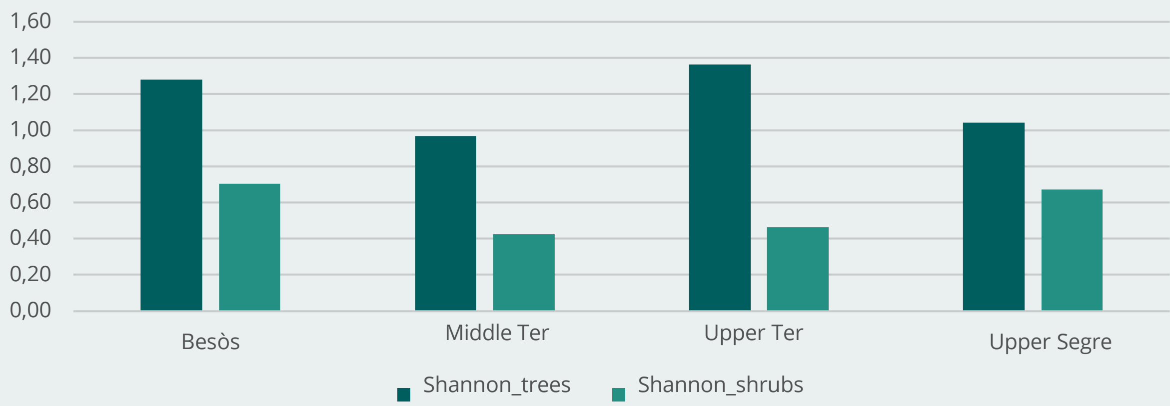

Figure 146 /

cological diversity (Shannon-Wiener Index) of tree and shrub species in the three LIFE ALNUS basins.

The vegetation's vertical stratification is complex, with some considerably high coverage percentages, from the grass layer to the tall tree layer (more than 8 m high), through the low shrub layer (0.5-2 m high) and a tall tree-like lianoid and shrub layer (2-8 m high) (Figure 147). Tree height does not rise beyond 16-20 m, and black poplar, white poplar and common ash are the tallest species. More than 50% of soil is usually covered by grasses and creeping shrubs (highly represented by brambles) in all basins. Low shrubs are less important. Close crowns limit the shrub layer, especially in pure alder groves, which are made up of a sciophilous undergrowth, dominated by hygrophilous or nemoral grasses, with abundant geophytes and pteridophytes, alongside nitrophilous species if nutrient uptake due to the river or livestock treading is significant (see below in the RVI analysis). In contrast, the most heliophilous shrubs develop well in forest glades and edges, often dominated by brambles. Shrubs that tend to achieve a decent height, like the hazel, common hawthorn and elder, are common even under dense woodland coverage, close to closed crowns. Forests in a mostly urban landscape tend to have lower coverage, especially of higher layers, probably due to greater anthropogenic pressure and a lower quality ecological site. According to basin, we observed that the Segre compiles a structure with high coverage —or relatively higher coverage— at all layers. Taller layers demonstrate a gradient from less to more coverage between the Besòs, Ter and Segre. This can be due to an ascending gradient of greater soil fertility, rainfall and greater structure and width of the riparian forest.

Figure 147 /

Plant coverage distribution of the riparian forest according to height distribution suggested by Prodon and Lebreton (1981), basin and dominant soil cover (CREAF, 2009) surrounding each stand that has been inventoried.

The woodland has an irregular forest structure with descending density of the different age classes (Figure 148). In the Upper Ter and Upper Segre is where the riparian forest has a greater representation of young and middle-aged classes, which denotes greater regeneration capacity, whether vegetative or sexual, a situation that is consistent with the greater vertical structure of plant coverage, as mentioned above. In the middle course of the Ter river and the Besòs, young classes feature a smaller foot density. This can be due to different factors that respond to a wide range of situations: narrower forests, greater flood influence, greater anthropogenic pressure, etc. Through the dominant landscape matrix, we observed how the riparian forests in mainly forest areas are denser and follow a more irregular age class structure, probably like those of zonal forests. However, riparian forests in mainly urban areas are relatively less dense in small and medium-sized trees and tend to regulate themselves. It is likely that their less strong width and exposure to disturbances reduce their regeneration capacity and the number of younger class feet. Riparian forests in agricultural matrix are in an intermediate situation.

Figure 148 /

Diameter distribution (average diameter, measured at a height of 1.3 m on the trunk) of trees in the inventory sites of the LIFE ALNUS basins, by basin and according to the dominant soil cover (CREAF, 2009) surrounding each stand that has been inventoried. Density of small (diameter classes 10-20 cm), medium (25-35 cm), large (35-45 cm) and very large (>45 cm) trees.

The number of standing and fallen dead trees is significantly greater in forests with a landscape matrix dominated by crops, pastures and zonal forests (Figure 149). In these environments, riparian forests are usually wider and more natural than forests with an urban matrix. These factors encourage the appearance of dead wood due to natural tree decline (caused by natural mortality and competition) alongside the influence of river floods, which break or uproot a greater proportion of trees since there is a greater density of small and medium feet. Glades opened by trees declining, breaking or becoming uprooted are an opportunity to renew the system and can stimulate woodland regeneration. For example, after two storms in quick succession (Leslie and Gloria), we observed young alder regeneration where flooding had reduced competition and/or provided sediments and nutrients. This regeneration had not been observed before the storms. In the urban matrix, riparian forests are less wide and have a greater proportion of large trees, more resistant to the effect of floods. By basins, it is clear the Upper Ter and the Upper Segre have a greater density of dead wood since they are wider and more natural forests, on average. The dendro-microhabitats measured in the dead wood (cavities suitable as shelter for vertebrate fauna) fully correlated to the density of medium and large-sized dead wood. For this reason, their density follows the same trend.

The silvicultural improvement works performed by LIFE ALNUS in the Besòs and Ter basins have contributed to moderately reducing foot density, both of competing indigenous species and, especially, alien species (see Chapters 3 and 4 for more details on treatments). The post-treatment dynamic will be followed up post-Life since it is a medium- and long-term response.

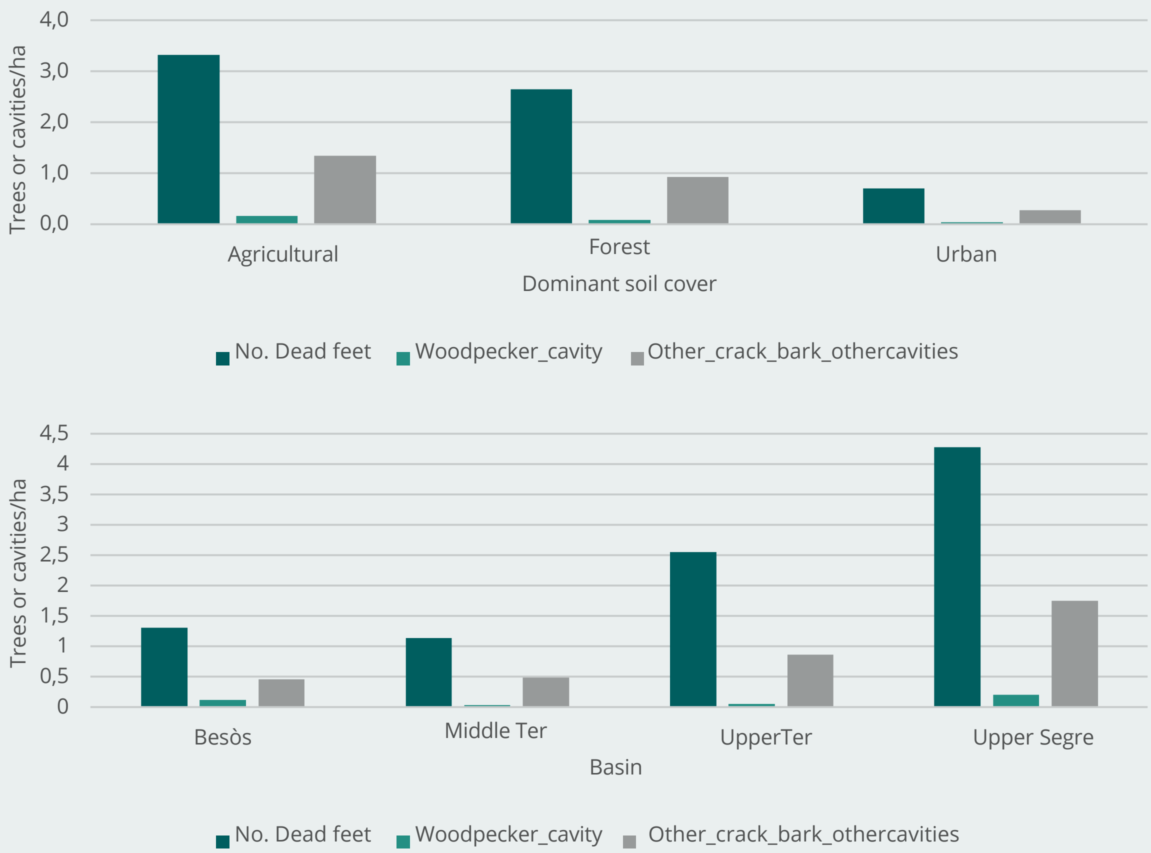

Figure 149 /

Density of standing dead trees, cavities hollowed out by woodpeckers and trunk cracks in inventory sites of the LIFE ALNUS basins, by basin and according to the dominant soil cover (CREAF, 2009) surrounding each stand that has been inventoried.

8b.4.3. Dead wood follow-up

Understanding the movement dynamics of dead wood on riverbanks and riverbeds allows us to write guidelines on how to manage it to maintain or strengthen the ecological dynamics of rivers and, at the same time, decrease risks to infrastructures. This need is a priority, especially in the case of large piles of dead wood produced by extraordinary floods. In these cases, as a management measure, they are usually systematically removed, without paying attention to ecological criteria. Preserving dead wood wherever it does not pose a significant risk to fluvial infrastructures can provide more benefits than disadvantages.

Between the properties of Can Batista and Les Gambires (Torelló) and El Sorral Island (Masies de Voltregà), in the Ter river, 100 medium and large pieces were marked, divided into the following species, according to availability on-site: white willow (58), black poplar (26), alder (10), white poplar (1), London plane (1), unknown species (4) (Figure 150). Average total dimensions were 44.9 cm in diameter at the base of the trunk, 34.35 cm in diameter at the centre, 24.9 cm in diameter at the end and 6.75 m in length. A large part of the trees had fallen but were still alive or in decline (28 feet), but most died recently, whether because of major storms or generated previously (38 feet); many pieces were decaying (branch loss, 26 feet, advanced decay, 8 feet). Living trees or those in decline had fallen and were uprooted in the same spot, they had not been moved by the water. Some of the dead trees were from the same location or had been transported by the storms. Storm Leslie, the first of the two, knocked over and transported a lot of biomass that had accumulated since the last big flood, in the 1980s. Regarding location and stability, 37 pieces were part of a pile of wood debris stuck in standing living trees, 14 pieces were attached to live wood without forming a pile, five were on the ground without being stuck in standing trees, and 20 units were standing dead wood. All these pieces were a certain distance (in metres) from the bankfull. Finally, 15 pieces were totally or partially in the riverbed and nine were in or remarkably close to the bankfull.

It is worth noting that part of the pieces moved by floods were felled feed that had been left in the forest before the storms. It is also significant that most of the wood that was cut to length and left on-site as a management measure after Storm Leslie was transported downstream by Storm Gloria and got stuck in weirs and reservoirs. Against the LIFE ALNUS project's recommendations, pieces were cut under 3 m in length, which enabled them to be moved more easily. Both for this reason and to simulate natural tree decline, we recommend not cutting dead wood to length.

Figure 150 /

Examples of large dead wood marked for follow-up in El Sorral Island, Ter river, Masies de Voltregà. Photo: Pol Guardis.

8b.4.4. Plantations

The list of plants used to restore alder groves in the three LIFE ALNUS basins is stipulated in Table 11. In each basin, woody species were selected in proportions according to the botanical inventories conducted in previous studies (Figure 151). The survival of woody species plantations was largely influenced by periods of summer drought and floods derived from storms Leslie and Gloria. In the Besòs basin, a significant part of plantations was planted during winter in 2019-2020 in the Congost river (Granollers). The effect of the floods caused by Storm Gloria (January 2020) was considerable. During the tree counts performed between the 18th and the 20th of February 2020, 34% of the alders planted survived, 81% of the Salicaceae stakes (several species) and out of the grasses and shrubs, all located closer to the water, only 7% survived. In certain areas, 90% of plantations failed in February 2020. To alleviate this, reinforcements were planted during the winter of 2021.

In the Segre basin, the plantation in Basses de Gallissà (Bellver de Cerdanya) also suffered significant casualties, in this case, due to the high temperatures and summer drought of 2020, which were heightened by the spread of the SARS-CoV-2 pandemic in March of the same year, which meant the plants could not be watered as planned. During the tree count performed in March 2021, 80% of planted alders survived. Their survival was high because they had been planted at the edges of ponds and channels connecting ponds, where the groundwater table was more superficial; of the common ashes planted, 31% survived, and of the willows, close to 30%. It is fair to say that the area is located on top of an old rubble dump and the soil structure in certain elevated areas is not good; in these areas, we decided to plant second-line ash species.

In the Ter basin, on Les Gambires Island (Torelló), after actions reconnecting the old branch and the area's fluvial dynamics, in 2022 more than 90% of the plantation had survived, and only 100 alders, 115 common ashes and 60 common dogwoods had to be replaced. Plantation follow-up was performed through a study performed by the Project Management of the Les Gambires Island action, by commission of the ACA, in accordance with the following premises:

- *Alnus glutinosa and Salix atrocinerea*: planted in locations with more soil moisture. Height below 1 metre from the sheet of water or at the bottom of hollows.
- *Salix purpurea*: planted on the riverbank of the main Ter riverbed.
- *Salix alba*: planted in moist soil, although it accepts a height of 2 metres from the sheet of water.
- *Salix elaeagnos*: planted in all previous areas, without a specific preference.
- *Farxinus excelsior*: planted in more raised and/ or drier soils, as part of the outside layer of the alder grove.
- *Ulmus minor*: clones from wild trees resistant to Dutch elm disease.
- The plantations were distributed creating natural irregular shapes.
- All the planting areas were not filled, but rather empty spaces were left for passive restoration.

Table 11 / **Woody species planted in each of the three fluvial basins of the LIFE ALNUS project. Production was through seeds or stakes collected from each hydrographic basin.**

Restoration project	Species	Units
Basses de Gallissà, Segre river	*Alnus glutinosa*	950
	Salix alba	535
	Fraxinus excelsior	765
		2.250
Congost and Tenes rivers, Besòs basin	*Alnus glutinosa*	3.887
Besòs basin	*Salix atrocinerea*	1.738
	Salix alba	2.576
	Salix elaeagnos	262
	Populus alba	450
	Cornus sanguinea	293
	Sambucus nigra	262
	Fraxinus angustifolia	800
	Ulmus minor	20
		10.288
Les Gambires island, Ter river	*Alnus glutinosa*	864
	Salix alba	380
	Salix elaeagnos	481
	Salix atrocinera	180
	Salix purpurea	180
	Fraxinus excelsior	880
		2.965
Alder grove defragmentation stands in Ter basin	*Alnus glutinosa*	2.591
	Salix atrocinerea	44
	Salix purpurea	94
	Salix elaeagnos	129
	Salixa alba	44
	Salix caprea	69
	Populus alba	12
	Fraxinus excelsior	171
	Ulmus minor	101
	Prunus avium	15
	Acer campestre	18
	Tilia platyphyllos / cordata	3
	Corylus avellana	18
	Euonymus europaeus	53
	Sambucus nigra	123
	Cornus sanguinea	50
		3.535
	Total	**19.038**

Figure 151 /

Alder grove reintroduction plantation after hydromorphology restoration in Les Gambires Island, Ter river, Torelló, Osona county. Photo: Jordi Camprodon.

