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Stream Barrier Removal: Are New Approaches Possible in Small Rivers? The Case of the Selho River (Northwestern Portugal)

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Abstract: The identification and characterization of barriers to river continuity are essential for the preparation of an inventory of hydraulic infrastructure. To this end, it is necessary to define the main identifying and characterizing elements of hydraulic infrastructures and descriptors of ecological continuity, with information that can characterize them from the point of view of their impact on the watercourse. Several authors have defined decision criteria for the removal of existing hydraulic structures in watercourses and their application, reinforcing the environmental benefits of the elimination of these hydraulic structures. In the present work, we proposed to develop a methodology for the evaluation of barriers in the Selho River (Guimarães Municipality, Northwest Portugal), elaborating an Environmental Condition Index (ECI) based on hydromorphological, socioeconomical, and ecological criteria, which allowed the identification of 43 weirs, of which 95% revealed quality inferior to Good. Following the application of a decision support methodology for the removal of hydraulic structures, it was possible to determine that 16 of the 43 weirs evaluated could be subject to removal, 26 would be under conditioned removal, and only 1 would be able to remain unchanged.

Keywords: barriers; connectivity; Environmental Condition Index; weirs

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1. Introduction

Rivers support some of the Earth's richest biodiversity [1] and provide essential ecosystem services to society [2], but are often fragmented by barriers [3]. Rivers are one of the most threatened ecosystems in the world [4], especially affected by the longitudinal disconnection of the fluvial systems [5–10].

River barriers can be defined as physical artificial structures of any type or height that are likely to have an impact on river ecosystem longitudinal connectivity [11]. Barriers to longitudinal connectivity can be classified into six types based on key features and extent of habitat modification [12]: dams, weirs, sluices, culverts, fords, and ramps [13,14]. Recently, more attention has been directed towards smaller structures, which are less well understood and constitute a large percentage of the barriers in many river systems [15,16]. These are structures with head drops of up to 1.0 m during low flow and streams and rivers with mean flows of less than 1.0 m^3/s [17]. In this work, we will focus on weirs—artificial obstructions that cause an increase in the water surface level in the watercourse for some, if not all, flow conditions [18], with less than 5 m height [12–14].

In 2020, AMBER, an EU research project, carried out extensive work on river barriers and recorded over 600,000 across Europe, 85% of which were small structures [13]. While much attention has historically been given to large dams [19,20], the potential importance of small barriers (<5 m) is increasingly being recognized [14,16,21–24]. Most low-head structures are unreported [25], and their number and location are consequently poorly known [16,26,27].

There is a wealth of scientific literature surrounding the multiple impacts of small river infrastructures [26,28,29]. The magnitude and direction of primary and secondary effects can vary considerably from site to site with barrier type and watershed characteristics [30–36]. The effect on connectivity depends particularly upon the location [37]. The effects of river infrastructure on native freshwater fish are particularly well documented in the literature [5,10,17,21,26,38–63]. Of all the environmental changes caused by river barriers, the disturbance of natural water flows is typically the most damaging [8,13,16,44,58,64–70]. Barriers can also alter sediment transport [64,71,72] and have a hugely negative impact on ecosystems and their processes [8,16,33,44,66–69,73–91]. Additionally, barriers often create conditions favorable to the establishment and expansion of non-native, invasive species [39,92] in the channel and adjacent riparian structures [29,72]. A number of studies have described how barriers impact stream processes and/or forms [33,36,39,93–101]. Indeed, the cumulative impact of multiple barriers along a river system is very difficult to assess [31].

Increasing concerns about these impacts has led to a growing call for the restoration of rivers through the removal of barriers [102,103]. The problem of how to remove structures in a systematic and cost-effective manner [11,14,29] is actual, and it is not surprising that it is often seen as a valuable form of restoration [37,104–106]. From an environmental point of view, removal represents the best solution in most cases and should always be the objective where feasible [17]. Where full removal is not possible, there are other options for reducing the impacts of structures [7,8,16,48,66,71,91,107–120]. However, many obsolete small river barriers remain in place, in part due to their historical and cultural significance and perceived insignificance in respect to river processes.

