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Innovation, green infrastructures and urban form

Towards regenerative city models

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Contents

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Problems and restoration strategies of urban mediterranean rivers in Spain

Guadalmedina river as a potential ecological corridor in the green-blue infrastructure of Malaga, Spain

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Abstract

Urban rivers in good hydrological and ecological condition are essential for the ecological connectivity of the territory, connecting fragmented habitats. Additionally, they provide benefits such as flood mitigation, CO2 storage, microclimate regulation, and air quality improvement. They act as natural filters and offer recreational and educational spaces. However, urban development has negatively affected rivers, disrupting their natural dynamics and ecological connectivity due to intense urbanization and infrastructure. The restoration of rivers using ecosystem-based strategies and nature-based solutions is proposed as one solution to address the challenges of climate change. After a literature review and analysis of Mediterranean urban river restoration projects, problems and strategies for their restoration are identified and systematized. The restoration proposal for the Guadalmedina River in Malaga, Spain, is analyzed as a case study. This proposal is relevant for its ecocentric, systemic, and integrated approach from the basin to the urban section, promoting its functionality as an ecological corridor that integrates into the city's green and blue infrastructure and involves the public in the design, execution, and management process of the restoration.

Keywords

Urban river restoration; Green-blue infrastructure; Biodiversity

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1. Introduction

1.1 Importance of urban rivers as ecological corridors in the territory

Urban rivers in a state of good hydrological and ecological condition are dynamic elements crucial for fostering ecological connectivity within the territory, as they can connect fragmented habitat areas, providing routes for fauna and flora that facilitate genetic exchange, species dispersion, and wildlife migration, essential for the survival of many species (Fang et al., 2023; Seddon et al., 2020; Vermaat et al., 2016).

In addition to their ecological function, these rivers provide numerous environmental and social benefits that are vital for human well-being and urban resilience (Gómez-Baggethun & Barton, 2013). Essential ecosystem services such as flood mitigation by increasing permeable drainage surfaces, and CO2 absorption and storage by incorporating green areas, are some of the benefits. Moreover, they regulate the microclimate, reduce the urban heat island effect, and improve air quality. Riparian vegetation also acts as a natural filter for stormwater and wastewater, reducing pollutant loads and enhancing water quality (Bernhardt et al., 2007; Graviola et al., 2022; Mitsch & Gossilink, 2000). At the same time, it is important to consider their balanced distribution in the city (Mobaraki, 2023; Pantaloni et al., 2024). From a social perspective, rivers can provide recreational and educational public spaces and revitalise degraded urban areas (Chiesura, 2004; McPhearson et al., 2016), and be planned on the basis of co-governance (Scheiber & Mifsud, 2024).

1.2 Deterioration of river ecosystems

Many cities worldwide have been established and developed around rivers due to the resources they provide, such as water availability, transportation, food, energy, etc. (Habersack et al., 2015). However, rivers are natural systems that have been profoundly affected by the exponential growth of cities, especially since the second half of the 20th century, with intensive urbanisation and urban planning disconnected from their territories.

The river space has been progressively occupied and filled with urban constructions and linear infrastructure such as roads and railways. The continuous human impact and control of natural characteristics have been executed through hydraulic and engineering approaches such as the construction of dams, reservoirs, levees, etc., or the channelisation, or even diversion, of river courses to prevent urban flooding (Du et al., 2020; Giovinazzi & Giovinazzi, 2011; Jing et al., 2019). Other issues are associated with land-use changes, agriculture, or deforestation often carried out in river basins. These anthropogenic pressures fragment rivers and habitats, greatly disrupting or diminishing river dynamics, hydrological and ecological connectivity (Booker, 2002; González del Tánago & García de Jalón, 2011; Gurrutxaga San Vicente & Lozano Valencia, 2012; Skoulikidis et al., 2016; Tockner et al., 2010). They restrict the mobility space of rivers and isolate channels from their natural floodplains, impeding or hindering the processing of materials and energy in any of the three directions necessary for their good ecological functioning - upstream to downstream, between the river channel and its floodplain, and between the riparian zone, hyporheic zone, and adjacent groundwater.

Often, rivers end up being converted into wastewater drains and waste dumping areas (Gumiero et al., 2013; Ministerio para la Transición Ecológica y el Reto Demográfico, 2023; Vannote et al., 1980). Therefore, all these anthropogenic pressures have affected, to a greater or lesser extent, the structure and ecosystem functioning of rivers, generating a series of common problems that have been systematised like finding.

1.3 Challenges and opportunities for urban rivers in the face of climate change

In the current context of global climate change, cities are experiencing increasingly extreme weather conditions and face numerous environmental, social, and economic challenges, such as heat waves, air pollution, torrential rains, floods, and sea level rise (Bai et al., 2018; Intergovernmental Panel on Climate Change, 2023).

Mediterranean cities are particularly affected and vulnerable to these extreme phenomena (Galderisi & Profice, 2012).

On the other hand, Mediterranean urban rivers face a number of concrete challenges:

- An overall planning framework that integrates the natural dynamics of rivers with sustainable urban development, connecting green and blue areas to generate climate resilience;
- Integrated river planning and management models that include multiple variables (ecology, risks and usability) and involve multi-stakeholder collaboration, aligning with the concept of a 'river contract';
- Sustainable economic processes based on ecosystem strategies that prioritise adaptation to climate change over rigid and costly infrastructures.

Urban nature is therefore crucial for addressing sustainability challenges. The restoration of rivers offers an opportunity to implement natural strategies to reverse the anthropogenic impacts they are affected by, mitigate and prevent the negative effects generated by climate change, and even turn these problems into improvements for the territory and cities, acting as ecological corridors that facilitate the movement of species and the flow of genes between fragmented ecosystems.

There is a growing scientific literature on the integration of rivers into urban planning to maximise their ecological and social benefits, and on understanding the role of urban rivers as ecological corridors (Francis, 2013; Johnson et al., 2019). Following a literature review, it appears that in recent decades there has been a paradigm shift in the management of stormwater and river spaces, from an anthropocentric approach dominated by hard engineering solutions aimed at controlling water dynamics, to a more ecosystem-based approach with multifunctional strategies designed to restore ecological processes and with ecosystem-based approaches (EBA) (Wu, 2014) and nature-based solutions (NbS). In this new approach, the preservation and/or restoration of rivers is considered the best way to address the increasing risks posed by climate change. These natural strategies are a more effective and economical alternative, providing more functions and benefits, and require slower timescales in line with natural processes, as they support and align with the proper ecosystem functioning of the riverine territory.

Unlike previous approaches to river interventions that created a fixed geometry and image of the river or focused on specific individual objectives, such as fishing, understanding the river as a resource or as a problem, it is now understood that rivers are complex systems that must be addressed from different dimensions. The Italian Centre for River Restoration (2017) proposes river restoration as an integrated and synergistic set of various actions and techniques (legal, administrative, financial, structural), allowing for the restoration of the natural processes of the river system and, consequently, its functional characteristics (geomorphological, physico-chemical, and biological). This approach aligns with a systemic approach proposed by both the New Urban Agenda and the United Nations Sustainable Development Goals (United Nations, 2015) to address the challenges of climate change in cities (González del Tánago & García Del Jalón, 2007; Ministerio para la Transición Ecológica y el Reto Demográfico, 2023).

River restoration can be approached at different scales of intervention, each with its own specific focus and objectives. At the basin level, the goal is to manage and restore the hydrological and sedimentary processes that affect the entire river system, ensuring an integrated and sustainable approach. At the reach scale, the intervention focuses on specific sections of the river, addressing local issues such as bank erosion or disconnection from floodplains. At the substrate level, restoration targets the improvement of the riverbed, promoting habitat diversity for aquatic species by rehabilitating sediments and water flow. Collectively, ecological restoration aims to recover river processes and the natural dynamics of the river, focusing on reconstructing the existing river ecosystem before its deterioration, in order to restore its original functionality and biodiversity (González del Tánago & García Del Jalón, 2007; Cialdea et al., 2022).

This new approach and sensitivity also demand the integration of the public in river restoration processes. It recognises that humanity is part of nature and that social demands must be considered and addressed fairly in the process (Linton & Budds, 2013), and that human presence must be taken into account in constructing an environmental quality benchmark for these rivers (González del Tánago & García de Jalón, 2011; Lazzarini et al., 2024). River restoration has also become a widely accepted social goal in developed countries, as a restored river is not only healthier in terms of ecosystem elements but also more sustainable in its social functions.