8b.4.5. Riparian Vegetation Index

A total of 426 taxa of vascular plants have been registered in all four study areas (Segre, Upper Ter, Middle Ter and Congost), 66 of which (15.5%) correspond to foreign taxa. The highest percentage of invasive foreign taxa has been detected in sections of the Congost river and the Ter river in Osona county. A logical phytogeographical gradient is observed, with a greater presence of boreo-alpine and Eurosiberian taxa and a decrease in Mediterranean taxa alongside latitude. Multi-regional taxa, however, are more closely related to the degree of anthropization (Table 12). Out of all the recorded taxa, there is only one endangered species that is legally protected in Catalonia: *Scirpus sylvaticus*, located on the riverbank of the Segre river. The following rare plants or plants of interest for riparian vegetation conservation are noteworthy: *Aegopodium podagraria, Alopecurus geniculatus, subsp. geniculatus, Arctium lappa, Bidens tripartita, Dipsacus pilosus, Myosoton aquaticum* and *Stachys palustris*. Rare taxa can be considered indicators of conservation condition and of the quality of fluvial habitats. This list includes some plants native to nitrophilous grasslands, whose presence has been reduced and are becoming increasingly rare due to competition with foreign plants that share a similar ecology.

Table 12 / **Number of vascular plant taxa according to (simplified) chorological element and the establishment degree of foreign species in the different study areas of the LIFE ALNUS project. In brackets is the percentage in relation to the total or the total of foreign species. Locations are arranged from north to south. Source: Font & Casas, 2020.**

Basin	Total taxa	Boreo-alpine	Eurosiberian	Mediterranean	Multi-regional	Foreign	Invasive	Established	Unestablished
Segre	226 (53)	3 (1)	107 (47)	11 (5)	86 (38)	19 (8)	8 (42)	6 (32)	5 (26)
Upper Ter	148 (35)	3 (2)	94 (64)	6 (4)	33 (22)	12 (8)	6 (50)	4 (33)	2 (17)
Middle Ter	210 (49)	1 (0,5)	80 (38)	15 (7)	85 (40)	29 (14)	18 (62)	7 (24)	4 (14)
Middle Congost	106 (26)	0	27 (25)	16 (15)	40 (38)	23 (22)	14 (61)	5 (22)	4 (17)
Upper Congost	118 (28)	0	16 (14)	16 (14)	51 (43)	35 (30)	21 (60)	10 (29)	4 (11)
Total	426	5 (1)	163 (38)	49 (12)	143 (34)	66 (16)	34 (52)	21 (32)	11 (17)

Alongside the families that usually dominate local floral catalogues, some families are well represented, such as the *Cyperaceae* and the *Salicaceae*, due to being fluvial and hygrophilous environments, where these plants can develop optimally. In this sense, the genera *Carex*, *Populus* and *Salix* are among the best represented. The under-representation of alder, considering the potential range of alder groves, is due to anthropogenic (reduced water flow, breakwaters, channelling, felling) and ecological factors (calcareous substrates and or alluvial soils dominated by pebbles and gravel, excessively drained by the demands of alders and with a low groundwater table). Willow groves and white poplar groves are better at tolerating these conditions. Some genera of Compositae, such as *Bidens* and *Artemisia*, with many foreign taxa, are also rich in species in these environments. As well as genera with many representatives related to hydronitrophile environments, like *Polygonum* and *Rumex*.

In all the action areas, 12 CORINE habitats have been identified, six of which correspond to riparian forests; of these, two are Habitats of Community Importance (HCI): alluvial alder groves (HCI 91E0*) and willow groves and white poplar groves (HCI 92AO). The upper sections of the Segre river and the Ter river are eminently forest, while in the lower section of the Congost river most of the surface area corresponds to secondary grassland communities. The alder grove (and black poplar grove) with *Circaea lutetiana* of the montane zone is typical of the alder forests in the Segre and Upper Ter. The middle section of the Ter river and the Congost river feature alder groves (sometimes black poplar groves) with dead nettles (*Lamium flexuosum*), from the rainy lowland and the submontane zone. Alongside the alder grove, we find the lowland and mid-mountain white willow grove (Segre, Ter and Congost) and a second riparian strip of Pyrenean ash grove (Segre and Ter), mesohygrophilous hazel grove (Upper Ter) and sporadically lowland white poplar grove (and black poplar grove) (Middle Ter and the Congost river) and lowland elm grove (Lower Congost). The main non-tree communities are mesoxerophilous brambles (Upper Ter), grasslands with nitrophilous creepers at the water's edge and high nitrophilous fields, from often flattened riverbank quagmires (Middle Ter and the Congost river).

The quality of riparian forests in all the sections under study was mainly good, according to the degree of naturalness (Figure 152). Nonetheless, the riparian forests in the middle course of the Ter river tend to be of mediocre quality, but with a lot of variation between the different stands. The good quality exhibited by the riparian forests in the middle stretch of the Congost river is particularly noteworthy. The differences in riparian forest quality between the different sections should be found especially in the coverage percentage of ruderal or nitrophilous species and foreign species, many of which are associated to the abundance of hydronitrophile grasslands and flattened fields (Figure 152). The presence of foreign taxa increases from headwater areas to alluvial plains, following an anthropization gradient. Only in the case of the Upper Segre there is a stark contrast between the coverage percentage of species native to the riparian forest (more than 50% of the total taxa) and that of ruderal and foreign species. The good condition of the Segre river is due to the existence of lagoons and bogs and less anthropogenic deterioration of the forest. The presence of ruderal and nitrophilous species in the upper course of the Segre and the middle course of the Ter can be attributed to the presence of livestock that moves through and/or graze in these areas. In the case of the lower course of the Congost, the high anthropization of the environment entails an increase in the coverage of ruderal species. On Les Gambires Island (Ter river), plant colonisation is important after a hydromorphology restoration project (see Chapter 6). Coarse sediments were transported from the island upstream and fine sediments that had been previously separated were deposited on the island again, as superficial cover. This action was finalised in May 2022 and between June and August of the same year, ruderal and nitrophilous vegetation had progressively taken over the space, including some black locust sprouts or saplings. Plant colonisation is important in areas where coarse sediments were deposited, where on the same island, fine sediments were reincorporated.

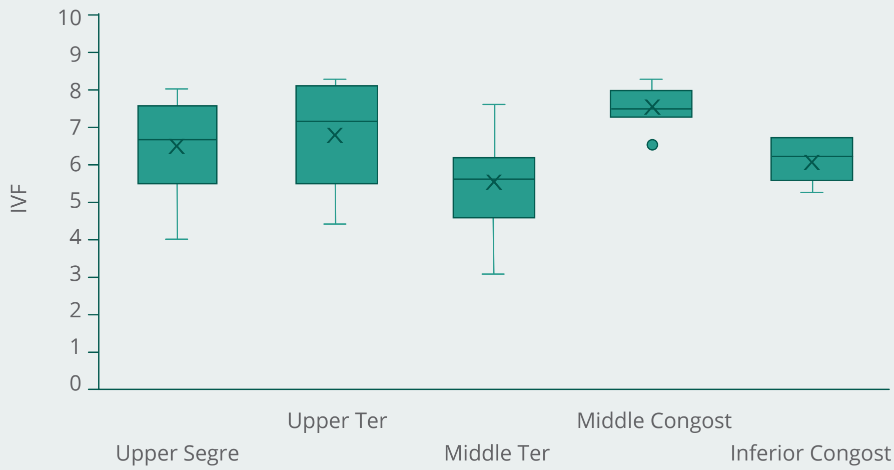

Figure 152 /

Riparian Vegetation Index (RVI) in the four study areas of the LIFE ALNUS project. The RVI score is indicated for "permanent, semipermanent" watercourse types (ACA, 2006). Index categories: very good (10-8), good (8-6), mediocre (6-4), deficient (4-2), poor (2-0). Source: Font & Casas, 2020.

Dogwood (*Cornus sanguinea*). Alder curb in the river Ter. Photo: Jordi Bas.

8b.4.6. List of riparian fauna according to habitat structure

Riparian forest birds compared to zonal forests

The absolute wealth of riparian forest birds comes from 75 species in listening sites, with an average wealth of 10.1 species/site and an average abundance of 15.5 specimens/site. Table 13 lists the most abundant species. Riparian systems host a larger abundance of specimens (statistically significant) but not species per site, in comparison to different forest typologies representative of the three LIFE ALNUS basins (Figure 153). A greater absolute wealth of species is indeed observed (Figure 154). At the same time, riparian forests contribute to the conservation of species of particular interest, only occasionally detected at the listening sites. This is the case of heron breeding. A Ter river alder grove in Torelló contains one of the six large known heron colonies in Catalonia (Figures 155 and 156).

Table 13 / **Bird species detected in the three basins of the LIFE ALNUS project at listening sites in riparian forests, indicating the ecological guilds according to habitat specialisation and nesting and food substrates. We distinguish between relative abundance expressed as the average contacts per site in the total sample and in three dominant landscape matrixes in a 100-m buffer around the centre of the site: forests, open areas (crops, pastures and shrubs) and urban areas. Only species with more than 0.1 average contacts per site are included.**

Species	Habitat specialization	Nesting habitat	Foraging habitat	Forests	Open areas	Urban	Total
Sylvia atricapilla	Specialist	Understory	Understory	1,60	1,15	0,77	1,27
Turdus merula	Generalist	Understory	Ground	1,15	1,08	1,17	1,13
Parus major	Specialist	Tree cavity	Overstory	1,05	0,77	0,87	0,92
Troglodytes troglodytes	Generalist	Understory	Understory	0,95	0,79	0,53	0,81
Luscinia megarhynchos	Generalist	Understory	Understory	1,03	0,23	1,00	0,79
Columba palumbus	Generalist	Overstory	Ground	0,79	0,36	1,07	0,73
Certhia brachydactyla	Specialist	Tree cavity	Overstory	0,68	0,64	0,53	0,63
Anas plathyrhynchos	Aquatic	Ground	Aquatic	0,58	0,21	1,27	0,63
Fringilla coelebs	Generalist	Overstory	Overstory	0,56	0,87	0,13	0,56
Erithacus rubecula	Generalist	Understory	Understory	0,45	0,74	0,43	0,53
Serinus serinus	Mosaic	Overstory	Ground	0,44	0,33	0,93	0,52
Passer domesticus	Ubiquitous	buildings	Ground	0,24	0,03	1,67	0,50
Cettia cetti	Aquatic	Understory	Understory	0,44	0,05	1,13	0,48
Sturnus vulgaris	Ubiquitous	buildings	Ground	0,52	0,03	0,63	0,40
Turdus philomelos	Specialist	Overstory	Ground	0,29	0,56	0,10	0,33
Cyanistes caeruleus	Specialist	Tree cavity	Overstory	0,31	0,38	0,17	0,30
Carduelis carduelis	Ubiquitous	Overstory	Ground	0,16	0,21	0,63	0,28
Motacilla cinerea	Aquatic	Ground	Aquatic	0,18	0,36	0,30	0,26
Picus viridis	Mosaic	Tree cavity	Trunk	0,16	0,00	0,80	0,26
Oriolus oriolus	Mosaic	Overstory	Overstory	0,37	0,23	0,00	0,24
Garrulus glandarius	Generalist	Overstory	Overstory	0,26	0,18	0,23	0,23
Aegithalos caudatus	Specialist	Understory	Overstory	0,27	0,26	0,07	0,22
Sitta europaea	Specialist	Tree cavity	Overstory	0,23	0,26	0,10	0,21
Chloris chloris	Mosaic	Overstory	Ground	0,16	0,00	0,50	0,19
Motacilla alba	Aquatic	Ground	Aquatic	0,15	0,10	0,40	0,19
Passer montanus	Ubiquitous	Tree cavity	Overstory	0,10	0,00	0,53	0,17
Cinclus cinclus	Aquatic	Aquatic	Aquatic	0,05	0,36	0,10	0,15
Dendrocopos major	Specialist	Tree cavity	Trunk	0,16	0,08	0,07	0,11
Phylloscopus collybita	Specialist	Understory	Overstory	0,15	0,13	0,03	0,11
Regulus regulus	Specialist	Overstory	Overstory	0,05	0,28	0,00	0,11
Muscicapa striata	Mosaic	Overstory	Overstory	0,08	0,08	0,17	0,10

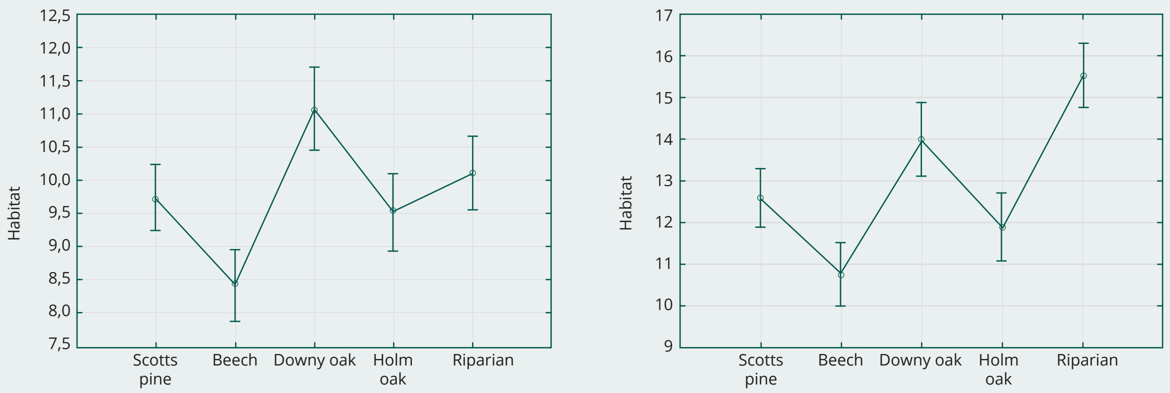

Figure 153 /

Correlation between average wealth and abundance of bird species in different forest types considered within the framework of the LIFE ALNUS project. Source of non-riparian data: Camprodon, 2013.

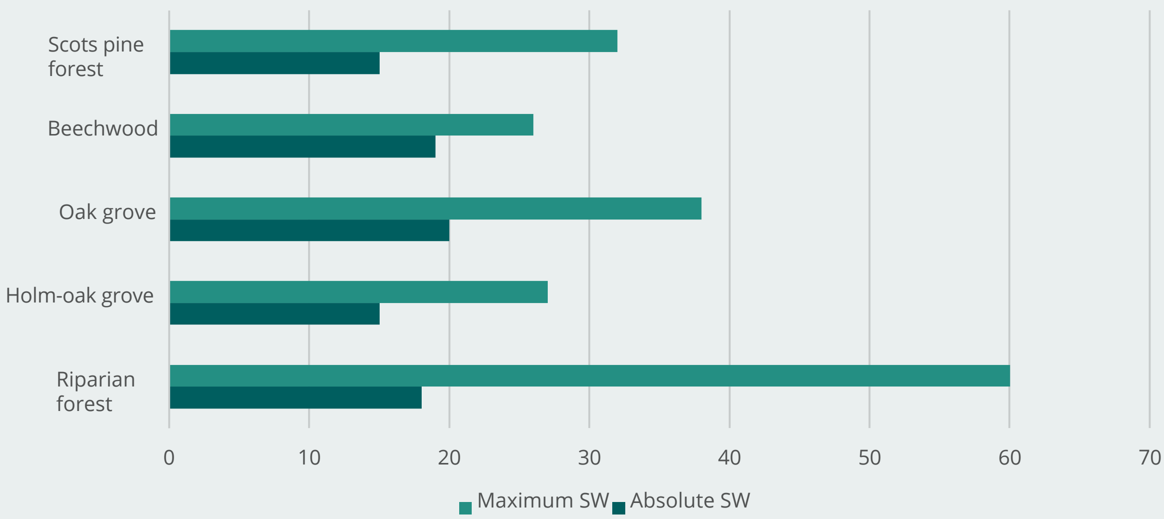

Figure 154 /

Absolute number of bird species and maximum average specific wealth per listening site in different forest types considered within the framework of the LIFE ALNUS project. Source of non-riparian data: Camprodon, 2013.