Strikingly, the extent of river connectivity remains little known for most European rivers, despite the fact that the concept of river continuity is enshrined in the European Union (EU) Water Framework Directive (WFD) [121]. Collectively, the negative impacts caused by small barriers can reduce the ecological status of the water body assigned under the WFD [17,31,122,123]. River continuity is a key environmental objective of EU legislations, especially the WFD and the EU Biodiversity Strategy for 2030 [17,122,124]. For a water body to be classified as of good ecological status, its hydromorphological condition must be such that the quality elements deviate only slightly from the reference conditions. This may involve removing barriers that prevent the river from reaching good status [8,18,31,44,68,69,93,112,125–131].

There are dozens of different barrier prioritization methods, which will typically consider not just barrier removal but also other options [37,132–136]. Opportunities for barrier removal depend on barrier typology, where they are located in the catchment, as well as their sizes, ages, conditions, and impacts [11]. Small structures are much more abundant [14] and also easier and cheaper to remove [11]. There is thus an increasing need for numerical tools to help decision-makers correctly allocate resources to prioritize restoration actions [137]. Removal of dams and weirs is a management tool that is increasingly being developed by an array of scientists, environmental organizations, and governmental actors [138]. We highlight the project AMBER, involved in the adaptive management of barriers in Europe [139], the scoring system called DAMROS—Dam Removal Opportunity Score [11]—which supports the shortlisting of applications for dam removal grants of European Open Rivers Programme, and the LANBIOEVA ("Landscape Biogeographical Evaluation") methodology, applied to Mediterranean environments [140].

As far as barrier removal and/or adaptation is concerned, Portugal is lagging far be-hind. In 2016, the Minister of the Environment created a working group (WG) with the purpose of proposing a plan to remove the infrastructures that proved to be obsolete, for lack of any socio-economic function, and the respective criteria to be adopted [141]. Seven-thousand weirs and dams were counted, mostly very old, obsolete, and unused structures. Some projects were developed using probabilistic models of structural connectivity [142–144]. Bochechas [145] refers to the need to create bases for the inventory and characterization of barriers in water lines and the elaboration of a proposal for the creation of the National Cadastre of River Continuity.

Concerning the Selho River (northwestern Portugal), the information is very scarce. In the Hydrographic Region 2 Management Plan, this watercourse presents the Ecological State of “Bad” (The assessment of ecological status is based on the classification of various biological, chemical, physicochemical, and hydromorphological quality elements. Ecological status is classified into one of five classes—Excellent, Good, Fair, Mediocre, and Bad [146]. Significant pressures are quantified and associated with urban, agricultural, and industrial uses, responsible for the classification obtained [147]. Consequently, Guimarães Municipality, through its Landscape Lab [148], is committed and involved in the rehabilitation of this watercourse, as well as the other rivers within its territory. Between 2018 and 2020, researchers from the Center for Communication and Society Studies (University of Minho, Braga, Portugal) and the Landscape Lab (Guimarães, Portugal) developed the project “Inventory and Environmental Assessment of barriers in the Selho River” [149]. Based on this project, we have defined and discussed a methodology, which will be presented in this paper, to assess 43 identified infrastructural barriers, considering the feasibility of their removal and taking into account environmental aspects. Therefore, the objective of this work is to present the methodology implemented and field-tested on the Selho River, which is an innovative assessment method applied to small extent and highly fragmented rivers, with a highly anthropized catchment area, using the cross-referencing of an index (Environmental Condition Index—ECI) with the technical feasibility study. We consider that this methodology has the potential to be applied in existing rivers throughout Europe and in other parts of the world, with characteristics similar to those of the Selho River. For the case of the Selho River, we considered all types of barriers, highlighting the small weirs and following the Biodiversity Strategy for a focus primarily on “obsolete barriers”.

2. Materials and Methods

The Selho River basin is a sub-basin of the Ave River, with a predominant NE–SW direction. The area of this basin is 68 km^2 and is located almost entirely in the Guimarães municipality. The Selho River runs for a distance of almost 21 km, resulting in a medium-low average slope of only 2.4% in its main course. Forty-three weirs were identified and located along the Selho River, distributed predominantly in the middle course of this watercourse (Figure 1).