After analysing urban river renaturalisation projects in the Mediterranean context, there are very few examples where restoration has been implemented at the basin level and in a systemic manner (see Tab.1), with the river functioning as an ecological corridor, and simultaneously connected with other biological spaces in the city. A successful example of ecological restoration in the Segura river basin are the LIFE+ Segura Riverlink and LIFE+ Ripisilvanatura projects (Oliva-Paterna et al., 2015), implemented between 2013-2017 and 2014-2019, respectively, by the Confederación Hidrográfica del Segura (CHS) with the collaboration of local institutions. Segura Riverlink focused on the renaturation of the river by removing artificial barriers, restoring habitats and improving ecological connectivity. Ripisilvanatura focused on the recovery of the riverbank forest, controlling invasive species and restoring priority habitats such as willow and poplar forests, actively involving local communities in both cases to ensure long-term sustainability. This work uses the case study of the Guadalmedina river restoration proposal in Málaga carried out by Rizoma Foundation[1], which incorporates ecosystem-based strategies, integrating the river as an ecological corridor in the city's green and blue infrastructure, and through a participatory process in the design, execution, and management of nature-based proposals. Due to its systemic and comprehensive nature and its alignment with the new ecosystem-based paradigm, it can help inform policy actions for the restoration of this river, or others with similar characteristics in the Mediterranean region.

Component	**Description**
Ecological	Recovery of the ecological functionality of the river system: ecosystem connectivity, water quality and climate resilience.
Social	Recognition of the river as a common good. Integration of local communities in management through participatory processes in the design, implementation and monitoring of proposals.
Economic	Balance between ecological restoration and local economic activities, promoting sustainable practices and long-term benefits.
Key interactions	Relationship between the river, its watershed and human activities, considering cross-impacts and seeking synergies in restoration efforts.
Systematisation by scale	- Local scale: Restoration of urban sections of the river, integrating ecological corridors into urban infrastructure. - Basin scale: Catchment-wide management to improve connectivity, water quality and habitat recovery. - Regional scale: Linking strategies with Mediterranean policies to develop scalable and adaptable restoration models.
Restoration strategies	- Hydrological restoration: Improving water retention and flow regulation. - Ecological connectivity: Restore natural corridors and habitats. - Community-based management: Fostering participatory governance.
Nature-based solutions	Application of natural approaches to river management, such as wetland restoration and reforestation, integrating the river as an ecological corridor within the city's green and blue infrastructure.
Regulatory framework	Alignment with Spanish and European regulations for river restoration, such as the Water Framework Directive and nature restoration policies.

Tab.1 Systemic approach

[1] Rizoma Foundation is an entity dedicated to the critical, analytical, and creative research of the territory and cities—from architecture, urbanism, and urban geography— with special attention to the geographical area known as ZoMeCS (Metropolitan Zone of the Costa del Sol)

2. Objectives and methodology

The main objective of this work is to explore and analyse the role of Mediterranean urban rivers and the opportunity for their restoration as ecological corridors integrated into the green and blue infrastructure of cities, helping to mitigate the effects of climate change. Current issues of urban rivers are identified, and strategies for their ecosystemic restoration are studied. The case study focuses on the restoration proposal for the Guadalmedina River in Malaga (Spain).

To achieve this, a phased methodology has been designed as shown in Tab.2:

- PHASE 1: Literature Review. A bibliographic and scientific literature study on urban rivers has been conducted, identifying the most relevant themes and issues related to the restoration of urban rivers.
- PHASE 2: Identification, Characterisation, and Systematisation of Common Issues and Proposed Strategies to Address Them. Evaluation of river renaturalisation projects within the Mediterranean context in Spain.
- PHASE 3: Case Study: Guadalmedina River Restoration Proposal. The proposal is explained, analysed, and systematised by scales, and its suitability is assessed and discussed within the framework of an integrated ecosystemic approach and in relation to the identified restoration strategies.
- PHASE 4: Extraction of specific actions according to the problems and general strategies detected.

Main phases	Sub-Phases	Description
1. Literature Review	1.1 Urban rivers as ecological corridors	Benefits: Connectivity with fragmented habitats | Flood mitigation | CO_2 absorption | Microclimate regulation | Natural filter for rainwater and wastewater | Recreational and educational spaces for the public
	1.2 Deterioration of river ecosystems	Issues: Urban developments | Large infrastructures | Changes of use in the river basins
	1.3 Urban rivers rol in the face of climate change	Aim: Systemic approach | Restoration of ecological processes | Ecosystem-based approaches (EBA) | Nature-based solutions (NBS) | Integration of citizens in river restoration processes
2. Identification, Characterisation, and Systematisation	2.1 Selection of case studies	Selection of river through project, location, intervention in urban section or basin.
	2.2 Comparative	a) Isses: Alteration of the hydrological flow regime | Geomorphological modification | Loss of biodiversity | Water management problems | Flooding | Pollution | Landscape and recreational degradation | Lack of comprehensiveness | Lack of collaboration and difficulty in management b) Strategies: Restoration of the natural hydrological regime | Geomorphological rehabilitation | Revegetation and habitat restoration | Integrated water management | Flood risk reduction | Improvement of water quality | Promotion of recreational and educational use | Comprehensiveness and territorial function | Collaboration and Co-governance
	2.3 Identification of the most representative case	Analysis of the project that develops the issues and strategies of the previous phase in a more systemic way.
3. Guadalmedina River Restoration Proposal	3.1 Start point	a) Basin: Pollution of the river due to the discharge of waste water from streams. It has two sections as Sites of Community Importance (SCI) due to the presence of species protected by Directive 92/43/EEC. b) Agujero and Limonero Dams: The dam poses a threat due to its location in clayey soil and does not eliminate the risk of flooding. There are a large number of neighbourhoods built directly on the flood plain of the river. c) Urban section: Blockage of the natural flow of the river by the construction of the dam or the channelling of the river channel.
	3.3 Proposal	a) Basin: Reintroduction of riparian vegetation, restoration of meanders and wetlands, and creation of flood zones.

		b) Urban section: Opening of the dam, modification of the canal section and incorporation of riparian vegetation. c) Green and blue infrastructure: Analysis and integration of the rivers with other existing green spaces or those susceptible to renaturalisation in the urban and peri-urban environment.
4. Assessment and identification of actions	4.1 Strategies and actions	Specific strategies and actions are extracted for each general strategy. This can be a toolbox for future river action projects.

Tab.2 Phases of the methodology

3. Systematisation and study of issues and strategies for the restoration of urban rivers in the mediterranean context

For the study of urban river renaturalisation projects in the Mediterranean context, nine cases of Spanish rivers have been selected as shown in Tab.3: 1. Guadalmedina, 2. Oro, 3. Manzanares, 4. Genil, 5. Isuela, 6. Castaños Galindo, 7. Cadagua, 8. Vinalopó, and 9. Besós. For each of these rivers, their location and length have been identified, along with the scope of the interventions undertaken, the current status of the proposals, and the references from which the analyses have been conducted.

River	Location	Scope	State	Reference
1. Guadalmedina (51,2 km)	Málaga (Andalucía)	Integral: River Basin and Urban Section	Project	(Fundación Rizoma, 2011)
2. Oro (13,6 km)	Melilla (Ciudad autónoma de Melilla)	Partial: Urban section	In progress	(Ecologistas en Acción, 2016)
3. Manzanares (92 km)	Madrid (Comunidad autónoma de Madrid	Partial: Urban section	In progress	(Área de Gobierno de Medio Ambiente y Movilidad - Ayuntamiento de Madrid, 2016)
4. Genil (359 km)	Granada (Andalucía)	Partial: Urban section (7.4 km)	Project	(Ecologistas en Acción, 2019a)
5. Isuela (44 km)	Huesca (Aragón)	Partial: Urban section (1.45 km)	Project	(Ecologistas en Acción, 2019b)
6. Castaños-Galindo	Barakaldo (Pais Vasco)	Partial: Urban section (3,11 km)	Project	(Ecologistas en Acción, 2019c)
7. Cadagua (70 km)	Barakaldo (Pais Vasco)	Partial: Urban section (5 km)	Project	(Ecologistas en Acción, 2019c)
8. Vinalopó (96,5 km)	Elche (Alicante)	Partial: Urban section (2,5 km)	Project	(Ecologistas en Acción, 2020)
9. Besós (17,7 km)	Barcelona (Cataluña)	Partial: Urban section (4,3 km)	In progress	(Àrea Metropolitana de Barcelona, 2023)

Tab.3 Renaturation projects analysed

Based on the literature review, national and European regulations, and projects on the renaturalisation and restoration of Mediterranean rivers, a series of common issues have been identified following the pressures and impacts discussed in section 1. These have been grouped into nine general thematic frameworks: 1. Alteration of the hydrological flow regime, 2. Geomorphological modification, 3. Loss of biodiversity, 4. Water management issues, 5. Flooding, 6. Water pollution, 7. Landscape and recreational degradation, 8. Lack of integration and collaboration, 9. Difficulty in management and collaboration, and 10. Relationship to planning systems.

