Restoring and Rehabilitating Watercourses in the Ria Formosa Nature Park (Algarve): Intervention Principles, Processes and Techniques

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Abstract: - The core objective of this article is to contribute towards defining a project methodology for rehabilitating fluvial ecosystems in strongly humanized Mediterranean landscapes. To achieve this objective, interrelated with the management and maintenance of these landscapes, we took into consideration the theory and the praxis that frame interventions in watercourses experiencing situations of risk. This article spans these two core, interwoven facets, approaching both the theoretical research and the applied research undertaken within the scope of proposals for rehabilitating five watercourses in Eastern Algarve. The project approach to the restoration of the ecological corridors associated with the downstream sections of the Cacela, Canada, Tronco, Bela-Mandil streams, and the Seco River thus accounted for the shortage and irregularity in the distribution of precipitation and the torrential regime characterizing the region in conjunction with the high level of artificialism displayed by these fluvial systems. Under the auspices of the project process, the aforementioned watercourses were perceived as dynamic, complex, open, and multi-functional socio-ecological systems with a role and importance in ensuring the biological balance and physical stability of the coastal plain and the Ria Formosa lagoon system. The project concept was rooted in a strategy based on intervention flexibility, taking into account a balance between the rehabilitation of natural values and resources and the presence of human activities. Hence, in the rehabilitation proposals developed, the materials applied were entirely natural (plants, wood, and stone), with recourse to technical-scientific concepts and procedures drawn from the fields of Landscape Architecture and Biophysical Engineering.

Key-Words: - Algarve, Ria Formosa, Hydrographic Basin, Watercourses, Mediterranean Fluvial Systems, Rehabilitation Project.

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1 Introduction

This article puts forward a set of interventions on the downstream sections of five tributary streams into the hydrographic network adjoining the Ria Formosa lagoon system, specifically, from west to east: the Rio Seco, Bela-Mandil, Tronco, Canada, and Cacela watercourses in Eastern Algarve. This review of the respective projects for restoring and rehabilitating these watercourses [1], spans: (i) a brief ecological and sociocultural interpretation of the respective hydrographic sub-basins; (ii) the identification and characterization of the general principles and means of intervention and alongside the construction processes and techniques; and (iii) a description and justification of the main project options and solutions.

The methodological approach for the first project phase focused on characterizing the conditions prevailing in the hydrographic networks and the interfluvial areas by carrying out fieldwork in these respective areas. In addition to surveying and recording the various hydrographic basins involved, depicting the watercourses and adjoining vegetation, this phase also produced hydrological and hydraulic studies.

This fieldwork also underpinned the subsequent diagnosis and definition of the main types of problems faced, which then provided support for the subsequently implemented solutions. These solutions for restoration and enabling the functionality and sustainability of these ecological corridors were defined through a wide-reaching and integrated approach that simultaneously incorporated scientific, technical, artistic, ecological, and cultural aspects as the foundations for the interpretations and interventions in the riverside landscapes across the various contexts, both natural (the riverside areas along Cacela and Bela-Mandil) and artificial (the remaining watercourses) in character. Given the distinctly different ecological and urban contexts of these watercourses, the project also planned and developed rehabilitation solutions that sought to reconcile the objectives of hydrological-hydraulic functionality, the conservation of nature, and the recreational facet. The opportunities and challenges faced by each landscape intervention project strive for the long-term development both of nature and of society.

Underlying the aforementioned proposals is the understanding that fluvial systems constitute socio-ecological corridors that perform multiple functions (protection, production, recreation) and produce diverse ecosystem services for society. Hence, this correspondingly recognises the most recent watercourse concepts, as green and blue infrastructures, with increasingly important roles to play in land planning processes across the regional, municipal, and local scales, making a fundamental contribution to the sustainability and resilience of territories.

Thus, this study seeks to contribute towards defining project methodologies for the restoration, rehabilitation, and valuation of fluvial ecosystems in deeply humanized Mediterranean landscapes. To comply with the objective, interrelated with the role of managing fluvial corridors (integrated into a global vision of the landscape), this contemplates the theory and the praxis surrounding interventions in watercourses associated with flooding risks [2], whether of fluvial or coastal origin.