The Project “Inventory and Environmental Assessment of barriers in the Selho River” lasted for 2 years (2018/2019) and was divided into 3 phases:

– Phase 1—inventory preparation. Initially, we defined the data to be collected and included in the database to be built, taking into account the project objectives and identifying the barriers based on the implementation of geospatial technologies and preliminary visits to the Selho River [150–153].

In order to facilitate the fieldwork, we created a geodatabase (based on ESRI technology) that allowed for the survey of georeferenced data, the geometric characteristics of the barriers, and the hydrological, ecological, and economic–social conditions existing on the respective banks and riverbeds, in a 50 m buffer around the stream to the riparian zone.

The fieldwork took place during 6 months in the year 2019 and had the collaboration of students from the Masters in Geography of the University of Minho and joint coordination with the Landscape Lab (Figure 2).

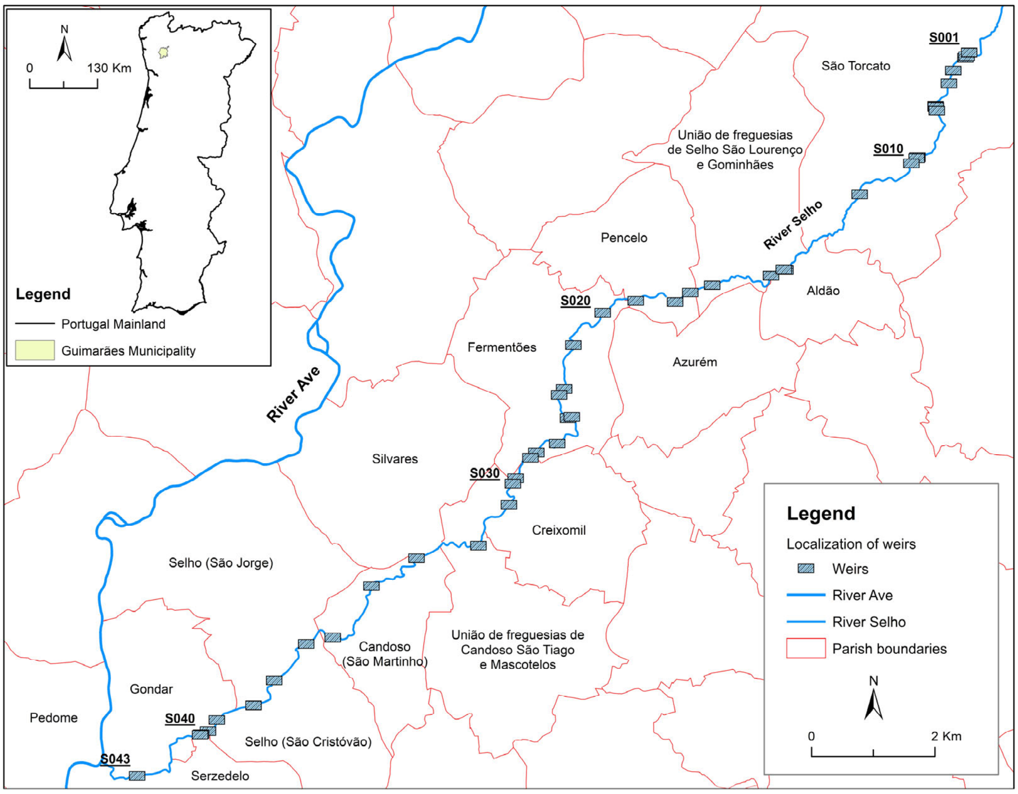

Figure 1. Localization of the 43 weirs along the Selho River.

Figure 2. Fieldwork and sampling and measurements along the Selho River.