Correspondingly, using the same methodology, all proposed actions to address these issues have been identified and grouped into nine ecosystem-based strategic frameworks as shown in Tab.4, considered necessary to approach integrally and synergistically to achieve appropriate restoration of urban rivers as ecological corridors: 1. Restoration of the natural hydrological regime, 2. Geomorphological rehabilitation, 3.

Revegetation and habitat restoration, 4. Integrated water management, 5. Flood risk reduction, 6. Improvement of water quality, 7. Promotion of recreational and educational use, 8. Integration and territorial function, 9. Collaboration and co-governance, and 10. Contrast or Integration with current plans.

Issues	**Strategies**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Alteration of the hydrological flow regime	Restoration of the natural hydrological regime	✓	✓	✓	✓	✓	-	-	✓	✓
Geomorphological modification	Geomorphological rehabilitation	✓	✓	✓	✓	✓	-	-	✓	✓
Loss of biodiversity	Revegetation and habitat restoration	✓	✓	✓	✓	✓	✓	✓	✓	✓
Water management problems	Integrated water management	✓	-	-	-	-	-	-	-	-
Floodin	Flood risk reduction	✓	-	-	-	-	✓	✓	-	-
Pollution	Improvement of water quality	✓	-	-	✓	✓	-	-	✓	✓
Landscape and recreational degradation	Promotion of recreational and educational use	✓	✓	✓	✓	✓	✓	✓	✓	✓
Lack of comprehensiveness	Comprehensiveness and territorial function	✓	-	-	-	-	-	-	-	-
Lack of collaboration and difficulty in management	Collaboration and Co-governance	✓	-	-	-	-	✓	✓	-	-
Relationship to planning systems	Contrast with current plans	✓	-	-	✓	✓	✓	✓	✓	-
	Integration with current plans	-	✓	✓	-	-	-	-	-	✓
1. Guadalmedina | 2. Oro | 3. Manzanares | 4. Genil | 5. Isuela | 6. Castaños Galindo | 7. Cadagua | 8. Vinalopó | 9. Besós										

Tab.4 Summary of conceptual issues and strategies extracted from the projects analysed

It is important to highlight that most of the projects focus on interventions limited to urban sections of the river, rather than encompassing the entire river basin. Additionally, none of these projects comprehensively address all restoration strategies, except for the proposal concerning the Guadalmedina River, which is analysed in depth as a case study in this work.

In most cases, the proposals are based on the premise of the impossibility of returning to the pristine natural conditions of the river and do not propose a systemic river restoration, but rather a renaturalisation understood as the recovery of naturalness of the urban section within the possibilities that exist in each city. These actions, such as revegetating the riverbanks, provide environmental and landscape benefits for cities that are increasingly valued and demanded by citizens. However, it is difficult to find renaturalisation projects approached systematically at the basin level, which would restore the river's function as an ecological corridor connecting ecosystems before and after the urban section of each city.

According to Kondolf (2011), the most effective approach to river restoration is to allow them to "heal themselves" by facilitating the physical processes of flooding, sediment transport, erosion, deposition, and channel change to create and maintain complex river forms. However, one of the greatest challenges of this approach in urban sections, most of which are channelised, is the space required for the river to move in all three spatial directions and sufficiently recover the flow regime and sediment load.

It has been proven that a "process-based river restoration", which focuses on correcting anthropogenic disturbances and promoting self-restoration with minimal corrective actions, allows the fluvial system to develop its own morphology and enhances its resilience capacity (Díaz-Redondo et al., 2022; Vermaat et al., 2016). An interesting example is the Manzanares River as it passes through the city of Madrid, where a renaturalisation plan proposed to permanently open the dams in its urban section. By achieving a constant flow of water, although the river remains channelised, it has recovered part of its original dynamics and improved, to some extent, its hydrological and ecological functioning, and has regained landscape, cultural, and social functions. This approach aligns with the objective proposed by some authors (Pires Veról et al., 2019), who understand that environmental recovery cannot reach the original natural characteristics of the river, but can improve it compared to the current situation of the river, not aggravating its current state of degradation and reversing, as much as possible, the degraded conditions.

4. The Guadalmedina River in Malaga as a case study

4.1 Guadalmedina, the city river

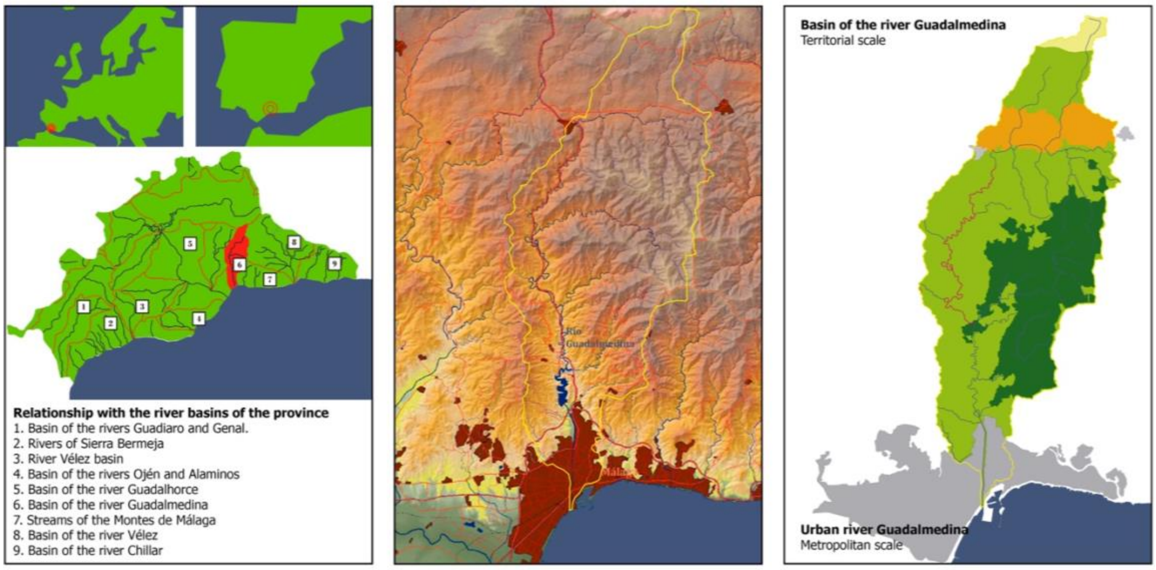

Fig.1 Location of the Guadalmedina river in Malaga, Spain

The relationship between the city of Malaga and the Guadalmedina River has been complex and changing. Initially, the city was established at the estuary of the Guadalhorce River and later moved to the mouth of the Guadalmedina, giving rise to present-day Malaga and shaping its identity.

Deforestation of the river basin for agricultural use increased runoff and sedimentation, which facilitated overflows and led to recurrent and disastrous floods (such as the one in 1661 that caused 601 deaths). Over the centuries, measures were implemented, all engineering in nature, to mitigate these problems, such as lowering the riverbed or channeling the river in 1876, which significantly altered its course and ecology.

The great flood of 1907 prompted the construction of the Agujero reservoir and a shift in focus, centering the solution at the source of the problem through the reforestation of part of the river basin to combat desertification and erosion. In 1919, the Guadalmedina Basin Correction and Reforestation Project was agreed upon, partially executed with 5,000 hectares between 1930 and 1980, which improved flood control and allowed the creation of the Montes de Málaga Natural Park in 1989. Despite these efforts, the reforestation remains incomplete, and over 7,000 hectares are still pending.

4.2 Characterisation and identification of pressures and impacts of the Guadalmedina river

Territory of the river basin: The river basin of the Guadalmedina River, covering an area of 180 km², is located in the north of Malaga province, encompassing the municipalities of Antequera, Casabermeja, Colmenar, and Malaga. The Guadalmedina River features a subtropical pluvial regime and torrential dynamics, resulting in a seasonal hydrological pattern with significant flows in winter and dry conditions in summer. It originates from a karst spring at an altitude of 1,306 meters and flows for 51 km through various habitats, including forests, scrublands, and agricultural areas, traversing the Montes de Málaga Natural Park until it reaches the Limonero dam. From the dam, the river is channeled for its final 7 km, forming the urban section of the city of Malaga, until it discharges into the Mediterranean Sea, where the port of Malaga is located in its floodplain.

The water quality of the river deteriorates upon entering Malaga due to contamination from untreated wastewater from converging streams. Nevertheless, the Guadalmedina River holds significant environmental value, with notable biodiversity of flora and fauna, including several species of birds, mammals, and plants that rely on the river and its margins for survival. It still preserves natural sections that could serve as habitats for various species. Additionally, it has two sections in its upper and middle basin designated as Sites of Community Importance (SCI) due to the presence of species protected under Directive 92/43/EEC.