2 Problem Formulation

The restoration project for the ecological corridors established by these watercourses necessarily took into consideration not only the shortage and insufficiency of precipitation but also the torrential regime characteristic of such rainfall in conjunction with the highly artificial reality these watercourses now display. For such reason, within the scope of the project process, the watercourses were approached as socio-ecological, dynamic, complex, open, and multi-functional systems and of importance to the biological balance and physical stability of the coastal plain and Ria Formosa lagoon system.

The hydrographic network that drains into the Ria Formosa is fundamental to maintaining its lagoon system as, in supplying freshwater and sediments, it guarantees flows of materials and energy as well as ensuring connectivity across the system.

The present study spans the sub-basins of the Cacela, Canada, Tronco, Bela-Mandil, and Rio Seco streams (Figure 1 below and Table 1 in Appendix), focusing especially on the respective downstream sections.

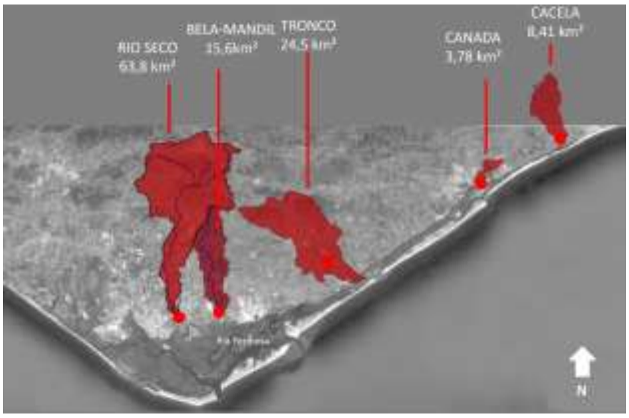

Fig. 1: Sub-basins of the Cacela, Canada, Tronco, Bela-Mandil, and Rio Seco streams

This stems from how, in this particular case, the risk of flooding and watercourses breaching their banks may be of both fluvial and maritime origin. Such a situation may worsen whenever flooding occurs simultaneous to high levels of flow through these watercourses and/or the rise in sea levels coinciding with peak tides. The probability of such events happening has been duly considered in developing the intervention proposals within the framework of adapting the watercourse ecosystem to the effects of sudden flooding to avoid the dangers and damage that, in such vulnerable zones, frequently threaten people and their properties.

Following the work to characterize and diagnose each of the five watercourse sections, and despite the existence of numerous similarities, we verified how each displayed its own specific and unique features, which were then taken into account in designing the solutions proposed in their respective restoration projects.

The Cacela and Bela-Mandil watercourses display a markedly natural character in relation both to the less artificialized stretches and those in deeply rural surroundings. The Rio Seco watercourse runs in a direction (transversal and longitudinal profiles) subject to major alterations over time interrelated with agricultural activities and the construction of the viaduct for the road and rail routes. In turn, the Canada and Tronco watercourses, following the widespread intervention, display highly artificial profiles over the course of their routes through urban tourism contexts and are also predominantly impermeabilized.

Given this landscape and territorial diversity, there were different challenges over the course of the intervention within the framework of ecological restoration. The first watercourses referenced above, took on the character of a “light” intervention with the practical application of non-invasive techniques essentially spanning the elimination of invasive vegetation and replacement by native plants characteristic of riverside environments.

In the case of the Canada and Tronco watercourses, we simulated three scenarios as regards the proposed construction of retention basins and dry basins. The objectives behind the installation of these basins include contributing towards (i) a reduction in the risks of downstream flooding, (ii) boosting the area for water spreading – natural contention, (iii) maintaining the water on flat sections for longer periods of time through deploying small dams associated with green areas for recreation and leisure; (iv) the dissipation of energy and the water runoff speed, and (v) boosting the level of water infiltrating into the soil and, correspondingly, recharging the aquifers.

The strategies and the measures designed stem from principles and practices that leverage the idea that a fluvial landscape is a socio-ecological system, both complex and dynamic as well as undergoing constant transformation. This requires the adoption of project solutions and intervention techniques tailored to both the natural conditions and the socio-cultural conditions surrounding each watercourse.