To complete the inventory of barriers, we collected data on water quality parameters and geomorphological and hydraulic characteristics of the river in 2 periods—late spring and early fall—in order to ensure the best safety and mobility conditions along the banks and in the riverbed. With the collected data, we developed a supporting Geographic Information System (based on a spatial database) for the following phases. Robust priority setting and action planning required robust data [31], and, in this context, data integration in Geographic Information System (GIS) allowed for seamless analysis and visualization of results.

– Phase 2—Creating a Multi-Criteria Index. We developed a matrix, adopting a multi-objective approach with several criteria and indicators selected and combining different assessment methods. The eco-hydrologic and social metrics are presented in a Multi-Criteria Index, which we called the Environmental Condition Index (ECI) and will allow us to infer the size of the impact caused by each barrier, as a first step to support the removal decision.

The selection of measurable criteria, indicators, and their values and weightings was based on an thorough search and analysis of specialized scientific works and articles from literature, national legislation, European directives (mainly the WFD), rules and regulations, reports, projects, and programs. A matrix following an organization chart of the assessment method was elaborated, in which we chose to apply a percentage to each criterion and a weighting index from 0 to 4 for the respective classes (Tables 1–3). As not all criteria had the same degree of importance, it seemed reasonable to consider differentiated weighting indexes to optimize the results. Here, the indicators were ranked based on an empirical evaluation of qualities and inputs.

We assessed each weir based on hydromorphological, ecological, and socioeconomic criteria and created an Environmental Condition Index (ECI), valuing each indicator and its classes qualitatively and quantitatively.

A maximum of five classes (0 to 4) were assigned to each criterion. Each class was related to a specific score, which varied according to the characteristics of the single criteria and its weighting. Class 4 of the classification referred to high-quality conditions (hydromorphological, ecological, and socio-economic), whereas class 0 referred to low-quality conditions. The scores of all assessed parameters were summed. The ECI value was computed as follows: ECI = hydromorphological criterion + ecological criterion + Socio-economic criterion. The score could range from 0 to 100. An index of 100 represented the maximum environmental condition within the investigated reach, whereas an index of 0 described minimum environmental conditions. Five environmental condition classes were defined, according to the WFD definitions. These classes ranged from Excellent to Bad and were defined as follows: 100–81 (Excellent), 80–61 (Good), 60–41 (Fair), 40–21 (Mediocre), and 20–0 (Bad) (Table 4).

With regard to the hydromorphological criterion, we assigned a total weight of 50%, taking into account the following indicators and classes:

– Typology—the weirs were classified according to their heights (small dams or weirs), characteristics of their obstacles (wall/enclosure), and conditions (permanent/provisional). This followed the rules established in the Portuguese legislation, namely, in Decree-Law 21/2018 and in the Regulation of Small Dams, annexed to Decree-Law 409/93, of December 14, referring to small dams with a height of less than 10 m or with a height equal to or greater than 10 m and less than 15 m whose reservoirs have a storage capacity equal to or less than 1 hm^3. Consequently, lower evaluation (0) was assigned to small dams (<10 m and >5 m) and higher (10) to provisional small structures (<1 m) made of wood or light materials (Table 1);
– Body of water forming—we took into account the volume of the water retention that the barrier could promote and whether or not there was enough hydraulic slope to determine a waterfall or even allow free flow. We, therefore, assigned a value of 0 to barriers with a reservoir and 10 to those that did not interfere with river flow;