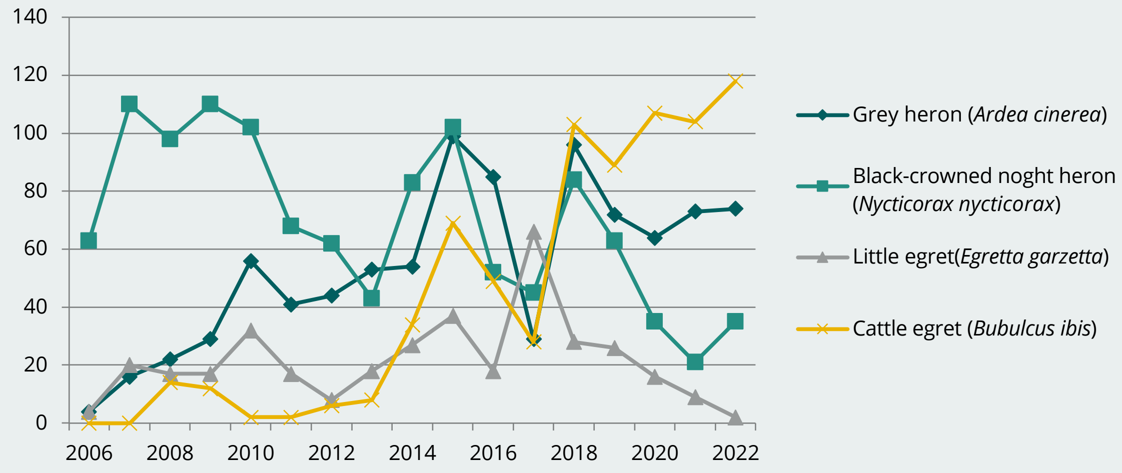

Figure 155 /

Development over time of the heron breeding colony on the riverbank of the Ter river in Torelló (Osona). Censuses correspond to the months of April-May each year. The dwindling number in 2017 is because that year the census was recorded in June. The year of maximum occupation was 2018, with 311 identified nests: 103 cattle egret nests *(Bubulcus ibis*), 96 grey heron nests (*Ardea cinerea*), 84 black-crowned night heron nests (*Nyxticorax nycticora*x) and 28 little egret nests (*Egretta garzetta*). Source: Centre for the Study of Mediterranean Rivers - University of Vic - Central University of Catalonia.

Figure 156 /

Heron breeding colony in an alder grove on the riverbank of the Ter river in Torelló (Osona), included in the fluvial network of the LIFE ALNUS project. Photo: Jordi Bas.

Birds and landscape composition

The neighbouring riparian forests surrounded by urban centres (and open areas) host a substantial number of generalist species (typical of landscape mosaics), ubiquitous species and those that feed on the ground, despite retaining a substantial proportion of forest specialist species. Forest specialist species show a preference for the forest matrix, due to their preferences for forests with dense tree cover (Améztegui et al., 2018), as well as for open mosaic (Figure 157). Ubiquitous species have a significantly greater representation in urban areas due to the presence of anthropophilic birds, such as the common pigeon, common magpie, house sparrow and common starling (Duguid et al., 2016). On the contrary, urban landscapes reveal less abundance of bird species considered sensitive to the degree of humanisation (Aronson et al., 2014).

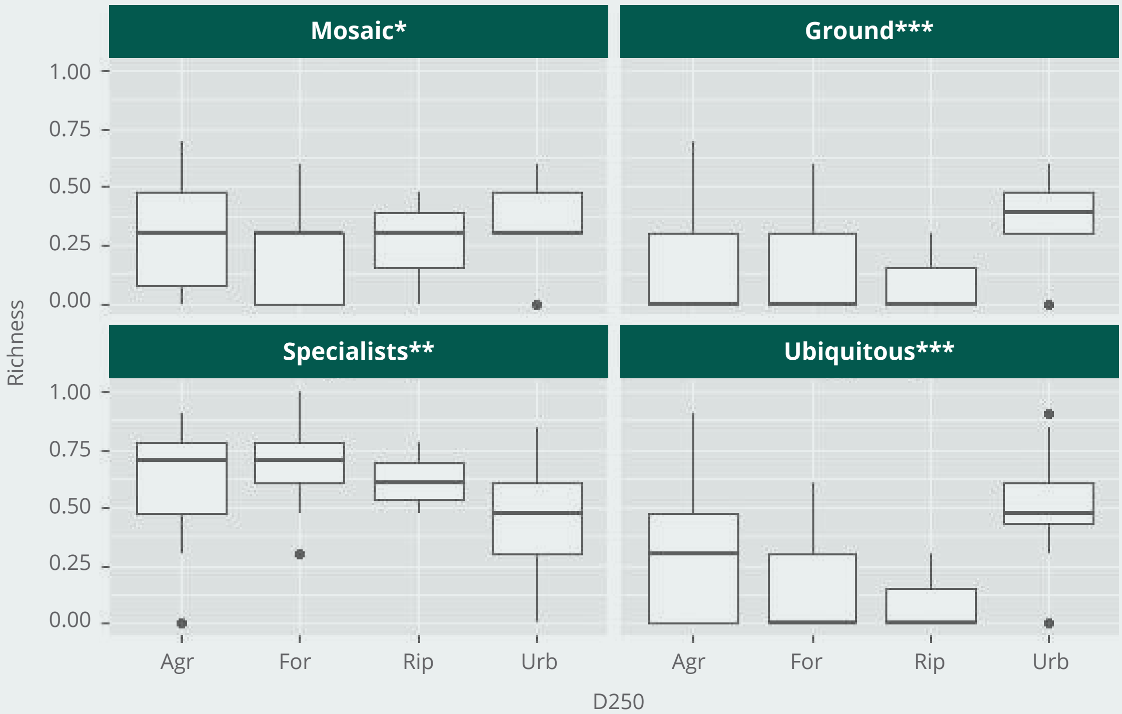

Figure 157 /

Average species from each ecological guild according to listening site (specific wealth) compared to soil cover considered within the framework of the LIFE ALNUS project. Agr: agricultural and open areas (crops, pastures and shrubs); For: forest (forests), Rip: riparian forest; Urb: residential and industrial urban areas. P-values: *0.05, **0.01, ***<0.001.

We observed a greater average wealth of forest specialist species and, within these, birds that breed in cavities and birds that hollow out tree cavities with a better structured riparian forest (here this is considered as stands that contain more than 25% of the very large trees and the large trees are above stand average, that is, 63.4 feet/ha) (Figure 158). Batisteli et al. (2018) observed the same trend. These preferences are reinforced and specified by the variable selection models that define the habitat structure internally (GLMM): forest specialist species and burrowing birds are associated with large trees and tall tree cover and avoid landscapes dominated by the urban matrix (Table 16). Tall large trees can offer more different niches (Bae et al., 2018) and the urban matrix is usually associated to a reduced surface area for the riparian forest and a decline in plants, trees and plant complexity (Minor & Urban, 2010; Aronson et al., 2014). Within the burrowing species, birds that hollow out tree cavities (woodpeckers) are the taxonomic group and ecological guild most closely related to the riparian forest's maturity and width (or surface area), and, at the same time, they relate positively to the density of large trees and standing dead trees. Woodpeckers have been described to use fallen or dead trees as breeding and/or food substrate (Camprodon 2007 and 2013; Roberge et al., 2008). Although the lesser spotted woodpecker (*Dendrocopos minor*) is widely present in riparian forests of a certain maturity in the study area, it has only been detected at one site and we believe it is underestimated due to its low detectability after the month of April, when breeding season starts.

Agroforestry mosaic species positively related to the combination of agricultural matrix and forest landscape, although not in a statistically significant manner. These species cannot be found in dense forests or open areas with isolated trees or fragmented forests with an irregular spatial configuration (Heikkinen et al., 2004; Le Roux et al., 2015) and are more typical of large forest fragments, spanning several hectares, surrounded by open areas (Camprodon, 2013). A combination of mosaic at different development stages can encourage forest and mosaic bird diversity in fluvial areas (Duguid et al., 2016; Mag & Ódor, 2015).

For more information on birds and the riparian structure, see Bertrans (2019).

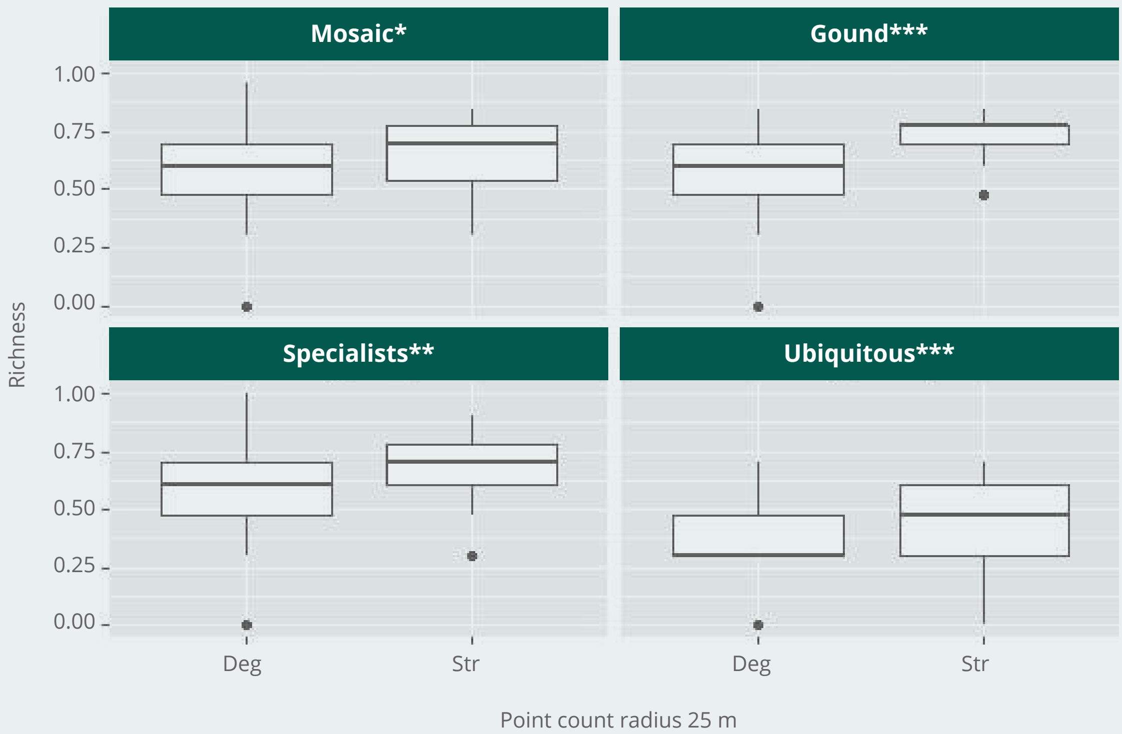

Figure 158 /

Number of average species from each ecological guild according to listening site (specific wealth) compared to the categorisation of the riparian forest as well structured (str) and deteriorated (det), considered within the framework of the LIFE ALNUS project. Structured: riparian forest with more than 25% of very large trees and large trees that are above stand average (63.4 feet/ha). P-values: *(0.01), **(0.001), ***(<0.001).

Bats and riparian forest structure

A total of 17 bat species have been identified. The species that has been detected in the greatest number is the common pipistrelle (*Pipistrellus pipistrellus*). Its large activity can be explained by its abundant distribution throughout Catalonia (Flaquer & Puig, 2012) and Europe (Barratt et al., 1997; Arlettaz et al., 2000). Species from the *Pipistrellus* genus, especially the common pipistrelle and Kuhl's pipistrelle, are well adapted to urbanisation and artificial lighting (Pauwels et al., 2019) and move well through more anthropogenic environments. Whereas the *Rhinolophus* and *Myotis* genera are more sensitive to artificial light, which decreases their physical abilities (Pauwels et al., 2019), and present less activity in the urbanised fluvial sections analysed. The common pipistrelle uses a wide range of habitats (Nicholls & Racey, 2006), more so than other species in the same genus. However, the soprano pipistrelle (*Pipistrellus pygmaeus*) and Kuhl's pipistrelle (*Pipistrellus kuhlii*), despite being less abundant, seem to use the riparian forest as shelter more than the common pipistrelle, judging by their greater occupation of shelter boxes (see below).

In the Besòs basin, less wealth and activity has been detected, with a relatively greater abundance of pipistrelles and less participation of forest specialist species (Table 14). This is probably related to the greater degree of urbanisation and greater deterioration of the riparian forest. The Ter and Segre basins, which are less urbanised and with a more diverse landscape (crops with forest masses), have a greater diversity of species, both generalist, such as pipistrelles, and others that do not feed in urbanised environments, such as species from the *Rhinolophus* and *Plecotus* genera and species such as the lesser noctule (*Nyctalus leisleri*) or the western barbastelle (*Barbastella barbastellus*).

Table 14 / **Representation of the number of species detected in the different basins of the LIFE ALNUS project, and total bat activity (average cries/night), total activity excluding the Pipistrellus genus and the activity of strict forest species.**

Basin	Maximum no. species detected	Total activity (average cries/night + sd)	Total activity without *Pipistrellus* sp. (average cries/night + sd)	Arboreal species activity (average cries/night + sd)
Besòs	7	683,6 ± 541,3	36,5 ± 37,5	2,3 ± 4,8
Ter	12	731 ± 547,1	55,4 ± 79,8	3,1 ± 6,2
Segre	12	722,3 ± 536	47,7 ± 62,6	3,2 ± 6,2

The wealth and activity of arboreal bats, as well as species that use the forest to feed and the total species excluding pipistrelles, positively relates to tree diversity, in stands with low undergrowth cover and located in peri-urban riparian areas (Table 16). In fact, tree diversity has been described as a factor that determines the wealth and abundance of vertebrates and invertebrates (Jung et al. 2012). Greater arboreal diversity can entail a greater availability of prey and shelters. Ober & Hayes (2008) describe a positive relationship between the abundance of insects and greater bat activity. A low availability of shelters can limit the distribution and size of the bat population (Sedgeley & O'Donnell, 1999; Vonhof & Gwilliam, 2007). Different flat-leaved tree species can offer different types of cavities. Woodpeckers prefer soft wood trees which are usually found on riverbanks, to hollow out their nests (Vonhof & Gwilliam, 2007; Charbonnier et al., 2016; Guixé & Camprodon, 2018).

The effect of the undergrowth is consistent with those described by other authors and seems to relate to the fact that an excessively dense

Golden eared (*Plecotus auritus*), an arboreal bat. Photo: Jordi Bas.

and tall shrub layer negatively impacts the flight ability of forest bats, meaning that they prefer to fly in areas with less shrub species and vines (Ober & Hayes, 2008; Guixé & Camprodon, 2018). Stands with less vertical plant cover become a meeting point for species adapted to hunting in denser and more open areas (Adams et al., 2009). The ideal distribution of the forest's vertical structure for different bat species to hunt would be made up of tall and diverse woodland with undergrowth mosaics combined with glades (Guixé & Camprodon, 2018). Otherwise, although one could think that the relationship between peri-urban forest areas and bats should be negative, we must note that forest habitats or fragments in conurbations can be of particular importance to arboreal bats or those that feed in the forest, since they are the only tree habitat available in an extensive area (Smith & Gehrt, 2010). The wide vital domains bats have, spanning several kilometres around the shelters, can help to dampen the effects of habitat fragmentation.