Agujero and Limonero Dams: Subsequent studies revealed that the Agujero Dam (located 9 km from the river's mouth) did not eliminate the risk of flooding. Consequently, the Limonero Dam was constructed in 1983 (2 km downstream) to regulate the flow of the Guadalmedina River and supply water to the city. These dams have controlled the river's flow regime to this day. The dam's location on clayey terrain, just 500 meters from the first buildings of a city with 550,000 inhabitants, poses a significant threat, as it is a gravity dam constructed with loose materials.

The channel in the 7 km urban section borders 16 neighborhoods with different social, economic, and urban characteristics. Along this route, the river initially restrained urban expansion toward the western part of the city until it succumbed, primarily due to construction pressure, resulting in intensive urban development, as evidenced by the number of neighborhoods built directly on the river's floodplain.

Urban section: This urban section is rendered ineffective in its hydrological and ecological functions as a river, with the flow regime altered by the dam. The entire stretch is channeled between stone and concrete walls, with the final 1.5 km having a concreted riverbed.

This anthropization and profound modification caused by transverse or longitudinal artificial barriers that block the river's natural flow, such as the construction of the dam or the channelization of its course, have led to several issues: water pollution, habitat degradation and fragmentation, discontinuity in the three spatial axes, and disconnection from its natural environment. The present vegetation consists of ruderal grassland with a proliferation of various invasive exotic species. From a social and landscape perspective, it is an environmentally and aesthetically neglected corridor in the city center, with limited use and accessibility.

4.3 Proposal for ecosystem restoration and integration into green infrastructure

The proposal by the Rizoma Foundation aims to potentially restore the fluvial ecosystem of the Guadalmedina River. The scope of analysis, diagnosis, and proposals has not focused solely on the channel of its urban section but has been approached systemically, considering the entire river basin territory. The proposal's design was carried out by an interdisciplinary team and developed in different phases: 1. River characterization (study of the basin, ecological function, and ecosystem services), 2. Diagnosis and evaluation (diagnosis of physical and biological conditions, assessment of the river basin's potential as a biological corridor, and integration of the urban section), and 3. Proposal design through the determination of strategies and actions (proposal plan and comprehensive management integrating ecological, social, and economic aspects, promoting the participation of citizens and various interested stakeholders).

For the collaborative process of developing the proposals, various actions have been carried out over time: classes and lectures by specialists; field studies on the characteristic ecosystems of the basin with the collection of environmental and biological data; multidisciplinary workshops involving students, technicians, groups, and associations; agent mapping; expert interviews; surveys; awareness workshops in educational centers; and the study of satellite images and the use of GIS. In parallel with the design process, a pedagogical effort has been made to raise awareness about the environmental, social, and cultural (identity, heritage) values of urban rivers.

The restoration proposal is based on the determination of strategies by dimensions: a) Fluvial dimension: Forestry and hydraulic-hydrological solutions, b) Heritage dimension: Identity, heritage, and equipment, c) Economic-financial dimension, d) Legal dimension. However, this research focuses on the fluvial dimension, with forestry and hydraulic-hydrological solutions as the main elements of river restoration as a biological corridor. In this work, due to space limitations, only the fluvial dimension is addressed, focusing on forestry and hydraulic-hydrological solutions.

It is worth mentioning that the project proposed by the Rizoma Foundation does not suggest a formalization of the proposed strategies; instead, actions are gradually formalized through collective consensus with the community, associated with a pedagogical process over time, according to needs, demands, and economic resources. It does not propose a closed technical project, but a series of activities over time as participatory mechanisms that operate as dynamic tools for the co-creation of solutions. The impact of the solutions is continuously evaluated through a system of indicators that allows the strategies to be adjusted and reconfigured according to their effectiveness and the fulfilment of the objectives. An adaptable and evaluable model is proposed, with the capacity to generate synergies between the actors involved and to maximise the potential of the territory in environmental, social and economic terms.

Territory of the river basin: The proposed approach at the river basin level is to carry out hydrological-forestry reforestation (Fig.2 and Fig.3), respecting the more traditional land uses, such as agriculture, in areas where it is more deeply rooted and serves as an economic livelihood for the population. It is proposed to undertake actions in areas with sufficient natural potential and those degraded by traditional agricultural use, which currently do not have a defined purpose. The species used for reforestation would include a mix of broadleaf and pine trees, along with typical Mediterranean shrub species, with the aim of restoring the area's potential vegetation according to bioclimatic series, improving forest management, and expanding the recreational uses of the basin. Hydrologically, the reforestation would decrease flood risk by reducing peak flows during the intense rains typical of the Mediterranean climate and increasing the response time to these events. Additionally, the vegetation would increase rainfall interception, reducing erosion and sediment transport to the reservoir, thus stabilizing the soil and slopes.

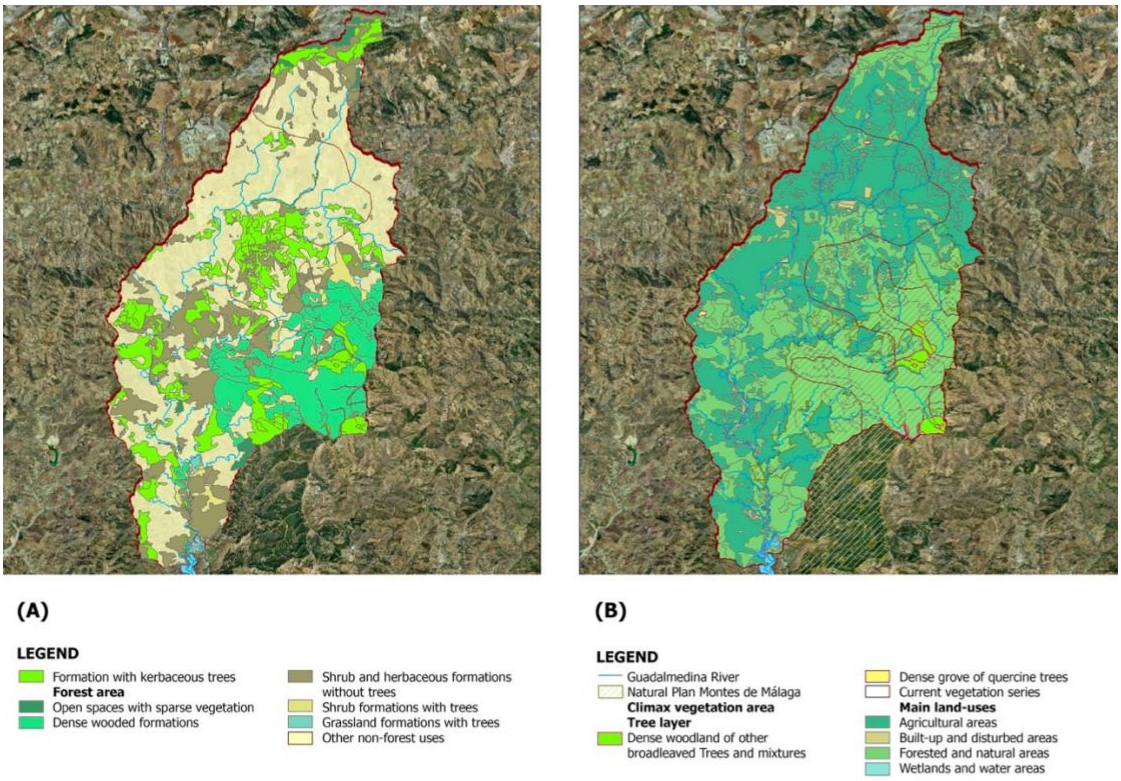

Fig.2 (A) Current vegetation of the Guadalmedina river basin and (B) Potential vegetation of the Guadalmedina river basin

The intervention proposals include the reintroduction of riparian vegetation, the restoration of meanders and wetlands, and the creation of controlled flood areas to mitigate flood risks and promote biodiversity by providing habitats for various species that depend on this ecosystem (Gomes Miguez et al., 2012). The basin presents a high potential for transforming the river into an ecological corridor due to its central position in the territory, allowing it to act as a link between the contiguous sub-basins of the Jabonero and Guadalhorce rivers through the various tributaries of the Guadalmedina. This route preserves numerous elements of hydraulic heritage, such as mills and an aqueduct, which are proposed to be restored and managed appropriately.