– Passability—the height, slope, and construction characteristics of the weir were the elements considered to define the passability of fish species, which meant the existence of conditions to allow the passage of fish species upstream and downstream. Passability was dependent on several parameters (e.g., barrier height, water depth, barrier type, and presence of vertical drops) and varied depending on the swimming, jumping, and climbing capabilities of each fish species [13,154]. The attribution of values was according with the situation identified in each weir, considering the classes of "Unsurpassable" (value 0) to "Fully Transposable" (value 10);
– Sediment accumulation—we measured sediment depth upstream of each barrier using a $\frac{1}{2}$-inch Allen or a crow bar and, in some cases, using a probe. Higher evaluation was attributed to barriers with a small amount of or no sediment accumulation (7.5) and lower evaluation to the ones that promoted an accumulation superior to $\frac{3}{4}$ of the barrier height (0). Cases with sediment accumulation of about 50% of the height of the barrier were attributed a value of 1.875;
– Erosion/sedimentation balance—we calculated the balance through the forms of erosion and sediment accumulation observed on the bed and banks, upstream and downstream of the weir. Considering the previous criteria evaluation, the erosion/sedimentation balance considered the relation of sediment accumulation both upstream and downstream of each barrier, the situations being considered with higher values when the barrier did not interfere with sediment flow (7.5), or when there was a balance on the sediments (5.625), and lower values when there was a significant difference between erosion and accumulation (0);
– Downstream sediment loss—the classes were defined based on the relation between the sediments deposited/transported downstream of the barrier. The excessive transport of sediments downstream of the barrier was considered a negative factor, being valued with 0, whereas the maintenance of sediments was valued with 5;
– Flow type—based on the observation of the current upstream of the barrier, we identified the type of flow according to those established in the reference works in fluvial geomorphology, with imperceptible flow valued at 0, and turbulent flow valued at 2.5.

Table 1. Environmental Condition Index support matrix: hydromorphological criterion.

Hydromorphological Criterion (50%)	Class	Weighting	Value	References
Typology (10%)				
	Small dam/wall	0	0	[11,13,17,141,145,155–162]
	Rockfill Weir	1	2.5	
	Weir with sill/drain	2	5	
	Provisional	4	10	
Body of water forming (10%)				
	Reservoir	0	0	[72,143,155,157,158,163–165]
	Backwater	1	2.5	
	With waterfall	2	5	
	Without waterfall	3	7.5	
	Without interference	4	10	

Table 1. *Cont.*

Hydromorphological Criterion (50%)	Class	Weighting	Value	References
Passability (7.50%)				[72,143,155,159,160,162,165]
	Unsurpassable	0	0	
	Difficult	1	1.875	
	With device/easily transposable	3	5.625	
	Fully Transposable	4	7.5	
Sediment accumulation (7.50%)				[26,155–157,159–164,166–169]
	Very high	0	0	
	Preponderant	1	1.875	
	Null/No interference	4	7.5	
Erosion/sedimentation balance (7.50%)				[26,155,156,159,162–164,167,168]
	Strongly unbalanced	0	0	
	Balanced	3	5.625	
	Imperceptible/not visible	4	7.5	
Downstream sediment loss (5%)				[26,155,156,160,162,163,166–168]
	High	0	0	
	Intermediate	1	1.25	
	No loss/insignificant	4	5	
Flow type (2.50%)				[26,155,157,159,163,164,167]
	Standing water/imperceptible	0	0	
	Laminar	2	1.25	
	Chaotic/turbulent	4	2.5	

To assess the ecological criteria, physico-chemical analysis of pH (Sorensen Scale), dissolved oxygen (% O_2 saturation), and conductivity (µS/cm, 20 °C) was carried out. We also defined indicators on riparian vegetation, distinguishing the situation on the bank and on the bed, based on the species observed. We added the indicator "Solid waste", defining the different classes, taking into account the amount, type, and area of deposition (beds and banks).

For pH, the classes were defined according to the following: Bad = pH > 11; Mediocre = pH between 4.5 and 5 or between 10 and 11; Fair = pH between 5 and 5.5 or between 9 and 10; Good = pH between 5.5 and 6.5 or between 8.5 and 9; and Excellent = pH between 6.5 and 8.5. The discrimination of dissolved oxygen classes (% O_2 saturation) was performed according to the following: Excellent > 90; Good 70–90; Fair 50–70; Bad 30–50; and Very Bad < 30. Conductivity classes (µS/cm, 20 °C) were distinguished as follows: Excellent < 750; Good 750–1000; Fair 1000–1500; Bad 1500–3000; and Very Bad >3000.

Margin structure refers to the existence or absence of vegetation and its quality. Aquatic vegetation consists of identifying the type of vegetation present in the watercourse, and solid waste criteria correspond to the presence or absence of pollution in terms of solid residues and deposition area (bed and/or banks) (Table 2).

Table 2. Environmental Condition Index support matrix: ecological criterion.