Carnivores, small mammals and riparian forest structure

Through tracks and camera traps, 21 species have been counted. The species that have averaged more than 20 tracks/km on the riverbanks of the three ALNUS basins are, in descending order, the otter, wild boar, American mink, red fox, common rat and the Iberian water shrew (Table 15). In the headwater areas of the Segre and Ter rivers, we find the Pyrenean desman, an endangered species typical of mountain watercourses in good ecological condition. Iberian water shrews are a rare species, with an unknown distribution in Catalonia. They have appeared in all three basins, especially in the Pyrenees. Tracks do not allow us to distinguish between species. The southwestern water vole is a species that has become rare in recent decades. Nevertheless, tracks have appeared in relatively well-preserved sections of all three basins, especially in the Upper Ter and Upper Segre. There are no reliable data to analyse the European polecat. The tracks reported can only be considered likely trails. 27 camera traps were installed, which registered likely European polecat tracks, but none were confirmed on-site.

Table 15 / **Kilometric Abundance Index for tracks of different species of terrestrial and semi-aquatic mammals in the three LIFE ALNUS project basins.**

Species	Upper Segre/ Upper Ter	Middle Ter	Besòs	Total	Average
Lutra lutra	137,15	117,24	20,21	274,60	91,53
Sus scrofa	43,13	81,85	51,75	176,73	58,91
Neovison vison	11,39	104,40	21,47	137,26	45,75
Vulpes vulpes	51,41	42,82	4,84	99,07	33,02
Rattus norvegicus	19,39	22,05	35,11	76,55	25,52
Neomys fodiens/N. anomalus	40,80	19,35	0,83	60,98	20,33
Martes foina	38,41	16,93	0,83	56,17	18,72
Capreolus capreolus	31,63	23,29	0,85	55,77	18,59
Arvicola sapidus	25,85	9,17	1,33	36,35	12,12
Meles meles	14,45	12,36	3,21	30,02	10,01
*Mustela putorius**	17,73	2,64	0,00	20,37	6,79
Genetta genetta	7,79	5,60	1,33	14,72	4,91
Apodemus sp.**	3,78	6,59	2,16	12,53	4,18
Mustela nivalis	6,17	4,76	0,85	11,78	3,93
Cervus elaphus	4,24	6,69	0,00	10,93	3,64
Galemys pyrenaicus	10,27	0,00	0,00	10,27	3,42
*Erinaceus europaeus/Atelerix algirus****	4,86	2,68	2,16	9,70	3,23
Oryctolagus cuniculus	0,00	0,76	6,27	7,03	2,34
Felis silvestris	3,34	0,00	0,00	3,34	1,11
Elyomis quercinus	2,27	0,00	0,00	2,27	0,76
Talpa euroapea	1,69	0,00	0,00	1,69	0,56

** likely tracks, not confirmed by camera trap.*

*** identified by camera trap, including tracks that could belong to other mice or voles.*

****Atelerix algirus is present in the Besòs basin and Erinaceus europaeus in the headwaters of the Besòs basin and in the other basins.*

The abundance of forest carnivores has been positively related to human influence (positive selection of proximity to urban or industrial areas and roads). Secondly, they show a preference for forests with greater plant cover, between 0 and 16 m (Figure 159). The model explains the variance of 35.8% (Table 16). The first association can be interpreted as a greater ease to feed in the periphery of urban areas, since they are generalist carnivores from relatively large territories, up to 3 km^2 (Rosalino & Santos-Reis, 2002; Fischer et al., 2005; Bakaloudis et al., 2012). It is possible that they only need one core area within their territory with optimal conditions and for the rest of their vital domain, they can accept a wide range of conditions and suboptimal habitats as shelter (Camps & Alldredge, 2013). Roads are associated to fauna mortality, and this is a well-researched phenomenon for several groups of animals (Carvalho and Mira, 2010; Kociolek et al., 2011). Small mammals can use the edge of roads as shelter (Ruiz-Capillas et al., 2013) and be a reliable source of food for carnivores. A complex plant cover would offer greater protection and shelter availability as a core area, and at the same time good trophic availability, which they could complement with ecotones and anthropogenic environments, where there are abundant rodents like voles, mice, and rats.

The southwestern water vole and Iberian water shrew are bioindicators of the habitat's good quality, since they are overly sensitive to change factors and disturbances (Mate et al., 2013). Small semi-aquatic mammals are highly conditioned by the pressure of predation (Table 16); the American mink is an important predator, effect observed by García-Díaz et al. (2013). The American mink population dates to escapes from fur farms during the second half of the 20th century (Bonesi & Palazon, 2007). They have proliferated in the hydrographic network of the Besòs and the Ter and are a threat to other vertebrates, such as the southwestern water vole and the European polecat (Bonesi & Palazon, 2007; García-Díaz et al., 2013). Since it is a recent introduction, its distribution can be more influenced by this than by habitat characteristics (Balmori et al., 2015). It is uncommon in the upper Segre basin and Ter river, far from the points where it was released (Table 15).

The southwestern water vole and the Iberian water shrew show a negative correlation with domestic predators (Figure 159). Roaming domestic cats are probably the most abundant predator on the planet (Mori et al., 2019). Cats are especially problematic for the small vertebrates that can be part of their diet (Krauze-Gryz et al., 2012; Mori et al., 2019). Cats have been reported to hunt shrews (Mori et al., 2019) and in riparian ecosystems they hunt Iberian water shrews, but they do not eat them because of the unpleasant odour their scent glands release (Champneys, 2012). The direct correlation with the abundance of indigenous predators can be partially explained because both groups look for good quality habitats and the umbrella indigenous predators open against the American mink (Sergio et al., 2008).

Small semi-aquatic mammals choose undisturbed habitats (Champneys, 2012; Mate et al., 2013): without weirs, channelling or bridges, infrastructures that can modify the fluvial dynamics and morphology of the riverbank. The model explains the variance of 13.7 % (Table 16). We observed a negative relationship with nitrophilous species, which can be explained by the structural simplification that high nettle covers represent.

Contacts with the Eurasian otter (*Lutra lutra*), the American mink (*Neovison vison*), the European polecat (*Mustela putorius*), the red fox (*Vulpes vulpes*), the wild boar (*Sus scrofa*) and the roe deer (*Capreolus capreolus*) have not shown any statistically significant relationship or any environmental variable. In the case of the otter, other habitat traits concerning hydromorphology could be explored or connected to the biomass of its prey (mainly crabs and fish).

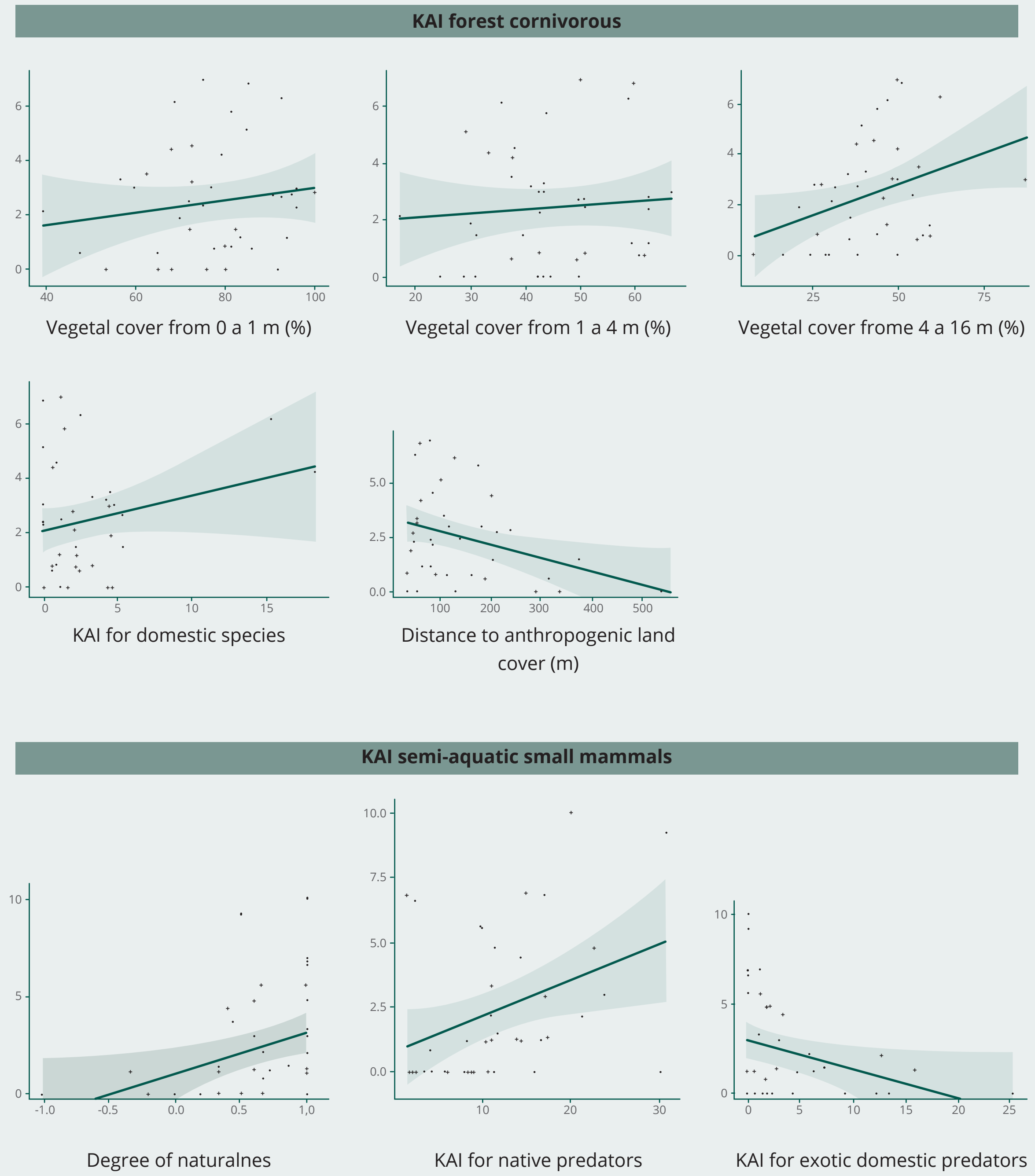

Figure 159 /

KAI (Kilometric Abundance Index) for forest carnivores (top) and small semi-aquatic mammals (bottom) in relation to variables selected by GLMM models considered within the framework of the LIFE ALNUS project.

Table 16 / **Selection of variables at landscape and stand scale by different groups of vertebrates considered within the framework of the LIFE ALNUS project based on generalised linear mixed models (GLMM). In green: positive relationship of the group to the environmental variable; in orange: negative relationship. Woodland cover (4-16 m): percentage of plant cover, basically trees, between 4 and 16 m high. Large trees (> 47.5 cm): density of trees larger than 47.5 cm in average diameter in feet/ha. Undergrowth (1-4 m): percentage of undergrowth cover (shrubs, vines and small trees) between 1 and 4 m high. Tree diversity: Shannon index for tree species. Fluvial naturalness: absence of infrastructures (breakwaters, weirs, bridges), tested on terrestrial and semi-aquatic carnivores. Landscape diversity: Shannon index in a 500-m buffer. Proximity to anthropogenic covers: Distance to urban centres and main roads. Native predators: abundance of indigenous carnivores (beech marten, genet, European badger and red fox). Foreign predators: abundance of foreign carnivores (American mink, domestic cat and dog). Significance level (p-value): *(0.05); **(0.01); ***(<0.001).**

	Forest birds	Burrowing birds[1]	Arboreal bats[2]	Bat wealth	Forest carnivores[3]	Small mammals[4]
Plant cover (4-16 m)		**			*	
Large trees (> 47.5 cm)	**	**	*	*		
Undergrowth (1-4 m)				*	*	
Tree diversity			***	*		
Fluvial naturalness						*
Landscape diversity				**		
Proximity to anthropogenic covers	***				***	
Native predators						*
Foreign predators						*

1. Sitta europaea, Certhia brachydadyla, mallerengues. 2. Nyctalus leisleri, Nyctalus cf. lasiopterus, Myotis crypticus, Barbastella barbastellus. 3. Genetta genetta, Martes foina, Meles meles. 4. Arvicola sapidus, Neomys sp.

Shelter availability

To improve the habitat's suitability for fauna and as a component of biological follow-up, shelter boxes were installed for bats and holts were built for otters. The first encouraged forest bats in riparian forests and allowed the occupation follow-up in the long term. In 2019, 222 Schwegler boxes with three different models were installed (Figure 160). They were distributed in groups of 3 (one box per model) in different stands within the basins of the LIFE ALNUS project, coinciding with the echolocation sites. The occupation in 2020 was 35% (24% in the Besòs, 48% in the Ter and 29% in the Segre).

The boxes were occupied by the following species: soprano pipistrelle (42%), Kuhl's pipistrelle (29%), lesser noctule (23%), brown long-eared bat (3%) and common pipistrelle (3%).

Figure 160 /

Bat boxes installed in an alder grove. Photo: Jordi Bas.

Otter holts were built in different sections of the Besòs and Ter basins alongside riparian forest restoration actions. They were built with felling debris, especially black locust, wood that is highly resistant to being exposed to the elements. They functioned as a temporary shelter for otters in suboptimal habitats, to encourage the section's shelter capacity during their movements (Figure 161). In some cases, they could even be used for breeding, but this is not their intended use. They were installed making the most of pits in the lands or the surface was dug up to make them larger, in spaces far from ordinary floods and paths and trails. The pit was covered in medium-sized pieces of wood covered by thinner branches. All to encourage the shelter's occupation and durability. Follow-up through camera traps will allow us to assess its usefulness.

Figure 161 /

Otter holt in the Besòs basin built within the framework of the LIFEALNUS project with plant materials from habitat improvement forest works. Photo: Pol Guardis.

CONCLUSIONS

1. The fluvial areas in the three basins from the LIFE ALNUS project (Segre, Ter and Besòs) have been greatly transformed for centuries. Despite inner deterioration, fragmentation and habitat loss problems, they maintain sections with complex hydromorphology and stands with diverse riparian forests, with a considerable diversity of riparian organisms. Anthropogenic and ecological factors interact to explain the distribution of riparian flora and fauna throughout the biogeographic gradient of all three basins: Mediterranean plant communities in the Besòs, sub-Mediterranean communities in the Middle Ter and central-European communities in the Upper Ter and Upper Segre. The headwater areas of the Segre and Ter rivers are the areas that feature greater floral wealth and structural complexity. Nevertheless, the Middle Ter and Besòs, despite their greater degree of anthropogenic transformation, preserve some sections of considerable structural complexity of the riparian forest and biological diversity associated to different indicators analysed: flora, vegetation, birds and mammals.

2. Anthropogenic factors (human footprint) are decisive to explain the differences in structure and expanse of riparian vegetation. Riparian forests in the ALNUS basins are also very dynamic according to flood patterns, topography and geohydromorphology. The floods caused by Storm Leslie and Storm Gloria moved sediments, broke and felled many small and medium-sized trees (especially in the Ter river), and probably encouraged the sprouting of alder regeneration, not observed before the storms.

3. The study conducted in the headwater area of the Rigat river (Ter basin) proved the influence of recurring drought on alder decline. Decline also occurs in headwater areas in the Catalan Coastal Range. If stream flows do not increase, alder decline and death may increase with climate change and the accumulation of forest biomass in basin headwater areas.

4. More maintenance stream flows must be provided where there are collection points. Although alder decline occurs in headwater areas with few collection points, we must take into account that the increase in evapotranspiration due to growing tree biomass in the whole basin takes groundwater table and superficial water away from the bottom of valleys. Active forest management on the one hand and the natural progression of forests towards more mature systems (with the start of decline processes and glades opening up in a set of tree masses that are now young and dense), alongside disturbances of a larger scope, such as forest fires, would reduce evapotranspiration and increase stream flow in watercourses.

5. The greater wealth of species and structural heterogeneity a riparian forest has, the greater resilience it can have to global change factors. For example, if fallen alders are not saved, other species in the system, such as willows, black poplars, ashes or limes can occupy their place in the riparian system. Planting elms resistant to Dutch elm disease can also contribute to making forests more resilient to change.