2.1 Intervention Principles, Processes and Techniques for Watercourses

Integrated territorial management essentially requires the enhancement and planning of the hydrographic network coupled with the restoration and rehabilitation of watercourses and their adjoining zones [2]. These actions are of great importance to ensuring the hydrological, hydraulic, ecological, and landscape functioning of fluvial systems [3], thereby contributing to their diversity, sustainability, and viability. Thus, the requalification of these systems reflects a fundamental measure for planning the territory so as to reduce risks to the communities present, lowering conflicts over usage and ensuring the protection of ecosystems [4].

Boosting the effectiveness of the mitigation of problems inherent to hydric resource management, especially in Mediterranean regions, necessarily requires integrated approaches and the establishment of principles and rules able to guarantee the efficient response of fluvial systems to the respectively prevailing hydrological, hydraulic, and eco-environmental factors of any hydrographic basin. Such systems require requalification in accordance with the specific facets of each watercourse, which takes into account the bio-physical, landscape, ecological, and socioeconomic aspects [5], [6].

Within the scope of interventions in fluvial corridors, the need to consider the environmental and aesthetic role of water in the landscape implies the adoption of four general principles [7], [8], [9], [10]: (i) spatial and functional continuity that guarantees ecological connectivity, enabling the flow of energy and the circulation of materials and living beings; (ii) elasticity, which conveys the capacity of the system to adapt to a diversity of situations and events; (iii) the meandering able to boost the effects of the watercourse and the exchanges between the bed, the banks and the adjoining zones, and (iv) the intensification able to boost the ecological activities ongoing as well as the capacity for the self-regeneration of the river ecosystem.

These general watercourse intervention principles come in addition to the planning principles for green infrastructures that integrate them as fundamental components both at the urban level and on the territorial (municipal, regional) scale: (i) integration into the city and the region in keeping with the existing built spaces; (ii) spatial and ecological connectivity as a contribution towards establishing a continuous system of green spaces; (iii) the multi-functionality associated with the provision of different functions (socioeconomic, cultural, ecological and environmental) and (regulatory, supply, support and cultural) ecosystem services, and (iv) social inclusion, considering a participative and collaborative approach under the auspices of the planning and intervention process [11].

Water, as an element that supplies countless benefits, whether for people or for ecosystems, plays a role and is of crucial importance to defining the concept of green infrastructures [12], which integrates fluvial corridors as fundamental socioecological infrastructures. Hence, within the framework of watercourse ecosystem interventions, adopting an integrative and relational approach is essential to clearly and operationally coordinate both these perspectives, the social and the ecological, within the scope of obtaining the following objectives: (i) adaptation to climate changes, (ii) managing precipitation and preventing flooding, (iii) increasing the wellbeing and quality of life, and (iv) contributing both to recreational usage and nature tourism [13].

This framework thereby stipulates a set of interventions designed to bring about the rehabilitation and requalification of the hydrographic network with recourse to techniques drawn from Landscape Architecture and Biophysical Engineering, which derive from integrating and articulating the interdisciplinary aspects capable of enabling, stimulating, and accelerating the processes, taking into account the specific characteristics of each watercourse in which the conjugation of the material features of the environment ensures the swifter and more effective regeneration of these spaces, [5], [14]. To provide an example, some of the techniques for watercourse interventions make recourse to materials that may be living (plants) or inert (wood, stone): living palisades with borders, living rockfill, living stakes, living support walls, plant gabions, bio-rolls.

While the interventions planned for the bed and the banks are markedly hydraulic in type (guaranteeing the flow for T = 10 years), they are primarily designed to consolidate the flow conditions even if such interventions take effect in conjunction with improvements to the environmental and ecological conditions in effect along the watercourse, providing support to the establishment of a *continuum nature*.

2.2 Scope of the Projects

The proposals for development span the functional, morphological, ecological, and environmental facets associated with the fluvial systems under study and aspects related to their future conservation and management. The definition of solutions for the functional and morphological improvements focuses on the objective of guaranteeing the hydrological services and, simultaneously, prioritizing the reinforcement of the ecological and environmental services. In parallel to the study and the redefinition of the watercourse routes (longitudinal, transversal, and vertical), this requires the selection of the most appropriate stabilization and containing techniques with recourse to natural materials (wood, stone, and plants). This phase is to be complemented by the selection of plants and sowing capable of coping not only with the general climatic characteristics but also, especially, the bioclimatic circumstances of each subsector in these fluvial corridors. Based on the observations in Table 2 (Appendix), we may verify the incidences of the different project options and solutions proposed for each stretch of these watercourses.