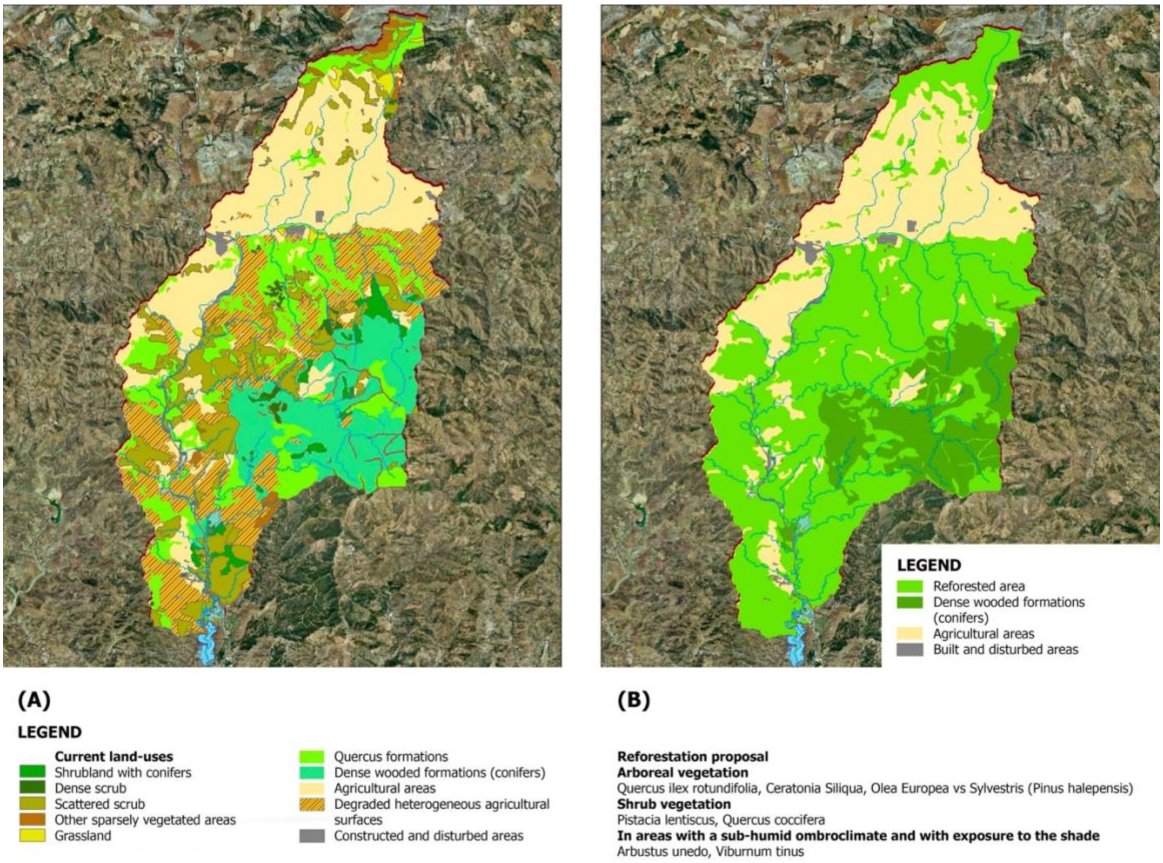

Fig.3 (A) Current land-uses in the Guadalmedina river basin and (B) Climax status of the Guadalmedina river basin

Urban section:

- Opening of the Dam. A study of the Limonero Dam is conducted, comparing different intervention possibilities based on its operation, as well as its potential removal. It is proposed to open the dam permanently so that all the water from the Guadalmedina River at this point, which amounts to 15 hm^3 annually, is allocated to provide the ecological flow;
- Modification of the Channel Section. A modification of the channel sections is proposed, changing the geometry to a configuration more analogous to the natural terrain forms (Fig.4 and Fig.5), attempting to provide maximum river space while respecting the low-water channel or main drainage path of the river. Medial bars and islands are incorporated to allow the river flow to split into different channels, creating heterogeneity in the channel and forming a complex of multiple threads. It is proposed to achieve total permeability of the channel by demolishing the existing concrete slab in the final stretch, which is 1,058 meters long. To calculate these new sections, hydraulic simulations were conducted for different return periods to characterize and identify flood-prone areas and promote the reduction of risks associated with river floods;

- Incorporation of Riparian Vegetation. The proposal includes the eradication of exotic and invasive vegetation while preserving the phreatophytic herbaceous vegetation (reed and bulrush) that temporarily appears in the channel. Subsequently, different types of revegetation will be introduced according to the space they occupy in each section of the channel, respecting the natural bands of the channel and the riverbank, allowing effective ecological connectivity, and improving the hydraulic functioning of the flow. After demolishing the walls, topsoil will be applied for profiling and conditioning the new sections, with the introduction of bioengineering techniques, such as coconut fiber mats, for slope retention and to enable subsequent revegetation and/or spontaneous colonization by native riparian vegetation.

Integration into the urban fabric. Green and blue infrastructure: The restoration of the river as an ecological corridor connects the more natural ecosystems of the upper and middle basins, such as the Montes de Málaga Natural Park, with the coastal ecosystem. Since the river traverses the entire urban territory of Malaga over a distance of 7 km, it is used as an ecological connector with other existing green spaces or those susceptible to renaturalization in the urban and peri-urban areas.

The large urban green spaces already existing in the city (Guadalhorce River, Victoria Hill, Gibralfaro Park, etc.) are analyzed as core spaces, and connections with other green spaces functioning as nodes are proposed. These are integrated into a network forming green and blue infrastructure through ecological connectors, with the river as the central ecological corridor, along with other naturalized streets and spaces. The plan is for the river to integrate into the city in such a way that it gradually colonizes all spaces adjacent to the river, such as creating flood zones that mitigate the river's rises.

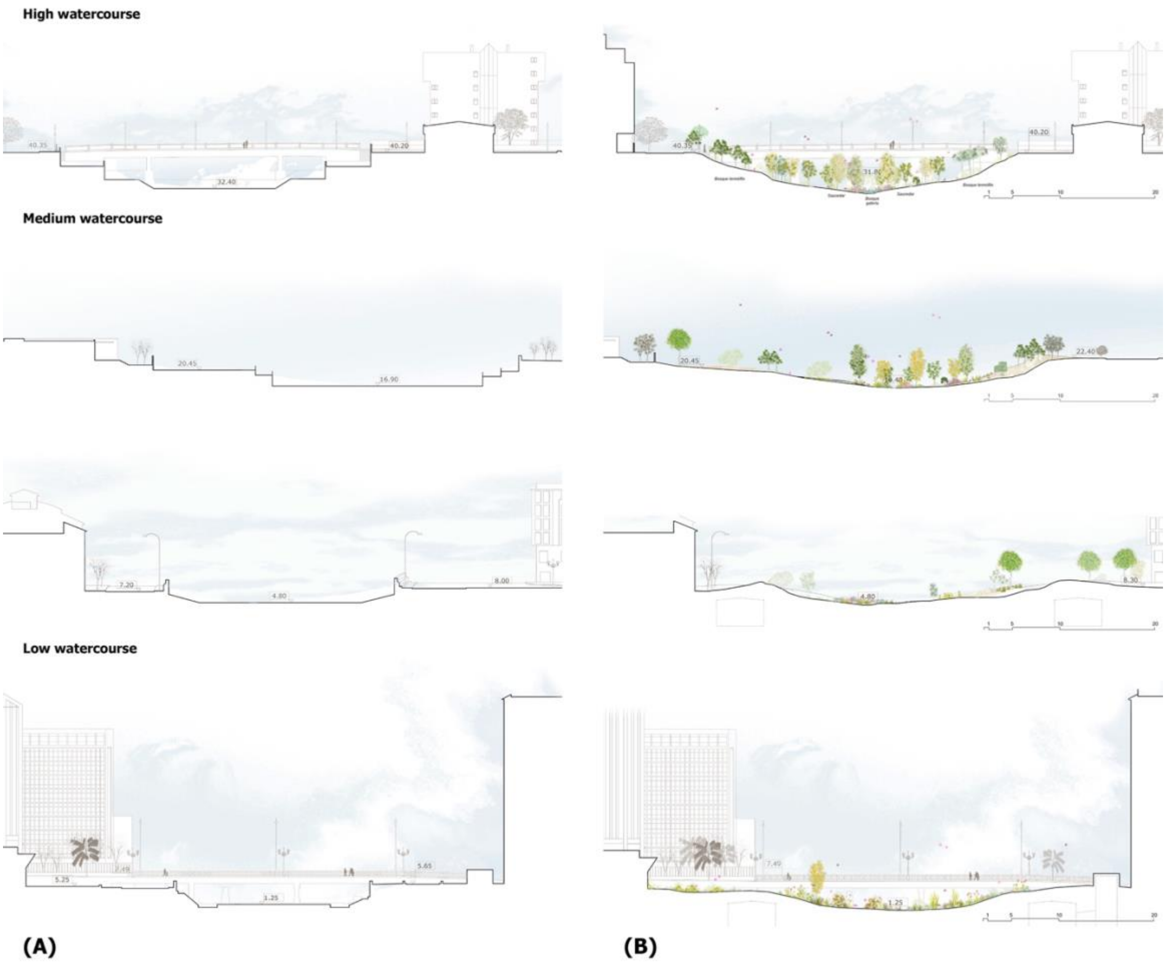

Fig.4 (A) Current state of the Guadalmedina river and (B) Proposal for a biological corridor of the Guadalmedina river