6. The diversity of tree species in the LIFE ALNUS basins is considerable. The combination and proportion of species varies greatly between sampling sites, within the same river section and along the phytogeographical gradient.

7. The vegetation's vertical stratification is extraordinarily complex in the riparian forests of all three basins, especially in forest and agricultural landscape matrixes. It is also more complex in wider and more natural sections of the riparian forest (Upper Ter and Upper Segre). Vertical heterogeneity is extremely variable from one fluvial section to the next and within each section small stands with different structures can form due to substrate and watercourse conditions and human footprint.

8. The riparian forest age classes make up an irregular structure, which contributes to vertical heterogeneity. This irregularity is most obvious in the Segre and Ter rivers. The tree structure tends to regulate itself in urban landscape

matrix sections, where riparian forests are less dense in small and medium trees.

9. Structural elements that indicate forest maturity (large trees,

10. dead wood and glade-forming dynamics, dendro-microhabitats such as cavities) are more evident in riparian forests in forest landscape matrixes, followed by agricultural ones. Urban matrix forests maintain, on average, similar large tree densities to riparian structures in contact with zonal forests and open areas; however, the dead wood and cavities associated to them are significantly scarcer in urban riparian forests.

11. The riparian forest flora in the ALNUS basins is considerably diversified (more than 400 taxa and 12 CORINE habitats in inventoried areas). A clear phytogeographical gradient from more to less mediterraneity is observed. Hygrophilous taxa grow with the fluvial system's complexity (presence of secondary branches, flooded areas). Few endangered or rare taxa have been located. The Riparian Vegetation Index (RVI) is considerably high in all three basins. It decreases with the human footprint, especially in urban sections. In riparian sections where domestic livestock moves through the forest, the undergrowth is simplified with dominant covers featuring ruderal and nitrophilous species. The wealth and abundance of alien taxa also increases with the degree of anthropization, with a minimum in the Segre, a maximum in the Besòs, and a gradient from less to more between the Upper Ter and the Middle Ter.

12. Forest birds and bats are associated to a greater density of large trees. Tre diversity is clearly selected by bats. Tall tree covers are preferred by burrowing birds and forest carnivores, and carnivores are also associated to tall undergrowth cover. So, better structured forests (large trees, tree layer diversity and vertical plant heterogeneity) are considered the most decisive variables for fauna wealth and abundance in fluvial areas.

13. At landscape level, forest birds are significantly more abundant in large riparian forests and, independently, when the forest matrix is dominant. Landscape heterogeneity, however, benefits fauna with large vital domains, such as bats (wealth of species) and forest carnivores (abundance). The agricultural and urban landscape matrix favours the presence and abundance of anthropophilic, generalist, and agricultural-forest mosaic species. In terms of human impact, small semi-aquatic mammals prefer fluvial sections that are highly natural with scarce pressure from anthropophilic and/or foreign predators.

14. Fluvial restoration with the dual purpose of a) recovering deteriorated or missing riparian forests (extension of the width and length of the forest) and b) achieving greater maturity and heterogeneity of the riparian system, is essential to maintain diverse and complex organism communities. The proximity to extensive zonal forest covers provides a buffer against the entry of ubiquitous, anthropophilic species or those with a wide ecological spectrum. Nevertheless, the fluvial landscape mosaic with forests and open areas seems to not damage semi-aquatic and forest species, as long as the system is maintained at a high level of naturalness/maturity and benefits species with wide vital domains and birds from the agricultural-forest mosaic.

15. Post-Life follow-up can assess the effect of the LIFE ALNUS fluvial restoration actions on the growth and vitality of alders and other riparian vegetation, as well as the success of plantations. Maintenance irrigation is essential to overcome periods of drought. Proper species selection according to ecological site and substrate (soil atrophy and proximity to the groundwater table), based on botanical inventories and knowledge of the ecology of species and the land to be restored, are key factors for efficient plant restoration.

16. The post-Life follow-up of medium and large dead wood will allow us to assess the residence time and mobility due to floods, as well as the decaying process and the creation of dendro-microhabitats. These data are key to offer wood debris management recommendations, especially after floods.

17. Finally, we must note that vascular flora and the bird community are useful as direct bioindicators of the degree of naturalness of riparian systems, thanks to their diversity of species and ecological traits, sensitivity to change and relatively low sampling costs.

8c / **HYDROMORPHOLOGICAL MONITORING OF THE RESTORATION MEASURES EXECUTED ALONG THE MIDDLE STRETCH OF THE TER RIVER**

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8c.1. Introduction

The Ter River suffers from a chronic structural sedimentary deficit that has deteriorated the river's morphological and sedimentary activity. The construction of dams, as well as other more localized impacts (arid mining), have altered the longitudinal and lateral connectivity, leaving the flood plains disconnected in some cases, with direct effects on the riparian vegetation. Dams disrupt the longitudinal continuity of rivers, interrupting the transport of sediments downstream and may alter the natural flow regime. When it enters the pit of the dam, the flow loses some of its power, leading to the sedimentation of coarse materials (bed load). In contrast, finer materials, which are carried in suspension, are generally transferred downstream. Under these circumstances, the sedimentary balance will be affected by the disruption of continuity caused by the dam. Many of the dams on the Ter River were built in the late 19th and early 20th centuries, which means that the river has gradually adjusted its morphology to the sedimentary imbalance caused by the dams for over a century.

The chronic structural sedimentary deficit generates a state of sedimentary imbalance that leads to changes in the morphology of the channel downstream: incision of the channel, reduction of its active width, and increased armouring, eventually leading to a complete loss of the active morpho-sedimentary units. These changes may lead to a drop in the water table, disconnection from secondary lateral branches, a decline in the woody riparian vegetation and colonization by herbaceous and shrubby vegetation of the active sedimentary units, and changes in the morphological pattern of the channel (form and units). This has occurred to such an extent that, in some stretches, the river flows solely over rocky substrate, where the main morpho-sedimentary units (lateral and central bars) have eventually disappeared. This is the current situation of the Ter River.

Coarse sediments reincorporated into the river in the restoration of the Island of Les Gambires in the river Ter (Masies de Voltregà-Torelló). Photo: Jordi Camprodon.

8c.2. Area of study

The Les Gambires and El Sorral islands (Masies de Voltregà-Torelló, in Osona county) are two of the few remaining river islands left in the middle stretch of the Ter River (Figure 162), and among the best preserved. These islands contain a varied and valuable range of environments, including riparian forests, seasonal ponds and different river branches that provide shelter for an abundant selection of fauna. They are an example of good ecological complexity, although the state of conservation of the riparian forest is precarious, albeit with good potential for recovery. The stretch of river that contains the islands suffers from a significant degree of hydromorphological degradation, which was exacerbated by the excessive extraction of sediments of the main river bed along Les Gambires island in the last few decades of the 20th century. This led to the incision of the main channel and a reduction in the active width of the river, causing the loss of lateral and vertical connectivity. At El Sorral island, the construction of a large concrete ford at the end of the 1980s altered the longitudinal and vertical connectivity of this fluvial area. This has occurred to such an extent that the longitudinal slope of the island has been altered by the accumulation of sediments upstream of the ford, while downstream, erosion has become the predominant morphological process, forming a marked step as it passes over the ford. The Gambires-Sorral stretch of the river has become fragmented due to the presence of the Gallifa dam (Figure 162), altering the flow regime downstream and capturing the deposits of coarse sediment from the lateral tributaries, banks and the channel itself.

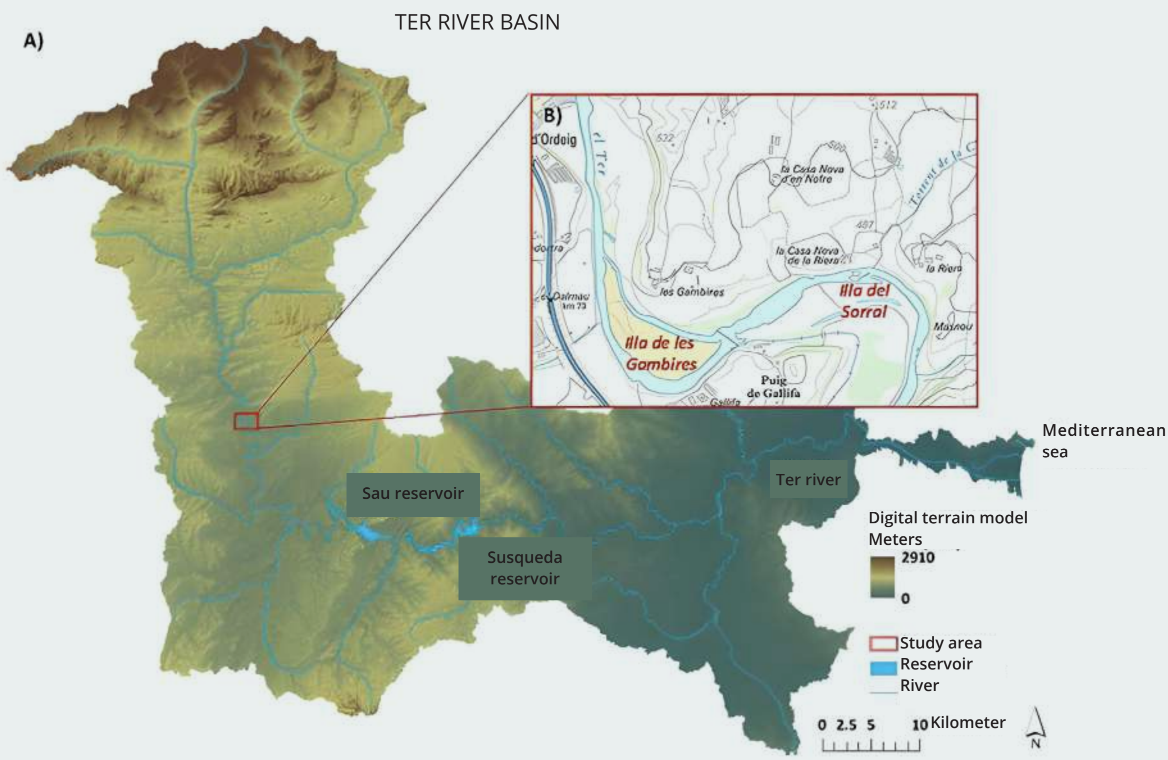

Figure 162 /

(A) Location of the stretch under study in the Ter River basin. (B) Detailed topography (1:10.000) of the stretch under study, with the Gallifa dam at the centre of the image, the Gambires island sector to the left and the El Sorral island sector to the right. Source: Institut Cartogràfic i Geològic de Catalunya, 2019.

8c.3. Background

Within this context, the LIFE ALNUS project was developed to undertake a series of conservation and morphological and sedimentary restoration measures in the fluvial area of Les Gambires island and El Sorral islands, of a demonstrative and experimental nature, under the supervision of and co-funded by the Catalan Water Agency. Before designing the actions to be taken, the morphological and sedimentary evolution and erosion processes were monitored. In addition, the flow rate and the water table (piezometers) were recorded continuously. This enabled the hydraulic characterization of the flow regime and the diagnosis of the hydromorphological dynamics along the stretch under study. Based on these studies, a project was developed for the hydromorphological restoration of the Ter River (for more details, see Chapter 6). For each sector, the project proposed and designed a series of actions to be taken based on the objectives to be achieved:

- Les Gambires island
    - Filling the main channel. Objective: Reversing the incision of the channel, increasing the lateral hydraulic connectivity and the height of the piezometric level.
    - Sediment extraction on Les Gambires island. Objective: obtaining sediment to fill the channel and reduce the height of the surface of the land on the island so that it is floodable in the highly frequent cases of flooding, as well as reducing the distance between the water table and the land surface.
    - Re-establishing the secondary branches upstream of Les Gambires island. Objective: increasing the wetted perimeter to decrease the incision capacity of the circulating flows, as well as increasing the hydraulic complexity of the system and the height of the water table.
- El Sorral island
    - Demolition of the ford. Objective: remove this rigid structure that alters the natural dynamics of the river (at a hydrological, sedimentary and morphological level) and the relationship between the river and the aquifer.
    - Conditioning the current secondary branches. Objective: reducing the hydrological dynamics of the main branch increasing the wetted perimeter and the height of the piezometric level, as well as facilitating connectivity with the secondary branches.

In December 2021, hydromorphological recovery and restoration works began in the fluvial area around Les Gambires island and El Sorral island. The work continued for 7 months, finishing in June 2022.

8c.4. Objective

This chapter gives an overview of the preliminary results from the monitoring of the morphological and sedimentary evolution of the bed of the Ter River after completion of the river restoration measures. Based on the data generated, the evolution of the hydromorphological and sedimentary dynamics of the reach under study will be evaluated in the short and long term (post-Life monitoring), as well as the success of the river connectivity expected to be achieved by the construction project.

8c.5. Methodological approach

A methodology divided into 3 modules was designed with the aim of studying the specific case of interest of the hydromorphological restoration undertaken within the framework of the LIFE ALNUS project, while developing a monitoring system that enables a more effective evaluation of this kind of measures.

Module 1 included **measuring** the water level of the river and the piezometric levels of the aquifer at the Les Gambires (Figure 163) and El Sorral islands. The objective was to obtain basic information to monitor the water resources, fluvial dynamics, aquifer dynamics and the relationship between the river and the aquifer. The measurements were taken on a continuous basis.

Figure 163 /

Transferring data from the pressure sensor installed on the piezometer on Les Gambires island. Photo: Jordi Tuset.

Module 2 comprised all the **fieldwork** tasks, which were conducted over the course of three campaigns spread over the period of the study. The first campaign took place just after the restoration works. The tasks carried out enabled us to gain an overview of the morpho-sedimentary state of the river reach studied, as well as the degree of river connectivity (lateral, longitudinal and vertical) for standard flow rates. The second and third campaigns determined the morpho-sedimentary dynamics during flood flows. Five tasks were performed at each stage: (i) direct flow measurements; (ii) topographic monitoring of the river bed geometry; (iii) river sediment sampling; (iv) bed load tracking with tracers; and (v) digital aerial imaging using an unmanned aerial vehicle (UAV).

i. Measuring the water speed and depth in the field (i.e., gauging) enabled us to calculate the flow rates and identify the variability of these parameters in the control section, and the relationship between them.

ii. Topographic surveys enabled us to assess the new geometry of the channel and the possible variations of the river bed in earlier cases of flooding. By comparing the surveys, the resulting topographic change can be identified in the periods under comparison. This calculation enables us to ascertain the surface area that has been eroded and the area on which sediment has been deposited.

iii. Characterization of the grain size distribution of the surface material on the river bed enables us to evaluate the magnitude and direction of the sedimentary changes over the course of the restoration works. Different methods were used for grain sampling.

iv. Tracking the bed load using tracers aims to determine the movement of representative particles in the area of study during episodes of flooding. In the field of river geomorphology, and specifically in bed load studies, the term 'tracers' usually refers to coarse particles (gravel and pebbles) that are monitored with the aim of tracking their trajectory over the course of relevant episodes (Figure 164).

v. The images taken by an unmanned aerial vehicle (UAV) enable us to determine the morphological units of the river bed resulting from the restoration measures. The images taken at the end of the project show the post-flooding adjustment of the morphology of the river bed now and in the future.

Figure 164 /

Example of painted tracers located in the lower stretch of the Ebro River. The particles are measured (axes) and painted. After flooding, the team search for the tracers visually. Photos: Álvaro Tena.

Module 3 consisted of all the **desk work**. In this module, all the data gathered in the different fieldwork campaigns was collated in order to analyse the morpho-sedimentary changes caused by the restoration measures, the hydro-sedimentary activity during flooding, and the river connectivity during periods of usual flow, thereby enabling us to assess the efficiency of the restoration works carried out. This module comprised four tasks: (i) characterization and analysis of the river connectivity post-intervention; (ii) hydromorphological characterization and activity post-intervention; and (iii) evaluation of the restoration works. Post-Life measurements will be taken after episodes of flooding, in which the circulating flow will have had enough power to mobilize sediments on the river bed.

i. The field observations, the topographic surveys, and the flow data and piezometric levels will provide enough information to characterise and analyse the hydraulic connectivity between the different fluvial elements, both in terms of ordinary and flood flows.

ii. The characterisation and analysis of the post-intervention hydromorphological activity focuses on quantifying the morpho-sedimentary dynamics of the stretch under study, with a particular emphasis on assessing the degree of stability of the post-intervention scenario using modelling and tracers.

iii. The hydromorphological indicators will be monitored primarily to evaluate the success of the restoration measures, analysing their evolution over the course of the monitoring process.