The application of the different project options and solutions is adjusted to the intrinsic characteristics of each of the downstream stretches of the river. In this sense, in each case, there was the need to eradicate invasive plants. In the case of the Canada and Tronco watercourses, the specific project solution incorporates the construction of retention basins to enable regulation of the water flow during periods of intense precipitation. The high level of impermeabilization of the areas in the sub-basins of these watercourses, a consequence of excessive urban-tourism occupation (especially in the first case), determined this project option as the means of mitigating the risk of flooding in urbanized areas (Conceição-Cabanas de Tavira and Alfandanga-Fuzeta, respectively). To scale these retention basins, we took into consideration three scenarios adjusted by simulation based on 100 years of return and the definition of the areas threatened by flooding (Figure 2).

It was also along the stretches of these watercourses, as well as along Rio Seco, that the project applied the "heaviest" solutions in response to the more artificial character of these sections and their banks and the more densely urbanized and/or artificialized contexts. These robust techniques were counterbalanced with the softer techniques applied to the ecological restoration (vegetation and water quality) of the five watercourses undergoing intervention.

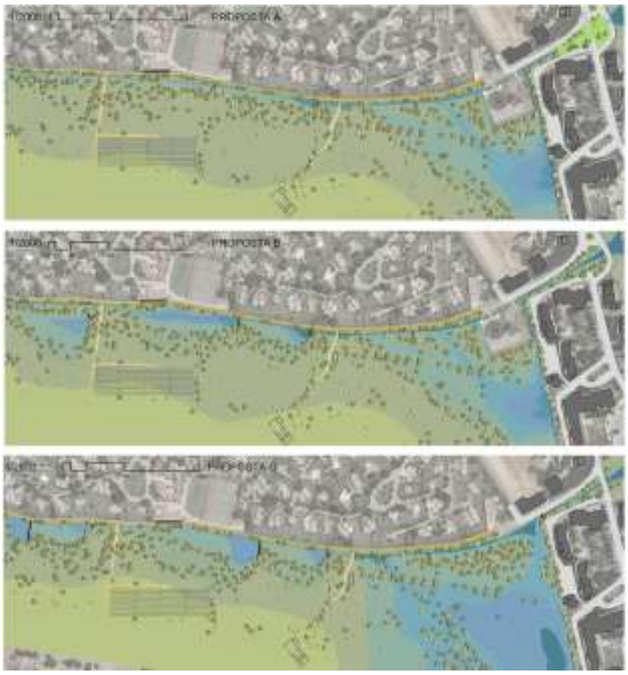

Fig. 2: Proposal for the Canada River Retention Basin: scenarios and simulations

3 Problem Solution. Project Solutions and Options

The proposals were designed with the objective of rehabilitating the ecological corridors associated with watercourses and boosting the biodiversity characteristic of a balanced and duly structured landscape. However, project development encountered the presence of anthropogenic factors that constituted clear limitations to this objective.

These limitations, conditioning the selection of project solutions and options, differ in their nature, highlighting: (i) the limited and occasional extent of interventions focusing exclusively on the downstream sections of the hydrographic basis, not foreseeing actions in the intermediate and upstream sections, therefore ruling out the vision of the functional and ecological interdependence and continuity of the fluvial basins as open systems; (ii) the need for the temporal projection of the hydrological and hydraulic processes reflected in the forecast for the periods of return; (iii) the torrential character of the precipitation regime prevailing in the Algarve region, worsened by the phenomena surrounding the global rise in temperatures, which both restricts and renders unpredictable the success of planting vegetation and the techniques for containing and stabilising the banks and their consequent ecological rehabilitation; (iv) the highly artificial condition of extensive stretches of these watercourses, including the beds and the banks, worsened by the dominant prevalence of invasive species (*Arundo donax*), which makes the morphological correction process still more difficult; (v) the property regime that, despite being in the public domain, remains under private ownership and thereby restricting the capacity to intervene beyond the area covered by the Hydric Public Domain, and (vi) the high number of entities with some form of jurisdiction over these areas.