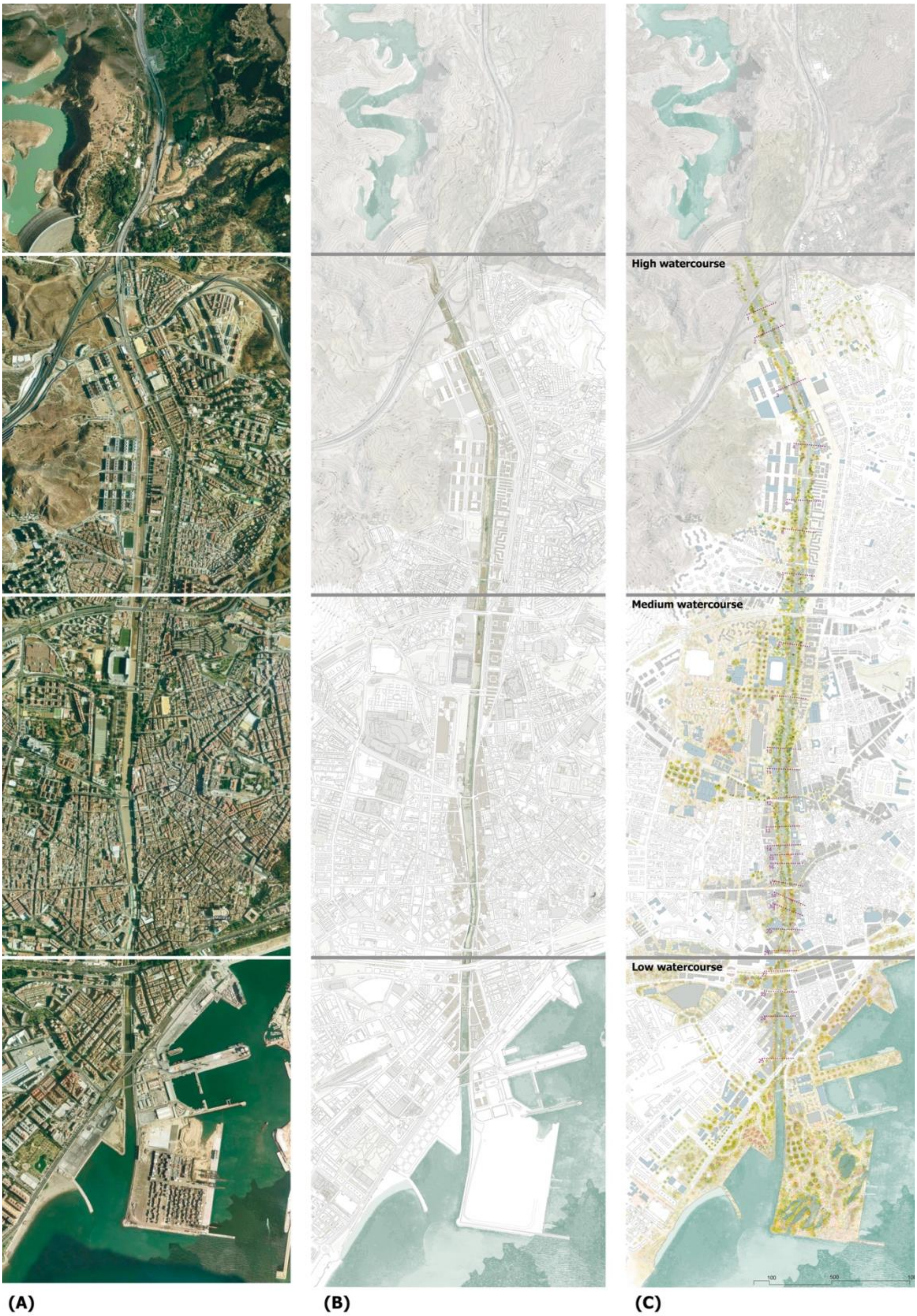

Fig.5 (A) Orthophotography of the urban area, (B) Current state and (C) Proposal for a biological corridor of the Guadalmedina river

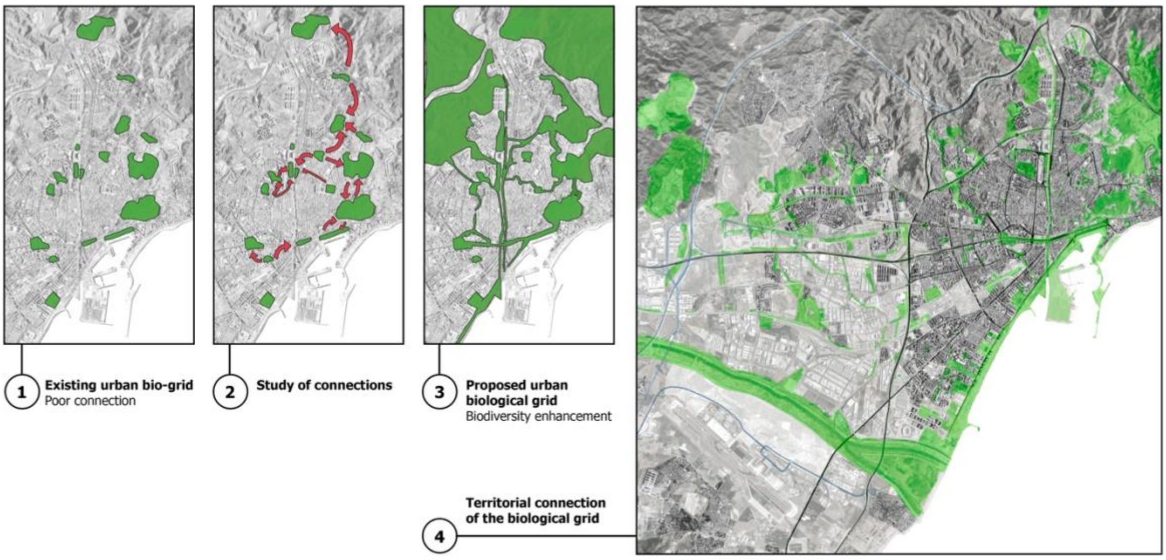

Fig.6 Guadalmedina river into the green infrastructure of the city as a grid of biodiversity

5. Assessment and identification of actions in the framework of a holistic ecosystem approach

Following the analysis of the restoration proposal for the Guadalmedina River, a series of results and actions have been identified in response to the detected issues, aligned with ecosystem-based strategies (Tab.5). The adequacy of these actions is evaluated and discussed within the framework of a comprehensive ecosystem approach and in relation to the previously identified restoration strategies:

Issues	Strategies	Actions
Alteration of the hydrological flow regime – Deforestation of the catchment – Changes in land use in the basin – Erosion and increase in slope gradients in the basin – Alteration of sediment dragging – Deviation of the natural course – Construction of dams, dykes and weirs – Longitudinal, transversal and vertical disconnection of the watercourse	**Restoration of the natural hydrological regime** – Reforestation of the catchment – Land use management – Retain soil on watershed slopes – Reconnection of rivers with their floodplains – Removal of dams and dykes and weirs – Allow minimum ecological flow – Restore hydrological connectivity (transverse, longitudinal and vertical) – Improve water retention and filtration	– Planting of 7,000 hectares – Creation of artificial wetlands
Geomorphological modification – Alteration of topography in floodplains Erosion of banks – Channelisation and artificial channelling of the river channel – Channel diversion – Urbanisation of the flood bed – Linear riverbank infrastructures – Waterproofing of soil – Decrease in surface water retention and infiltration – Increase in surface runoff (flow) – Construction of harbour at the mouth of the river – Existence of underground conduits for installations	**Geomorphological rehabilitation** – Giving more space to the river – Unclogging and restoration of natural watercourses – Stabilisation of riverbanks using bioengineering techniques – Creation of meanders and other natural structures to improve river dynamics – Dismantling of linear infrastructures on the riverbanks – Permeabilise soil – Increasing surface water retention and infiltration – Reducing surface run-off (flow)	– Creation of flood plains for river flooding – Increasing space in the river, creation of sediment islands, removal of old concrete defences
Loss of biodiversity – Destruction and fracturing of natural habitats – Introduction of alien and/or invasive animal and plant species – Fragmentation and degradation of aquatic and terrestrial ecosystems – Loss of ecological connectivity	**Revegetation and habitat restoration (increasing biodiversity)** – Planting of native vegetation on the banks of the river and its tributaries – Increase ecological connectivity to facilitate the movement of matter and species	– Creation of ecological corridors – Connection to other ecological spaces and corridors in the city (Green Infrastructure)