8c.6. Results

In December 2022, the first post-intervention sampling campaign was conducted to evaluate the hydromorphological activity after completion of the restoration works. Future episodes of flooding will help to validate the measures taken.

8c.6.1. Post-intervention hydrological characterisation

The characterisation of the flow regime enables the determination of the range of ordinary and extreme flows (dry season and flooding) in the area studied. This data is essential for defining the hydrological scenarios for analysis.

Based on the comparison between the readings from the Masies de Roda gauging station (EA085), located around 12.8 km downstream of the stretch under study (Figure 165) and the hydrometric stations installed in the area studied, the average annual flow rate is calculated to be 14.8 m3/s and the average flow rate in the month of August is 7.4 m3/s, the lowest of the year. The usual drought flow rate (flows above the 95th percentile) is 1.9 m3/s, which enabled us to determine the water level (availability) in the situation of water deficit.

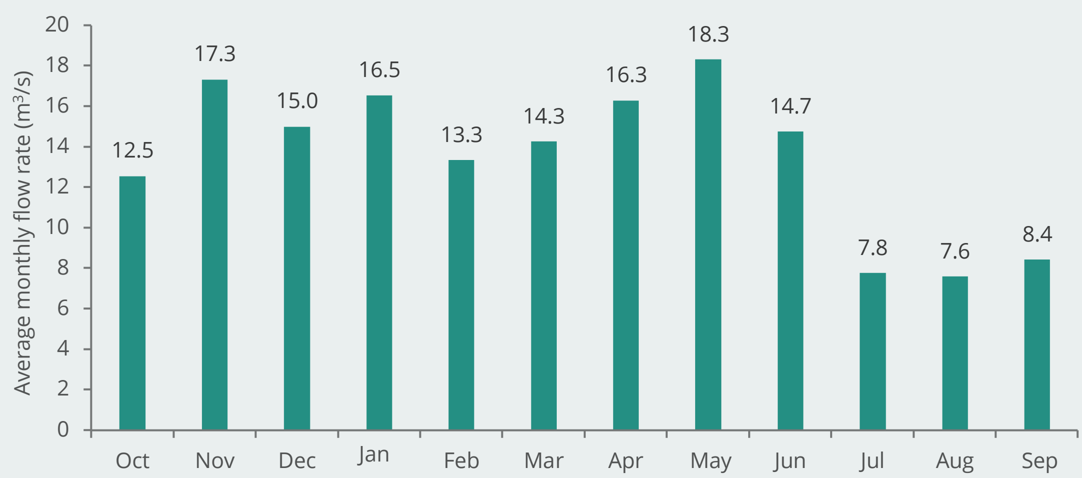

Figure 165 /

Distribution of the average monthly flow of the Ter River below the point of confluence with the Gurri River. The data was obtained from the Catalan Water Agency's website. The data is based on the sum of the readings taken from the Les Masies de Roda gauging station on the Ter River (EA085) and Gurri River (EA120) from 1996 to 2019 (11 full years of data).

8c.6.2. Lateral connectivity

- Les Gambires island

Before the restoration works, the secondary branch around Les Gambires island was disconnected from the main river bed when the flow rate fell below 33 m^3/s, meaning that water only flowed along the branch on 8% of the days of the year. After the restoration works, water now flows along the branch continuously, even in periods of low flows, such as the rate recorded on 27th July 2022: 3 m3/s, equivalent to the 86th percentile on the classified flow curve (Figure 166).

Figure 166 /

Image of the confluence of the main river bed of the Ter River and the secondary branch around Les Gambires island on 27th July 2022. The good health of the lateral connectivity resulting from the works can be observed, with a flow of 3 m3/s circulating without any problem. Photo: David Estany.

- El Sorral island

Neither El Sorral island nor Gallifa island displayed any significant lateral connectivity problems as they were regularly flooded.

8c.6.3. Vertical connectivity

- Les Gambires island

Before the restoration works, the piezometric level of Les Gambires island was controlled by the water level in the pit of the Gallifa dam, at the lower end, and by the input of water from the secondary branch at the top end (Figure 167A). This resulted in the alluvial aquifer at the northern end of the island being empty for most of the year. Previous extractions of sediments in the main bed of the Ter River disconnected the secondary branch from the main river bed during periods of ordinary flows, to the extent that the secondary branch was dry for a significant proportion of the year and the alders that grew there declined and eventually died. Without re-establishing the flows, it was not possible for the riparian forest to recover in this area. In contrast, the availability and stability of the water level at the dam ensured the good potential health of the riparian forest at the lower end of the island. As seen in Figure 167B, the lateral connectivity has improved the vertical connectivity at the island. Although no sensor is fitted at the northern end of the island, the aquifer is expected to remain active throughout the year.

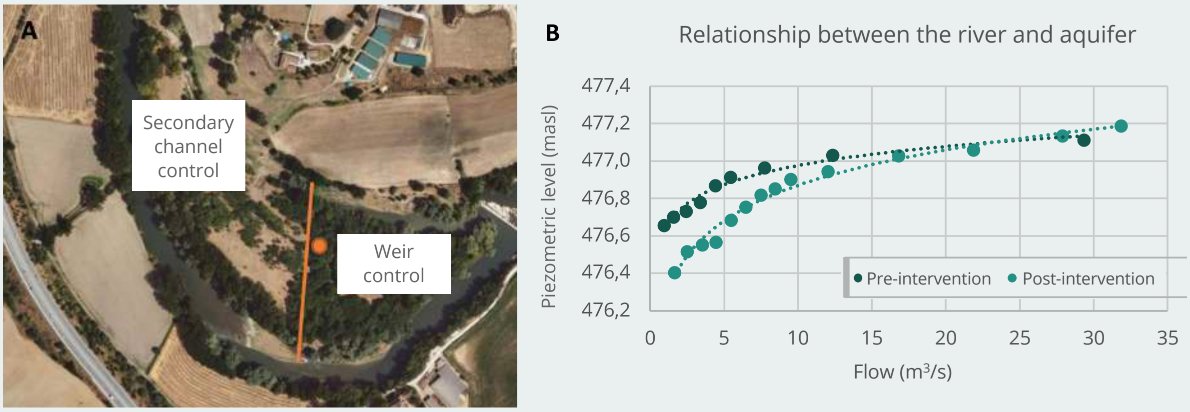

Figure 167 /

A) Image of Les Gambires island in 2022, before the works were undertaken. The orange line shows the border of the scope of influence of the piezometric level at the lower end of the island with the dam. This has facilitated good development of the riparian forest in this area. The orange dot shows the location of the piezometer. B) The relationship between the flow rate and piezometric level pre- and post-intervention. Before the restoration works, we can see that, for low flow rates (Q<5m3/s), the piezometric level was controlled by the dam and, indirectly, from the water collected by the catchment channels of the Les Gambires dam. After completion of the works, the piezometric level at the monitoring sensor is higher (30 cm, approx.) for low flow rates. In this case, the piezometric level of the whole island is controlled by the secondary branch.

- El Sorral island

To date, the elimination of the El Sorral island ford has not led to an improvement in the vertical connectivity. However, the range of circulating flows has been so low since the works were undertaken that it is not possible to draw definitive conclusions with respect to the relationship between the river and the aquifer post-intervention at this point. Once more data is available, it will also be necessary to analyse whether this can be explained by the fact that the secondary branches have not been conditioned (this measure is planned but not yet executed

8c.7. Acknowledgements

This study would not have been possible without the help of the RIUS Fluvial Dynamics Research Group (Consolidated Research Group of the Catalan Government, 2014 SGR 645).

Pebbles and gravels accumulated and in the process of quartz in the bed of a secondary arm of the river Ter, rehabilitated by LIFE ALNUS (current image). Before the hydromorphological restoration, only a certain flow circulated during floods. Island of Les Gambires, Torelló-Masies de Voltregà. Photo: Jordi Camprodon.

CONCLUSIONS

1. The works at Les Gambires island have achieved an improvement in terms of the pre-existing problems of lateral and vertical connectivity (the relationship between the flow rate and the piezometric level), promoting the relationships between the river and the bank.

2. In the case of El Sorral island, to date, there has been no improvement in the vertical connectivity, which will require a full analysis in the future when more data is available.

3. Once episodes of flooding have occurred in the stretch under study, it will be possible to analyse the morpho-sedimentary dynamics (degree of stability) and evaluate the efficiency of the hydromorphological restoration measures taken

9 /

THE PROCESS OF EXTENDING AREAS INCLUDED IN THE NATURA 2000 NETWORK AND INCORPORATING NEW ONES. THE CASE OF THE LIFE ALNUS PROJECT

9 / THE PROCESS OF EXTENDING AREAS INCLUDED IN THE NATURA 2000 NETWORK AND INCORPORATING NEW ONES. THE CASE OF THE LIFE ALNUS PROJECT

Quim Bach, Sara Pont, Francesc Diego

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9.1. Background

The Natura 2000 network of protected natural areas is the European Union's most important nature conservation policy initiative to date. Its overriding objective is to ensure or re-establish the conservation in a favourable state of habitats and species in their natural distribution area in the territory of the European Union (EU), in a manner compatible with the human activity that takes place in these areas.

The territorial implementation of the areas of the Natura 2000 network is deployed through Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (hereinafter, the Habitats Directive or HD), as Sites of Community Importance (SCI), and subsequently designated as Special Areas of Conservation (SAC), and by Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds (hereinafter, Birds Directive or BD), as Special Protection Areas (SPAs) for Birds. SCI, SAC and SPAs are classified as protected natural areas of the Natura 2000 network in accordance with article 42.1 of Spanish Law 42/2007, of 13 December, on natural heritage and biodiversity.

In 2006, the specific contribution of Catalonia to the Natura 2000 network was established through a Decision of the Government of Catalonia. The areas of the Catalan Natura 2000 network occupy a total of 1,067,560 ha (981,946 terrestrial ha and 85,614 marine ha). This represents almost 31% of Catalonia's land area. The Natura 2000 network is distributed in 117 areas.

Strategic documents have been drafted in the last two years that report on the current state of nature conservation:

a) **Reports on the implementation of the Habitats Directive and Birds Directive for the 2013-2018 period**

The reports for the 2013-2018 period on the state of conservation of the habitats and species of community importance present in Catalonia were published in December 2019, in accordance with the obligations deriving from article 17 of the Habitats Directive and article 12 of the Birds Directive.

The Habitats Directive requires habitat and species reports for each of the biogeographical regions established by the European Union that are present in Catalonia: alpine, Mediterranean and/or Mediterranean marine. Of the 99 habitats of community importance included in the HD that are present in Catalonia, the ones that are most at risk of disappearing are those related to inland waters and those with extremely small surface areas, as is the case of the coastal habitats of the Ebro Delta and the riparian forests and banks of many rivers.

The reports on the implementation of the Habitats Directive and Birds Directive for the 2013-2018 period can be viewed at:

https://mediambient.gencat.cat/ca/05_ambits_dactuacio/patrimoni_natural/senp_catalunya/xarxa_natura_2000/informes-aplicacio-2013-18-habitats-ocells/

b) **“State of Nature in Catalonia 2020” report**

The “State of Nature in Catalonia 2020” report, published in December 2020, is the first assessment of biodiversity based on the best available scientific information, in line with those published by the United Nations, the European Commission and leading countries in environmental matters. The report highlights the progressive and widespread degradation of biodiversity in Catalonia according to the Living Planet Index (LPI), showing a decrease of 25% on average between 2002 and 2019. On a global scale, the decline of wild vertebrate animal populations on the planet was 60% on average between 1970 and 2014.

The report states that the loss of biodiversity in Catalonia is not distributed uniformly across its various environments or habitats: it is 54% for animal species that live in rivers, lakes and wetlands, 34% for those that inhabit farmland and meadows, and 12% for those that inhabit forests and thickets. Although incomplete, the available data on the marine environment also indicates an unfavourable situation.

This loss of species in the Catalan territory is directly related to the alteration of their habitats. Changes in land use and its direct exploitation are the main culprits, although climate change and the arrival of invasive exotic species are having a growing impact. The underlying reason for this trend is a socioeconomic model that intensifies the obtaining of resources in certain areas while abandoning others that had been used more sustainably.

The results of the report show how human activity is seriously affecting the rivers of Catalonia, which is where biodiversity is facing the most critical consequences. The depletion of animal populations in rivers and lakes is evident: they have lost 50% of their individuals in the last twenty years. Moreover, almost 80% of the assessed species are in an unfavourable state of conservation, especially native fish, which have lost nine out of every ten individuals, due among other reasons to the arrival of invasive exotic species, which are now present in 64% of river courses and 73% of wetlands.

Apart from exotic species, inland waters have suffered the effects of water harvesting, pollution and artificialization that affects more than half of Catalonia’s rivers, with the occupation of alluvial plains and riverbeds, and with the consequent loss of the riparian vegetation and other habitats that occupy them.

The report can be viewed at the following links:

https://observatorinatura.cat/estat-de-la-natura/

https://mediambient.gencat.cat/web/.content/home/ambits_dactuacio/patrimoni_natural/sistemes_dinformacio/observatori-patrimoni-natural-biodiversitat/informe/estatgeneraldelabiodiversitatacatalunya-2020.pdf

c) **The LIFE ALNUS European project- LIFE Nature and Biodiversity Programme**

The LIFE ALNUS Project (LIFE16/ES/000768) is a project of the European Union’s LIFE Nature & Biodiversity Programme. It is coordinated by the Forest Science and Technology Centre of Catalonia (CTFC), which is implementing in Catalonia an experimental strategy for the conservation of the alder forests of the Alpine and Mediterranean biogeographical region. The strategy involves increasing knowledge in order to be able to reverse the regression and degradation of alder forests and contribute to their recovery, as a habitat of priority community importance (the 91E0* habitat), and to achieve the same goals with other riparian forests considered habitats of community importance in accordance with Annex I of the Habitats Directive.

The aim of the project is to implement actions for the conservation and restoration of alder forests (in a broad sense, including not only alders but also all the riparian and aquatic flora and fauna that are unique to and characteristic of these forests) that serve as a model for, and are transferable to, other river basins of Catalonia and the Mediterranean region that are affected by the same problems in the conservation of riparian ecosystems.

The project proposes various actions related to the direct improvement of the state of conservation of alder forests, the generation of knowledge and experience, and other socio-environmental objectives. The intervention areas are located in three pilot basins: the upper Segre sub-basin (Ebro river basin), the upper Ter river basin and the middle course of the Besòs river basin.

One of the project actions is aimed at increasing the physical and legal protection of the alder forest habitat as a Natura 2000 protected natural area. A working group was created for this action, comprising members of the LIFE ALNUS project and technicians of the Sub-Directorate General for Biodiversity and the Natural Environment (Government of Catalonia), which evaluated a proposal to modify the Natura 2000 network in relation to river areas. On the one hand, some of the boundaries of the river stretches currently designated as a Natura 2000 SCI were modified; and, on the other hand, new SCI areas were incorporated in the Natura 2000 network, based on the work of the priority HCI (Habitat of Community Importance) carried out in the area of the three aforementioned basins. On the basis of this proposal, which incorporates the improved information and the diagnosis made within the framework of a European project, the Catalan administration, as the competent Natura 2000 network authority, considers it necessary to improve its territorial protection in respect of the areas that form part of the Natura 2000 network. Link to the LIFE ALNUS project: https://lifealnus.eu/

The LIFE ALNUS project has generated new information and knowledge about the different types of alder forests present in Catalonia (sub-Mediterranean, pre-Pyrenean and continental), which in accordance with the assessment made by the Government of Catalonia, as the competent environmental authority in matters related to the Natura 2000 network, supports and necessitates the implementation of a proposal to modify the current areas of the Natura 2000 network in Catalonia, associated with fluvial systems and in accordance with the priority habitat of community importance.