Taking into account these limitations, we may detail the stages associated with the project process spanning, firstly, the characterization and diagnostic studies alongside the global interpretation of the areas subject to intervention, specifically the technical and scientific analysis of the landscape, its hydrology and hydraulics, phytosociology and the existing and potential flora and vegetation before, in a second phase, there came the presentation of the specific proposals for the morphological and ecological rehabilitation in keeping with the findings of the aforementioned studies.

This should also highlight that the public participation and awareness-raising activities taking place throughout project development are essential to engaging the population in decision-making and future management.

The proposal takes shape through the representation (graphic designs) of the key modeling solutions and the stabilization, contention, and finishing techniques appropriate to each particular circumstance.

Establishing the natural profile of the river banks, with a proportion of 1:3 and smoothed edges ("funneling channels"), enables the selection of a greater diversity of planting solutions and the applications of natural engineering techniques as well as ensuring greater guarantees as regards the stability of the banks and their resistance to erosion.

The integration of all the vegetation strata (trees, bushes, and herbaceous plants) into the bank stabilization strategies serves to provide higher levels of biological, ecological, and environmental diversity (water quality) and in addition to the greater radicular cohesion of the bank slopes. Recourse to natural fiber mats (straw, esparto, coconut fiber) represents an additional layer of protection for the bank slopes, especially those at steeper angles. This reflects how one of the greatest problems for interventions in fluvial systems, especially those long in extent and displaying significant alterations in their courses, is the stabilisation of the slopes of the marginal river banks. The loose and disaggregated substrata, without any vegetal covering, expose the entire surface to erosion (wind and water) with the consequent formation of ravines and soil loss. Only appropriate solutions enable vegetation to take root quickly enough to bring about the conditions necessary for the success of the interventions and begin the process of creating riparian galleries.

Other natural stabilization and contention techniques, such as placing stools on stone blocks, boxes (crib walls), and walls made from trunks, palisades, wooden fencing, and living rockfill and bio-rolls feature among the proposed techniques (Figure 3).

Some of the details relating to the contention techniques result from already (or partially) tested models, such as the type of attachment for the wooden fencing, living support walls, and the box of trunks (crib wall) (adapted from [15].

Despite having the need to make recourse to "typical solutions" (in profile, construction techniques, "modules" for planting and seeding), the solutions were tailored to each of the sectors and subsectors identified (Figure 4).

The extent of the intervention areas requires the adoption of modular solutions for project implementation. Furthermore, each stretch of these watercourses displays its own specific features and characteristics that determine the application of targeted criteria and are specifically ascertained for each particular location.

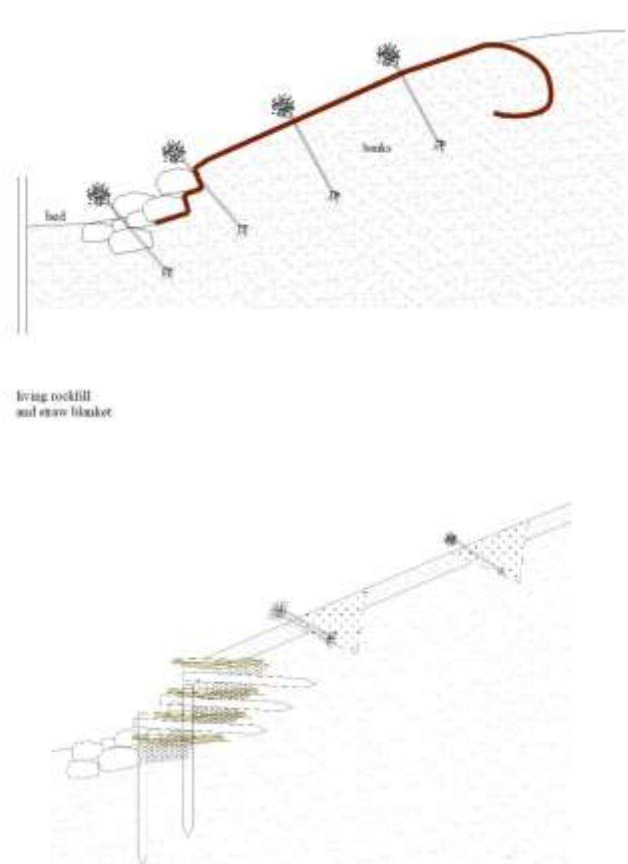

Fig. 3: Exemples of stabilisation and contention techniques
Source: [1], adaptad [15]