	– Improve the longitudinal continuity of flows, sediments and biota – Improve environmental conditions for the development of fauna – Control and eradication programmes for exotic and/or invasive species	
Water management problems – Overexploitation of water resources – Conflicts over water use between different sectors (industrial, agricultural, domestic)	**Integrated water management** – Development of water resources management plans at basin level – Promotion of efficient water use practices in agricultural, industrial and domestic sectors – Promotion of aquifer recharge and groundwater conservation	
Flooding – Reduction of natural flood areas – Increased flood risk due to urbanisation and soil sealing (surface flow)	**Reduction of flood risk** – Contribute to the lamination of river floods – Improving urban drainage and green infrastructure – Implementing early warning systems and emergency plans – Restore missing lagoon habitats – Protection of existing natural flood zones	– Creation of flood parks and temporary retention areas – Soil permeabilisation – Implementing early warning systems and emergency plans
Pollution – Discharge of sewage without adequate treatment – Discharge of industrial waste – Pollution from rubbish and solid waste	**Improvement of water quality** – Construction of wastewater treatment plants – Implementation of industrial waste management systems – River clean-up and rubbish collection programmes	– Construction of wastewater treatment plants – Riparian vegetation acts as a natural filter
Landscape and recreational degradation – Loss of green spaces and recreational areas – Disconnection of the river from the urban and social life of the inhabitants – Pedestrian disconnection – Citizen ignorance of ecosystem functioning	**Encouraging recreational and educational use** – Enhance scenic and aesthetic value – Increasing the recreational value of the river – Promote sustainable mobility (increase pedestrian and cycling connections) – Re-use and coordinate facilities around the river – Encourage citizen access – Promote education, awareness-raising and environmental education and dissemination	– Development of green spaces and riverside parks|Creation of longitudinal and transverse pedestrian and cycle paths – Creation of recreational areas along the river – Educational and awareness-raising programmes on the importance of urban rivers
Lack of comprehensiveness – Renaturalisation projects with rigid and non-adaptive proposals	**Integrality and territorial function** – Recovering the territorial function of the river – Integration into the green infrastructure of the city	
Lack of collaboration and difficulty in management – Lack of coordination between bodies that administer the public water domain – Non coincidence of basin boundaries with administrative boundaries (lack of coordination between municipal or provincial administrations) – Renaturalisation projects decided hierarchically	**Collaboration and Co-governance** – Generate systemic processes (integrated and synergetic set of diverse actions and techniques (legal, administrative, financial, structural) – Integrate citizens in the design, implementation and management processes of restoration	

Tab.5 Issues of urban rivers and main strategies and actions for renaturation

The proposal is based on an exhaustive analysis and diagnosis conducted over an extended period. Both the analysis and diagnosis phase and the creation of proposals have been carried out in an interdisciplinary way. An open, flexible, and comprehensive process is proposed, aimed at achieving the maximum possible improvement in the ecosystem functioning of the entire river basin (enhancements in geomorphological, physicochemical, and biological functional characteristics). This can be estimated in Tab.6, showing how the baseline situation can be improved by the project.

Indicators	Variables	Current Status	After project
Safety	Flood risk	● ● ● ○ ○	● ○ ○ ○ ○
	Sediment entrainment	● ○ ○ ○ ○	● ○ ○ ○ ○
	Loss of vegetation cover	● ○ ○ ○ ○	● ○ ○ ○ ○
	Loss of biodiversity	● ● ● ● ○	○ ○ ○ ○ ○
Environmental	Biodiversity	● ○ ○ ○ ○	● ● ● ● ○
	Ecosystem status	● ○ ○ ○ ○	● ● ● ● ○
	Biological connectivity	● ○ ○ ○ ○	● ● ● ● ○
	Adequacy of cyclical water status	○ ○ ○ ○ ○	● ● ● ● ○
	Water quality	● ○ ○ ○ ○	● ● ● ○ ○
	Air quality	● ● ○ ○ ○	● ● ● ○ ○
	CO_2 absorption capacity	● ○ ○ ○ ○	● ● ● ○ ○
	CO_2 emission per person/transport	● ● ● ● ○	● ● ○ ○ ○
	Soil permeability	○ ○ ○ ○ ○	● ● ● ● ○
	M^2 of green space per inhabitant	6.4 m^2	15 m^2
	Access to green space of 1000 m^2 within 200 m	10%	16%
	Access of 500 m^2 green space to less than 750 m	20%	30%
	Access to green space of 1 ha within 2 km	35%	50%
	Access to 10 ha green space within 4 km	12%	58%
Functional	Longitudinal connectivity	● ● ○ ○ ○	● ● ● ● ●
	Transversal connectivity	● ● ○ ○ ○	● ● ● ● ○
	Local, metropolitan and global interconnectedness	● ● ● ○ ○	● ● ● ● ○
	Habitability of urban space	○ ○ ○ ○ ○	● ● ● ● ○
	Accessibility by public transport	● ○ ○ ○ ○	● ● ● ● ○
	Pedestrian or non-motorised transport accessibility	● ○ ○ ○ ○	● ● ● ● ●
	Degree of urban complexity	● ● ○ ○ ○	● ● ● ● ○
	Diversity of activities	● ○ ○ ○ ○	● ● ● ● ○
Socio-economic	Agricultural land use	○ ○ ○ ○ ○	● ● ○ ○ ○
	Balance of land uses	○ ○ ○ ○ ○	● ● ○ ○ ○
	Use of renewable energy	● ○ ○ ○ ○	● ● ● ○ ○
	Energy distribution	● ○ ○ ○ ○	● ● ● ● ○
	Access to basic facilities and services	● ● ○ ○ ○	● ● ● ● ○
	Economic cost of maintaining urban space	● ○ ○ ○ ○	● ○ ○ ○ ○
Identity	Landscape	○ ○ ○ ○ ○	● ● ● ● ●
	Ethnological	● ○ ○ ○ ○	● ● ● ○ ○
	Anthropological	● ○ ○ ○ ○	● ● ● ● ○
	Heritage/Historical	● ○ ○ ○ ○	● ● ● ● ○
Citizenship	Transparency	● ○ ○ ○ ○	● ● ● ● ●
	Dissemination	● ○ ○ ○ ○	● ● ● ○ ○
	Participation	○ ○ ○ ○ ○	● ● ● ● ○
	Collaborative creation	○ ○ ○ ○ ○	● ● ● ● ○
Legal framework	Legal	● ○ ○ ○ ○	● ● ● ● ●
	Informal	● ○ ○ ○ ○	● ● ● ○ ○
	Common	● ○ ○ ○ ○	● ● ● ● ○

Tab.6 Estimation of the indicators before and after the Guadalmedina project

The proposed strategies are not formalized; instead, actions can be formalized through collective consensus with the community, associated with a pedagogical process over time, according to needs, demands, and economic resources. The proposed actions address the problems identified in all sections of the basin, are nature-based actions (NbS), and comprehensively tackle the strategies studied in section 5, which are proposed as necessary for the renaturalization of rivers. This approach contrasts with other proposals studied for other Mediterranean Spanish rivers, which only partially address these strategies.

- At the river basin level, the treatment of the vegetation cover is generally aimed at proposing riparian vegetation and forests and/or improving their conservation status, reducing fragmentation, decreasing the impact of invasive plants, and promoting the diversity of native species. This approach is particularly aligned with the requirements of the Habitat Directive and the ENIVCRE (Ministerio para la Transición Ecológica y el Reto Demográfico, 2023). The introduction of riparian vegetation, the restoration of meanders and wetlands, and the creation of proposed controlled flood areas contribute to mitigating flood risks and promoting biodiversity by providing habitats for various species that depend on this ecosystem (Gómez-Baggethun & Barton, 2013; Tockner et al., 2010).
- The opening of the dam achieves one of the main objectives of river restoration, which is to obtain a watercourse with improved environmental characteristics compared to the current situation of the river, which currently has a zero flow for most of the year, without further aggravating its current state of degradation and reversing the degraded conditions as much as possible (Pires Veról et al., 2019). This is consistent with the requirements for assessing ecological status identified by national water regulations (Water Law) and the European Water Framework Directive 2000/60/EC (WFD). According to an integrated analysis of the initial changes that occurred in the Manzanares River (Madrid) after the opening of the gates and the recovery of flow (Díaz-Redondo et al., 2018), achieving an ecological flow would improve the main components that determine habitat quality and heterogeneity (physicochemical, hydromorphological, and biological elements). According to the study, the river's natural processes would produce changes in sediment transport and water depth-velocity, which would, in turn, facilitate habitat improvement and the recovery of characteristic plant and animal biota of this type of Mediterranean river. In this way, "process-based" river restoration strategies are used, which help the river evolve through more cost-effective interventions focused on recovering self-forming dynamics, such as the opening of the dam (Díaz-Redondo et al., 2018). These strategies are considered appropriate as they have been successfully implemented in other studied projects. On the other hand, the opening of the dam would prevent an existing risk of sedimentation and overflow, as it is located at the head of the city and poses a significant danger.
- Channel Modification. The proposal aims to provide more space to the altered river channel, which is fundamentally required for the geomorphological restoration of a river. The proposed heterogeneity for the channel increases the diversity of hydraulic conditions and physical habitats compared to a single-thread channel (Belletti et al., 2015). Greater geomorphological diversity creates more variability in water depths and velocities, which in turn provide suitable habitats for a wider range of fish ages, sizes, and species (Ahilan et al., 2016; Booker, 2002). By giving space to the river and facilitating physical processes of flooding, sediment transport, erosion, deposition, and channel change, complex fluvial forms would be created and maintained, which, according to Kondolf (2011), is the most effective sustainable approach for restoring the river's ecological value and allowing it to "heal itself." At the hydraulic level, incorporating vegetation increases the Manning coefficient and stabilizes the slopes in the channel, ensuring that water speed, in case of a dam release or significant rain, can be dissipated, guaranteeing drainage and safety. Although the actions in the urban section also aim to generate more anthropogenic uses (recreational, hydraulic, aesthetic, etc.), a global approach is proposed, respecting the river's spatial and temporal dynamics and considering interactions between the urban section and its river basin. This comprehensive approach applies from the initial diagnosis of the pressures affecting the river to the specific actions to be implemented.