It should be noted that the current conservation status of alder forests in Catalonia is considered unfavourable-inadequate (U1) in the Mediterranean biogeographical region, and unknown (XX) in the Alpine biogeographical region, according to the latest assessment of their state of conservation deriving from article 17 of the HD, corresponding to the 2013-2018 period.

9.2. The proposal for extending current areas and incorporating new ones

9.2.1. The objective

From the Catalan Government (Generalitat de Catalunya), after evaluating the information generated, it is considered necessary to process a proposal for a Government Agreement to improve the presence of fluvial areas currently excluded from the Natura 2000 network. The proposal involves expanding several areas designated as SCI and create new ones in the Natura 2000 network, within the typology of continental water areas identified in Government Agreement GOV/112/2006, around the Alt Segre basin, the Alt Ter basin and in the Besòs basin.

The proposal to expand and incorporate into the Natura 2000 network improves:

- The representation of fluvial spaces of alluvial alder forest within the area of the Catalan Natura 2000 network, as a habitat of priority community interest in accordance with the Habitats directive, as well as other habitats and species of community interest associated with river areas.
- The continuity and defragmentation of networked river areas, as key elements of the state of conservation of river habitats, and of the associated species of community importance, while strengthening the coherence of the Natura 2000 network, in pursuance of the overall goal of community directives on nature protection.

The extension proposal represents an increase of approximately 970 ha of fluvial-riparian areas in the Natura 2000 network in Catalonia around 175 longitudinal km of river, which host approximately 225 ha of habitat of community interest associated with fluvial areas, of which about 125 ha are alder groves (table 17, figure 168).

At the Catalan regional scale, the proposal therefore adheres to the overall goal of the Natura 2000 network for Member States at a European scale:

to contribute to ensuring biodiversity through the conservation of natural habitats and wildlife. This proposal focuses on the 91E0* priority habitat: Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion, Alnion incanae, Salicion albae*), as well as on other habitats and species of community interest related to river systems.

Table 17 / **RList of fluvial-riparian areas included in the proposal for extending the Natura 2000 network.**

	Current N2000 network areas			Modification of N2000 network areas		Proposed N2000 network areas		
Basin	**Code**	**Name**	**GOV/112/2006 Decision**	**Extension**	**New**	**Code**	**Name**	**Resulting surface area (ha)**
Segre	ES5130002	Verneda River	75,47	X		ES5130002	Banks of the upper Segre River and tributaries*	685,96
	ES5130011	La Llosa River	84,12	X				
	ES5120022	Duran River	102,73					
	ES5130007	Banks of the upper Segre River	216,62	X				
Ter	ES5120019	Banks of the upper Ter River	409,83	X		ES5120019	Banks of the upper Ter River and of the Freser River	544,85
	-------	-------	-------		X	ES5110026	Meanders of the Ter River	460,09
	-------	-------	-------		X	ES5120030	Major Stream-Es-pinelves Stream	66,13
Besòs	ES5110025	ongost Stream	356,73**	X		ES5110025	Congost Stream-Cà-noves Stream	400,05

** The proposed "Banks of the upper Segre River and tributaries" area (ES5130002) incorporates the ES5130007, ES5130011 and ES5120022 areas.*

*** The surface area of the current area has been slightly modified by Decision GOV/139/2015 of the Government of Catalonia.*

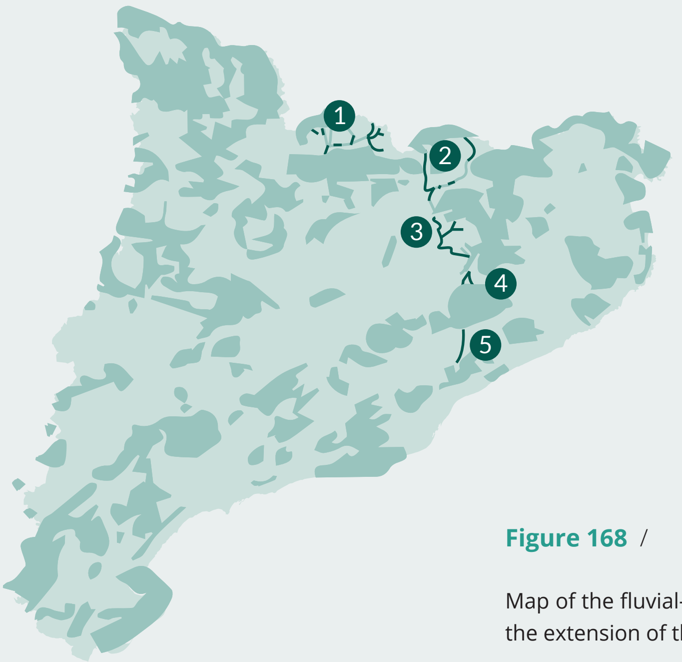

Figure 168 /

Map of the fluvial-riparian areas included in the proposal for the extension of the Natura 2000 network.

9.2.2. The process

First stage

In accordance with the procedure established for the creation of the Natura 200 network by the Habitats Directive, the declaration of Natura 2000 areas as Sites of Community Importance (SCI) begins with the proposal of Sites of Community Importance (pSCI) by the member state in the European Commission for its incorporation into the List of SCI that are published in the Official Journal of the EU (DOUE). In Catalonia, this proposal is prepared and approved by the Catalan Government (Generalitat de Catalunya) by means of a Government Decision Project (*Acord de Govern*) due to its powers with everything related to Nature 2000 (article 42 of Law 42/2007 on Natural Heritage and Biodiversity). The SCI list proposal must be fulfilled for each biogeographic region present in the EU that includes the Catalan territory: Mediterranean and Alpine biogeographic regions.

In the case of the SCI extension proposed through the LIFE ALNUS project, the technical team formed by the Forest Science and Technology Centre of Catalonia (CTFC), the Centre for the Study of Mediterranean Rivers (CERM) and MN Consultants prepared the preliminary technical documents and mapping, with the input of the other partners and collaborators of the project. Several meetings and consultations were held with local stakeholders, such as the Besòs-Tordera Consortium and the Ter Consortium, in order to present and agree upon an initial proposal drawn up on the basis of fieldwork and technical office studies. The proposal was initially based on a systematic modelling study carried out by LIFE ALNUS, in order to set out and prioritise the potential spaces, incorporating expert criteria during the consultation process. In the next stage of the process, the working group designated by LIFE ALNUS and the Natural Environment Planning Service of the Sub-Directorate General for Biodiversity and the Natural Environment (Government of Catalonia) held a series of meetings and worked together to draw up a proposal that could be fully supported in technical and scientific terms.

In order to reach a consensus with the territory, the record first went through a participatory process (carried out in the summer of 2022), in which stakeholders and individuals were invited to participate. This participatory process consisted of a meeting to present and discuss the proposal for the scope of the modification in each project basin and specific meetings with territorial actors

River section of the middle Ter sector known as “Meanders of the Ter”, proposed as a future SCI and future ZEC. Photo: Jordi Bas.

with significant weight in environmental and forest management.

Once the participation process was completed, the Natural Environment Planning Service began the administrative procedures corresponding to a file of a Government Decision Project (the documentation includes the text of the Decision Project, the supporting report, and the cartography) in accordance with the regulations. Within the framework of the established procedure, the file was submitted to a public information process, to the process of hearing the different actors affected by the proposal (interested local corporations, most representative agricultural professional organizations, associations and non-profit groups of forest owners representative of the area of interest, and to the rest of the interested entities), and in the request for mandatory reports from the department responsible for agriculture, livestock and fisheries and from the other departments and public bodies affected by the proposal, in accordance with in accordance with article 34.bis.3 of Law 12/1985, of June 13, on Natural Areas. Subsequently, the promoter unit prepares the assessment report of the allegations and closes the report with the final proposal of the Government Decision Project. Once the documentation has been validated at a legal level, the file is instructed to submit it to the Government of the Generalitat de Catalunya for its approval by means of the Government Decision Project, with its publication in the Official Gazette of the Government of Catalonia (DOGC).

Second stage

The Government Decision Project is sent to the European Commission through the Ministry for the Ecological Transition and Demographic Challenge (MITERD) of the Government of Spain, as it is responsible for dialogue with the EU in all matters related to the Natura 2000 network. European Commission (EC), through the “Habitats” Committee and together with the member state, analyses and selects the pSCI to be incorporated into the List of Sites of Community Importance (SCI) that are published as a Commission Decision in the Official Journal of the European Union (DOUE), granting the pSCI the status of SCI of the Natura 2000 network.

Third and last stage

In the last stage, again the Catalan Government has the responsibility, through the processing of a new Government Decision Project (same procedure carried out to approve the pSCI in the first stage), to declare the SCI as a Special Areas of Conservation (SAC). The management instrument is approved jointly. This document includes, as a minimum, the objectives and measures that must be carried out to guarantee the favourable conservation status of the Habitats of Community Interest and Species of Community Interest of the Natura 2000 network, within a maximum period of 6 years from the date of the first inclusion and publication of the SCI in the DOUE’s SCI List.

Hydroelectric, forestry, agricultural, livestock, urban, industrial, transport and leisure uses, among others, converge in the same stretch of river.
Future SAC "Meandres del Ter" / Photo: Jordi Bas

10 /

GOVERNANCE OF FLUVIAL AREAS

10 / **GOVERNANCE OF FLUVIAL AREAS**

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10.1. Background

In recent years, the need to review the relationship between institutions and society has been promoted in Europe, especially by its various public agencies. Indeed, new techniques have been gaining ground that provide a necessary opportunity for participatory instruments, with the goal of strengthening projects, processes and decisions, thus paving the way for the implementation of several tools that promote what we refer to today as governance.

According to the Commission on Global Governance (1995), "*Governance is the sum of the many ways individuals and institutions, public and private, manage their common affairs. It is a continuing process through which conflicting or diverse interests may be accommodated and cooperative action may be taken. It includes formal institutions and regimes empowered to enforce compliance, as well as informal arrangements that people and institutions have agreed to*."

In its White Paper on European Governance (2001), the European Commission provides the following definition: *"Governance means rules, processes and behaviour that affect the way in which powers are exercised at European level, particularly as regards openness, participation, accountability, effectiveness and coherence."*

Meanwhile, the *Gran Enciclopèdia Catalana* (Great Catalan Encyclopaedia) says that governance is *"A way of governing based on the interrelationship of the bodies entrusted with the political management of a territory and civil society, in order to give greater power, authority and influence to citizens when making decisions that directly affect public life."*

Visit of members of LIFE ALNUS amb municipal representatives i of the Life a l'espai natural program of les basses de Gallissà (Bellver de Cerdanya), riu Segre.
Photo: Jordi Camprodon.

10.2. Governance and fluvial areas

Accordingly, and from the humble perspective of a project with European funding, implemented in Catalonia but with a Mediterranean vision, we consider governance as a *method that enables us to incorporate the social factor in the process of making decisions for and with the territory through multiple tools*.

Although much work remans to be done in implementing the use of participatory instruments and processes across all the areas of the bodies responsible for the management of the fluvial-riparian area covered by the LIFE ALNUS project, their use has become an increasingly common practice, especially by the Government of Catalonia, for example through the Catalan Water Agency (ACA) in the implementation of the "Participatory processes for the third cycle of hydrological planning in the Catalan River Basin District". This planning tool is designed to improve the ecological state of the water bodies of rivers, groundwater and coastal areas in Catalonia, as set out in the Water Framework Directive.

Another example, to which a special chapter is devoted in this technical manual, is the initiative undertaken by the Natural Environment Planning Service of the Ministry of Climate Action, Food and Rural Agenda of the Government of Catalonia, consisting of a "Participatory process for a proposal to modify the spaces of the Natura 2000 network in Catalonia", in light of the fact that the state of conservation of its alder forests and other riparian forests, as well as that of the biodiversity typical of inland waters, is unfavourable. In order to turn the situation around, the proposal was made to extend the sites of community importance (SCI) in fluvial areas within the distribution area of alder forests (and other riparian forests). These areas are closely related to the work areas defined by the LIFE ALNUS project.

As we have pointed out, the detected problems associated with the habitat of alder forests represent myriad challenges and opportunities at multiple scales, given that riparian habitats are highly modified, occupied and abandoned areas: modified to preserve uses, infrastructures, goods and services; occupied by infrastructures and structures that perpetuate the simplification of habitats and natural processes associated with rivers and streams (as a whole); and abandoned to their fate due to a lack of space, sediments, organic matter and water, as basic elements for their survival. This situation is further compounded by the destabilization and anthropic simplification caused by the arrival and massive proliferation of invasive exotic species at all levels. Therefore, we can categorically state that these are highly endangered habitats, hence their inclusion on the European Union's list of Habitats of Community Importance.

To these multiple impacts and threats, we must add the social or cultural factor; that is, our relation to and our experience, use and enjoyment of the fluvial area from multiple and varied perspectives (multifaceted). As such, most fluvial areas, as we know them today, are the result of an implicit and ordinary cultural dimension that manifests itself in the practices and customs of nearby populations; and of an explicit cultural dimension, which is reflected in heritage, architecture, town planning, spatial planning, design, the landscape and the relationship with the area itself.

The fluvial areas of Catalonia, mainly riverbanks and riverbeds, are highly complex areas in terms of uses, properties and exploitation. This diversity of uses is generated by their multiple "users", who have markedly different interests.

The challenge facing us was to be able to establish networks of public-private-civil interaction within the core framework of riparian management, generating a positive exchange of ideas that facilitated constructive debates prioritising the expertise and representativeness of the sectors involved in the riparian-fluvial area.

In order to meet such a challenge, it is essential to understand that governance may prove ineffective if what has been achieved in the "creative" process of debate has no practical implementation on the ground.

Therefore, the fluvial governance strategy had to be considered from multiple perspectives, but with the clear goal of addressing key stakeholders in the ecosystem and generating proposals with a broad consensus.

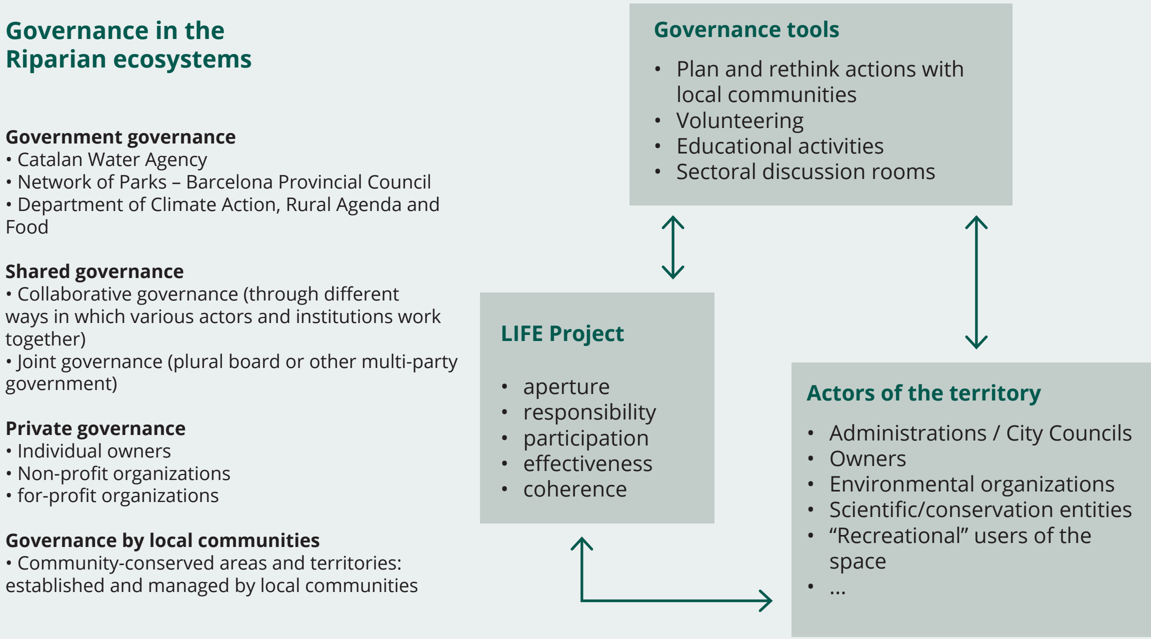

Figure 169 /

The complexity of riparian ecosystems is also proportional to the complexity of the uses, infrastructures and actors involved.