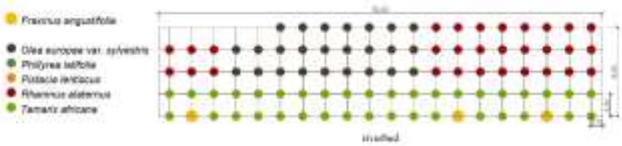

Fig. 4: Example of planting typologies (“modules”)
Source: [1]

4 Conclusion

These interventions were designed in an integrated and articulated approach taking into account, among other aspects, how the diagnosis produced not only identifies the core problems but also how the different actions might enable, stimulate, and accelerate the functioning, sustainability, and rehabilitation of ecological corridors associated with watercourses, including the deepening of the biodiversity characteristic of balanced and duly structured landscapes.

The project concept arose from a strategy based on flexibility in the interventions in keeping with a balance between the rehabilitation of the values and natural resources and the presence of human activities (production, protection, recreation). The proposals developed focus on the functional, morphological, ecological, and environmental facets associated with the fluvial systems studied and aspects relating to future conservation and management. This process required knowledge about the dynamic functioning of the main units and structures of fluvial systems impacted by significant anthropogenic alterations. The rehabilitation proposals developed make exclusive recourse to living (plants) or inert (wood, stone) materials while drawing on technical-scientific concepts and procedures from the fields of Landscape Architecture and Biophysical Engineering [16], [17].

Furthermore, the public participation and awareness-raising activities, which took place throughout the project development stage, were essential to gaining the engagement of populations in decision-making and future management. Interventions in dynamic systems have to incorporate global and integrated approaches capable of ensuring the land planning and revaluation of the hydrographic basin [18], 19] However, such approaches also require complex, integrative, and interdisciplinary analyses, extending to the surrounding populations, therefore simultaneously demanding careful supervision and monitoring of the parameters involved in keeping with how the state of these systems changes over the course of time and the solutions now proposed may eventually need their own respective adjustments.

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APPENDIX

Table 1. Main characteristics of the watercourses under study

Watercourse	Watershed area (km2)	Intervention section (m)	County	Main problems (common to all watercourses)
Rio Seco	63,8	1 400	Faro	dense occupation
Rio Seco	63,8	1 400	Faro	of *Arundo donax*
Bela-Mandil	15,6	1 800	Olhão	alteration of the natural course
Tronco	24,5	1 500	Olhão	of the watercourse
Canada	3,78	1 100	Tavira	Water quality
Cacela	8,41	320	Vila Real S^{to} António	

Table 2. Incidences of the different project options for each stretch of these watercourses

WATERCOURSES basin area/ extent section	Watercourse routes		Irradiation of invasive plants		Techniques (containment, stabilization)		Ecological restoration		Monitoring/ Management
	sections/ profiles	basin creation	less often	intensive	"light" solutions	"heavy" solutions	vegetation	water quality	
RIO SECO 6,80 km^2/ 1400 m	X	-	-	X	X	X	X	X	X
BELA-MANDIL 15,60 km^2/ 1800 m	X	-	-	X	X	-	X	X	X
TRONCO 24,50 km^2/ 1500 m	X	X	-	X	X	X	X	X	X
CANADA 3,78 km^2/ 1100 m	-	X	X	-	X	X	X	-	X
CACELA 8,41 km^2/ 320 m	-	-	-	X	X	-	X	-	X

Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)
Conceptualization, S.A.; methodology, S.A., C.A. and D.B.; software, S.A.; validation, C.A. and D.B.; formal analysis, S.A.; investigation, S.A., C.A. and D.B.; resources, S.A., C.A. and D.B.; writing—original draft preparation, S.A.; writing—review and editing, C.A. and D.B.; visualization, S.A.; supervision, C.A. and D.B. All authors have read and agreed to the published version of the manuscript.

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Conflict of Interest
The authors have no conflicts of interest to declare .