- Regarding the species for the proposed revegetations, both at the basin level and in the urban section, they are based on the planting of native trees and shrubs, as well as the system's own resilience, considering that natural fluvial processes will allow the recovery of natural vegetation around the channel after interventions. They are designed to achieve the territory's "climax" state, i.e., towards its maximum autonomy and biodiversity with minimal energy expenditure from all its components.
- With the proposal to integrate the river as an ecological corridor within the green and blue infrastructure network of the city of Malaga, the river's connecting function with other associated ecosystems is utilized, which is necessary to implement an ecological network at the city level that improves its ecosystem functioning and increases urban resilience. Additionally, linking to other parks or green areas in the city provides recreational and aesthetic value to the population, enhancing the urban landscape and increasing the inhabitants' well-being (Tunstall et al., 2000). The inclusion of trails and recreational areas along the river, and the promotion of sustainable uses, encourages the connection of citizens with the river and its surroundings, improving urban quality of life, increasing resilience to climate change, and promoting environmental education.
- From an economic perspective, it has been found that the renaturalization of the basin and the channel is much more economical than other interventions, being more beneficial in social and environmental terms for the city and the territory.

6. Discussion and conclusions

This work explores the role of Mediterranean urban rivers as ecological corridors integrated into the green and blue infrastructure of cities. Through a theoretical-practical approach, it addresses the most relevant issues in river channel restoration, as well as the various strategies necessary to carry out an adequate restoration within the framework of a comprehensive ecosystem approach.

Through a literature review and the analysis of various ecological restoration projects in Spanish river environments, this work aims to systematize the common problems, strategies, and actions implemented in urban rivers. This approach seeks to provide context and understand the key interventions in river restoration projects to serve as a reference for future actions in Mediterranean river channels.

Faced with the challenge of understanding Mediterranean urban rivers as complex systems that require a systemic and multidimensional approach, Foundation Rizoma's proposal for the restoration of the Guadalmedina river in Malaga is taken as a case study, notable for its systemic and integral approach. as it takes the opportunity to propose restoration not only as an ecological element, but also as an integral infrastructure that benefits both the natural environment and the urban fabric. From a more practical perspective, the Fundación Rizoma's proposal for the restoration of the Guadalmedina river in Malaga is taken as a case study.

By analyzing the problems and proposed actions, this project presents itself as a suitable example responding to the new requirements of national and European agendas and emerging sensitivities. The proposal for the river functioning as a fluvial corridor could guarantee medium- and long-term "socio-ecosystem services" for the entire city in terms of ecological stability, reduced hydrological risk, landscape beauty, recreational potential, economic sustainability, and conservation of the river's scientific, hydraulic, and cultural heritage. The operational challenges described in the challenges, such as fragmented catchment management and urban constraints, are addressed in the proposal for the Guadalmedina river by proposing an ecosystem approach, emphasising the need for comprehensive river restoration strategies that address multifaceted problems, from administrative fragmentation to urban pressures:

- An overall planning framework that integrates natural river dynamics with sustainable urban development, connecting green and blue areas to build climate resilience;

- An integrated river planning and management model that includes multiple variables (ecology, risks and usability) and involves multi-stakeholder collaboration, aligning with the concept of a 'river contract';
- A sustainable economic process based on ecosystem strategies that prioritise adaptation to climate change over rigid and costly infrastructures.

The restoration of the Guadalmedina River is presented as an opportunity to implement natural strategies that not only mitigate the negative effects of climate change, but also offer long-term socio-ecological benefits. In this sense, the work reflects how rivers can evolve from being considered urban 'scars' to functioning as dynamic 'arteries' that connect fragmented ecosystems, a metaphor directly related to the idea of rivers as ecological corridors and part of the green and blue infrastructure.

From the study of this specific proposal, a series of general conclusions can be drawn that can be transferable to other case studies. Thus it is proposed:

- A general urban and territorial planning framework that establishes plans compatible with the natural dynamics of existing rivers and is respectful of river spaces as environmental and landscape elements of cities with maximum value and conservation interest (Ministerio para la Transición Ecológica y el Reto Demográfico, 2023). This would also help define new land management strategies that incorporate traditional urban design principles as well as reintegrate stormwater into the design of public spaces—relating blue and green surfaces—and consider them an asset and a city resource rather than a threat (Mirsafa, 2017). This would increase effectiveness in reducing disaster risk in planning practice and achieve the sustainability of local water resources and the resilience of the urban environment (Barbarossa et al., 2021);
- River planning and management models that integrate multiple variables (ecology, risk protection, and usability), relating evaluation systems with planning instruments (Palermo et al., 2021). Effective collaboration through a "river contract" between administrations, institutions, sectoral authorities, local communities, and other stakeholders. Collaborative processes should be carried out, including citizens in the analysis, design, and management of river basins, especially when the river constitutes a landscape-identifying element (Cialdea & Pompei, 2021);
- From an economic perspective, budgeting for long-term processes that start with a comprehensive understanding of the territory and are addressed in phases over time is more in line with ecosystem-based strategies and nature-based actions. Proposals that align with natural processes tend to be more economical than large infrastructure projects and offer greater social and environmental benefits.

In general, river restoration efforts require a greater awareness and understanding of the problems and solutions related to urban rivers and a change of perspective from an anthropocentric to a more ecocentric society. From the outset, the proposal for the Guadalmedina River includes a pedagogical effort and the dissemination of ideas through workshops, activities, visits and tours of the river basin, the publication of a book, etc. The proposal for the Guadalmedina river, however, is of a theoretical nature and has not been carried out. Instead, Malaga City Council has developed a Special Plan for the urban section of the river which proposes to partially cover the riverbed by means of 'square bridges' without incorporating ecological considerations for the river. However, the original proposal remains valid as an alternative and more comprehensive approach to the regeneration of the Guadalmedina River, offering an ecological and sustainable vision for the future of the river.

It can be concluded with Tánago y Jalón (González del Tánago & García Del Jalón, 2007) that a viable outcome of an urban river restoration consists of a more self-sustaining system, which may or may not be similar to the natural state, but that adds environmental value to the river. At the same time, it contributes to flood mitigation and offers alternative uses for society, integrated into the city as a landscape reference element. Further research is needed to deepen the understanding of urban rivers as biological corridors: studies on functional connectivity, the impact of climate change, and renaturalization or ecological restoration practices that guide future conservation efforts (Gómez-Baggethun & Barton, 2013).

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Image Sources

Fig.1: Location of the Guadalmedina river in Malaga (Spain). Rizoma Foundation.

Fig.2: (A) Current vegetation of the Guadalmedina river basin and (B) Potential vegetation of the Guadalmedina river basin. Rizoma Foundation.

Fig.3: (A) Current land-uses in the Guadalmedina river basin and (B) Climax status of the Guadalmedina river basin. Rizoma Foundation.

Fig.4: (A) Current state of the Guadalmedina river and (B) Proposal for a biological corridor of the Guadalmedina river. Rizoma Foundation.

Fig.5: (A) Orthophotography of the urban area, (B) Current state and (C) Proposal for a biological corridor of the Guadalmedina river. Rizoma Foundation.

Fig.6: Guadalmedina river into the green infrastructure of the city as a grid of biodiversity. Rizoma Foundation.

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