10.3. The discussion rooms

Within the framework of the LIFE ALNUS project, aware of this diversity of perspectives, we set out to address five different topics that would enable us, on the one hand, to learn first-hand about some of the sectors involved in the day-to-day life of riparian areas and, on the other hand, to make the actions of the project known to stakeholders.

We began by identifying five broad topics:

1.- Agriculture, livestock and forest management in riparian areas.

2.- Governance of riparian areas at a municipal scale.

3.- River stewardship initiatives that could be undertaken by the private sector for the conservation of riparian areas.

4.- Recreational activities (fishing, hiking, mountain biking...) and conservation of riparian areas.

5.- Implementation of environmental flows and restoration of riparian forest in relation to hydroelectric energy production in hydro power stations.

With the help of ARC Mediació Ambiental company, we organised five discussion rooms (one for each topic), enabling the exchange of experiences and information between various sectors. This innovative initiative allowed us to build bridges of understanding in order to produce the final ten-item lists of recommendations on the basis of the points of consensus that emerged in the discussion sessions.

Life alnus discussion rooms (>150 participants)

Discussion room	Participants
Agro-livestock and forestry management	3 forest property entities Natural Environment Planning Service. Catalan Gouvernment Catalan Water Agency Section of Forests and Forest Resources,Catalan Gouvernment 4 scientists (hydromorphology and forest management)
Municipal governance	12 municipalities 2 county bodies 1 basin consortium
River custody	7 land agreement organizations
Recreational activities	Subdirectorate-General for Hunting and Fisheries, Catalan Gouvernement 2 Tourism consortia 2 Basin consortia 2 County councils 6 recreational activities companies 2 fishermen's organizations
Environmental flows and hydroelectric production	6 companies of the hydroelectric sector - 3 scientists (hydromorphology) ICAEN 3 environmental organizations

Figure 170 /

These discussion rooms proved to be an excellent support tool that fulfilled multiple purposes, such as 1) spreading the word about the project, 2) finding out about the concerns of the sectors involved in the discussions, 3) generating complicity and trust, and establishing references, 4) identifying shared challenges and 5) generating proposals and consensus.

10.3.1. Methodology

The chosen methodology was simple but highly effective. It entailed conducting a) several prior interviews with selected representatives of the sector and b) digital meetings* with various stakeholders (often with opposing viewpoints) in order to know at first hand the c) main challenges facing the sector, and to establish the key points and cornerstones that would allow us to d) classify the challenges in three or four categories (legal, technical, communicative, etc.). These challenges were then e) discussed in small groups f) which set out their points and proposals to hold a g) final discussion through which a consensus document was drawn up in the form of a list of ten recommendations.

**The onset of the pandemic in 2020 meant that the discussion groups had to meet through digital platforms. This might have proved a technical obstacle but in fact it did not affect the smooth running of the sessions and discussions.*

10.3.2. The final ten-item lists of recommendations drawn up by the discussion rooms

DISCUSSION ROOM 1 – Agriculture, livestock and forest management in riparian areas

List of ten recommendations – 25 May 2021

1. The common goal is to restore the favourable ecological status of the riparian forest in order to safeguard its ecosystem services, in compliance with the Habitats Directive and Water Framework Directive. Compatibility must be ensured with other goals, such as timber exploitation activities and public use.

2. Develop and foster joint technical plans for riparian areas among small landowners. This

could be a joint initiative between the Catalan Water Agency (ACA), the Forest Ownership Centre (CPF) and the Ministry for Climate Action, Food and Rural Agenda of the Government of Catalonia, thus ensuring coherence in actions for various river stretches and facilitating the execution of many tasks.

3. Use Technical Plans for Forest Management and Improvement (PTGMF) as consensus documents to manage riparian areas. On fairly sizeable private estates, these plans facilitate the integration of different perspectives on the planning of riparian areas and make it possible to reach agreements with landowners.

4. Offer incentives to landowners to extend riparian forest areas. Strike a balance between productive forest management and the presence of ecologically functional riparian forests of greater maturity and biodiversity. Options include fiscal measures, incentives for the adoption of good practices, and the facilitation of forest or river stewardship agreements.

5. Take advantage of the eco-schemes of the new CAP in order to restore riparian vegetation in transition zones. This funding is associated with interventions based on agricultural practices that benefit the climate and the environment.

6. Identify and recover stretches of riparian forests that are mature and in a good state of conservation in order to leave them to their natural dynamics and monitor them. They constitute highly functional and diverse benchmark systems for scientific monitoring and the application of management measures in multifunctional stretches.

7. Increase knowledge (through pilot tests) of various riparian forest management measures in relation to the risks (timber drift, flooding) of these forests and the environmental services they provide. Furthermore, assess the implications of the good management of river functionality and plant communities in reducing the risk of floods. Assess the incorporation of the traditional knowledge that forest managers and livestock farmers have of riverbanks and riverbeds in order to facilitate the recovery of riparian forests.

8. Reach a consensus on easily applicable, crosscutting management guidelines for riparian forests. The guidelines must be related to the recovery of the functionality of riparian forests and biodiversity, to the strengthening of the resilience of riparian systems in the face of climate change and, therefore, to the regulation and minimisation of the risks associated with flooding. They should also include clear instructions regarding forest uses. When it comes to making uses compatible, the provision of the ecosystem service of hydrological regulation associated with riparian forests must always be preserved.

9. The restoration of riparian forests involves a parallel effect to recover fluvial functionality and study aspects related to water-sediment imbalance, fluvial disconnection and simplification, and the river-aquifer relationship. Management guidelines should be drawn up to recover fluvial functionality (biophysical dynamics), lateral connectivity (secondary branches of the river) and flows.

10. Naturalise riparian plantations. Introduce natural elements typical of forests to plantations in order to improve ecosystem services and biodiversity. Facilitate management models and best practices for managers of plantations bordering riparian forests in order to strengthen their role as a connector and transition space. As a complementary measure, buffer zones could be generated, thus contributing to expanding riparian forest fringes.

DISCUSSION ROOM 2 – Governance of riparian areas at a municipal scale

List of ten recommendations – 21 January 2021

11. River courses must be considered a strategic green infrastructure. It is necessary to manage their urban uses in accordance with their risks and environmental values. The aim should be to make it possible to remove pre-existing urban structures that have a negative impact on the river and implement preventive and compensatory measures for buildings on riverbanks.

12. Disseminate existing good practices on the removal of obsolete infrastructures from the fluvial area in urban stretches. Publish

scientific and technical guidelines and criteria that demonstrate that the removal of these infrastructures, especially those built in concrete, facilitates the recovery of ecological connectivity and the natural dynamics of the river, as well as improving flood risk management.

13. Promote river stewardship as a priority instrument for harmonising urban/agricultural management with the conservation of riverbanks and riverbeds. Promote these agreements with the owners of estates adjacent to rivers.

14. Implement the more adaptive management of fluvial dynamics at a municipal scale. The recovery of fluvial dynamics is a potential solution when it comes to reducing flood risks, recovering flood plains and old river branches that help to relieve swelling rivers and reduce the impact of flooding on infrastructures. The study of hydro-morphological dynamics and prediction models can help us understand other problems, such as the progressive incision of water courses and the disconnection of groundwater from surface water.

15. Launch citizen awareness campaigns to explain the importance of urban river areas and the environmental benefits associated with the conservation of their natural values, especially the recovery of riparian forests. This should be done through innovative and visually attractive media in order to reach a non-specialist audience.

16. Address the issue of uncontrolled market gardens in riparian areas from a legal and operational perspective. Strong actions are required which must be led by municipal authorities, accompanied by monitoring from the social sphere, especially when vulnerable people are involved, to whom other, more suitable spaces must be offered as alternatives.

17. Involve citizens in the monitoring of projects carried out in fluvial areas through citizen science initiatives.

18. Improve the communication protocol between the Catalan Water Agency and local councils when special actions related to emergency situations are carried out, as well as in order to carry out minor actions in the municipality.

19. Co-produce general criteria for the management, restoration and conservation of fluvial areas at a municipal scale that serve as guidelines agreed with local councils aimed at achieving the naturalisation of the urban river area.

20. Provide municipal gardening teams with training on invasive plants and possible alternatives to their use, as well as on more naturalised landscaping models for the banks of urban stretches of rivers, striving to make them compatible with any other uses they may have.

DISCUSSION ROOM 3 – River stewardship in the private and public sectors

List of ten recommendations – 25 September 2020

21. Explore alternative demarcation formulas (such as the estimated Public Domain) in order to delimit fluvial areas, at the same time improving the compensation mechanisms (purchasing of felling rights, purchasing of productive crops or tax measures) for those who own land adjacent to fluvial areas.

22. Explicitly incorporate stewardship agreements in the review of the new hydrological basin management plans and the associated programmes of measures. River stewardship should be a key instrument in the management of the public hydric domain for all bodies that manage water and aquatic environments.

23. To facilitate management, promote the statement of responsibility in actions that do not involve substantial geomorphological changes to the riverbed.

24. Create a responsive collaboration instrument between the Catalan Water Agency and the Ebro Hydrographic Confederation that enables the Catalan Water Agency to sign agreements and include inter-regional basins (the Ebro and the Garonne basins) in river stewardship funding initiatives.

25. Design, on the part of the Catalan Water Agency, funding formulas for medium- and

long-term stewardship agreements (of at least five years) to guarantee maintenance and monitoring actions.

26. Have clear technical guidelines in place for the management of fluvial areas and all their complexity, combining conservation and production criteria: riparian vegetation, deadwood and sediments. The guidelines must be comprehensible both to the technical staff of the entities or municipalities that promote the actions, and to the staff of the companies that execute the tasks.

27. Involve stewardship entities in the monitoring and supervision of the actions carried out in riparian areas in accordance with technical guidelines agreed between the administrative bodies, landowners and stewardship entities.

28. Draw up a training and dissemination plan on the management of river areas aimed at technicians and organisations. The plan must include concepts such as riparian forest ecosystem services, tools to strike a balance between the environmental risks related to emergency events and the environmental benefits that high-quality riparian areas provide.

29. Promote volunteer programmes to increase citizen awareness of river stewardship, in order to devote more resources to the maintenance and conservation of these spaces and to strengthen landowners' interest in taking care of them.

30. Open a legal avenue to provide funding for river stewardship agreements managed by non-profit stewardship entities.

DISCUSSION ROOM 4 – Recreational activities in riparian forests

List of ten recommendations – 9 April 2021

31. Apply in a coordinated manner the sectoral legislation in force governing riparian areas, which already provides several tools to regulate the activities that take place in fluvial areas.

32. Compare the existing laws and regulations concerning the uses and the maintenance of the good ecological state of fluvial areas and water bodies, and ensure the compatibility of citizens' right of access to fluvial areas with regulatory measures to minimise the impact of recreational activities on fluvial areas.

33. Use the fees or income obtained from activities in fluvial areas (such as parking facilities, races or fishing competitions, or adapted bathing zones) in order to make improvements to the fluvial environment.

34. Offer incentives to companies and entities that carry out recreational activities with positive impacts on riparian and fluvial areas according to a code of good practices. For example, some of the income obtained at a local level could be used as funding for these companies and entities, or they could be offered certain exemptions.

35. Undertake a nationwide study (internal and inter-regional basins) and several case studies on the carrying capacity of riparian ecosystems, with implications for the management of the use of river areas, regulation and planning at a basin scale and at a local (municipal) scale. Plan the adaptive management of the knowledge generated by these studies, considering the specific characteristics of each stretch, the timing of recreational activities and the periods of activity and fragility of the flora and fauna.

36. Launch specific communication campaigns on the natural values of riparian areas in order to foster knowledge of these environments and understanding of the administrative and legal regulations established for their conservation. Significant educational work is required, in particular targeting users who visit these areas on their own initiative.

37. Draw up a document for the planning of uses at a basin scale in which the corresponding administrative body defines the compatibility of uses for specific stretches, with measures that foster their coexistence, knowing that in some cases simultaneous use be impossible. The document should set out how to regulate the preferential uses in each stretch, its access points and parking facilities, the time limits on the use of the space, and the establishment of possible restricted access zones. The regulation of uses should be agreed with

all the stakeholders involved and should be reviewed over time on a collaborative basis by the administrative bodies and representatives of the scientific, economic and social spheres.

38. Apply the "by appointment/pre-booking" concept to recreational activities in the fluvial area. The aim is to prevent the overcrowding of riparian areas in accordance with an established estimated limit that minimises the impact of recreational activity on the environment.

39. Pass municipal and supra-municipal by-laws to regulate access to fluvial areas. These by-laws should be accompanied by comprehensive information for users in order to achieve their full understanding and collaboration.

40. Foster a new culture of access to the natural and rural environment, equivalent to the UK's Countryside Code. This would involve getting the groups that use the area to transmit this new way of harmonising river environments with existing recreational activities and professional or agricultural uses.

DISCUSSION ROOM 5 – Environmental flows and management of the vegetation around hydro power plants

List of ten recommendations - 25 November 2020

41. Promote Basin Councils as entities that can foster collaborative work and the transfer and exchange of information on the management of fluvial areas between all the stakeholders.

42. Incorporate climate change and global change scenarios (which predict a significant decrease in circulating flows) in the future dynamics of riparian forests.

43. Create an online platform on which to check the degree of implementation and fulfilment of environmental flows, considering that this instrument would strengthen trust between stakeholders.

44. Install sensors and limnometric scales at all water diversions in order to automatically obtain more data on circulating and derived flows.

45. Study the impact of environmental flows on the maintenance of the water table, the progressive incision of certain rivers, the disconnection of riparian areas and the effect on riparian vegetation.

46. Identify and accurately characterise the river stretches that are influent and effluent in relation to the aquifer in order to better understand their impact on surface water flows.

47. Promote the active management of sediments in locks and large reservoirs to facilitate the transportation of solids (pebbles, gravel, sand and mud), considering that the transportation of sediments at a basin scale is as important for the maintenance of fluvial areas as environmental flows.

48. Select some pilot stretches to generate simple, small-scale hydraulic-hydrological models that enable us to understand the ecological dynamics of the riparian forest (regeneration, growth, conservation and decay).

49. Manage riparian vegetation and deadwood around hydro power plants, establishing forest areas with different types of intervention in order to make the different uses compatible and with the goal of minimising the risks for infrastructures.

50. Update public policies and legislation on the basis of all the new knowledge that is being generated related to a more integrated vision of fluvial dynamics. Accompany it with actions to disseminate and communicate this knowledge in plain language in order to make it accessible to all citizens.

Presenting the conclusions agreed by the discussion groups in the format of ten-item lists of recommendations has enabled us to summarise a wide variety of contributions and the key lines of agreement. The draft prepared by the LIFE ALNUS coordinating team was sent to the participants in order for them to make amendments. The final list of each discussion room has been distributed among the different sectors involved. Together, the lists serve as a reference document for the aspects of greatest concern and for the solutions suggested on the basis of experience and expertise for the improved governance of fluvial areas.

Alder forest in the Segre River, La Cerdanya county / Photo: Jordi Bas.

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Pair of grey herons (*Ardea cinerea*) in their nest in an alder. Ter River, Torelló / Photo: Jordi Bas.

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