Ecological Criterion (30%)	Class	Weighting	Value	References
Physical-chemical (7.50%)				[26,72,123,155,165,168–171]
pH (2.50%)				
	Bad	0	0	
	Mediocre	1	0.625	
	Fair	2	1.25	
	Good	3	1.875	
	Excellent	4	2.5	
Dissolved Oxygen (2.50%)				
	Very bad	0	0	
	Bad	1	0.625	
	Fair	2	1.25	
	Good	3	1.875	
	Excellent	4	2.5	
Conductivity (2.50%)				
	Very bad	0	0	
	Bad	1	0.625	
	Fair	2	1.25	
	Good	3	1.875	
	Excellent	4	2.5	
Margin structure (7.50%)				[26,72,155–157,159,161,162,169,172]
	Without vegetation	0	0	
	Weed/invasive	1	1.875	
	Fragmented riparian vegetation	3	5.625	
	Continuous Riparian	4	7.5	
Aquatic Vegetation (10%)				[26,72,155,157,159,162,165,169,172]
	Without vegetation	0	0	
	Weed/invasive	1	2.5	
	Herbaceous	2	5	
	Aquatic	3	7.5	
	Varied	4	10	
Solid Waste (5%)				[157]
	Bed and banks	0	0	
	Bed or banks	1	1.25	
	Meaningless	4	5	

As for the indicators of the socio-economic criterion (Table 3), we followed the normative and regulations of the Portuguese legislation in force. Regarding the “Status” indicator, we considered a weir “Inactive” whenever it was obsolete and/or in ruins and/or abandoned. A weir was active when it was functional and simultaneously associated with the production of a given economic activity.

Table 3. Environmental Condition Index support matrix: socio-economic criterion.

Socio-Economic Criterion (20%)	Class	Weighting	Value	References
Status (10%)				
	Inactive	0	0	[31,141,143,145,158,173,174]
	Functional	2	5	
	In operation	4	10	
Legality (5%)				
	Illegal	0	0	[31,141,145,173]
	Authorization	2	2.5	
	Concession	4	5	
Function (5%)				
	None	0	0	[31,145,161,168,170,173,175,176]
	Agricultural/industrial	1	1.25	
	Hydraulic	2	2.5	
	Multiple	4	5	

After the elaboration of the matrix, we defined the classification and ranges of the ECI, based on what was established for ecological assessment in the WFD (Table 4).

Table 4. Environmental Condition Index (ECI) classes.

Classification		Interval
Excellent		81–100
Good		61–80
Fair		41–60
Mediocre		21–40
Bad		0–20

– Phase 3—Feasibility conditions and technical decision for the removal of the barriers. The ECI was created to understand the level of impact caused by the barriers of the Selho River. However, we considered the need to validate the results of the ECI with a technical decision to confirm or not the removal of the barriers that arose from the assessment of the feasibility conditions. The technical decision was based on a summary sheet implemented for each weir/dam, in which we included the ECI, the main impacts, and the main feasibility conditions, structured in a set of 9 items, which led the decision process to the most appropriate measure: location; characterization of the obstacle (structure); status; legal situation; impacts; ECI value; technical decision; justification; and viability.

Three feasibility possibilities were defined as follows:

– Maintenance—for weirs with ECI greater than 60 points and a legal situation framed with the Portuguese Environment Agency (APA);
– Removal—for weirs with ECI lower than 61 points and an illegal situation;
– Conditional Maintenance—whenever one of the conditions defined for the "Removal" decision or other duly substantiated factors were not met. It was the case of the ignorance of the legality of the weir, the costs with barrier removal, impacts of removal in other structures or river/ecosystem dynamics, or patrimonial value of the infrastructure.

In cases of maintenance (effective and conditional), mitigation measures should be indicated in accordance with the hydrological and ecological impacts identified.

This sheet assists the assessment process by breaking it down into a set of questions with the objective of identifying the most appropriate measures. In some cases, additional information will be required to finalize a decision.

The workflow of the barrier removal decision assessment is schematized in the flowchart in Figure 3.

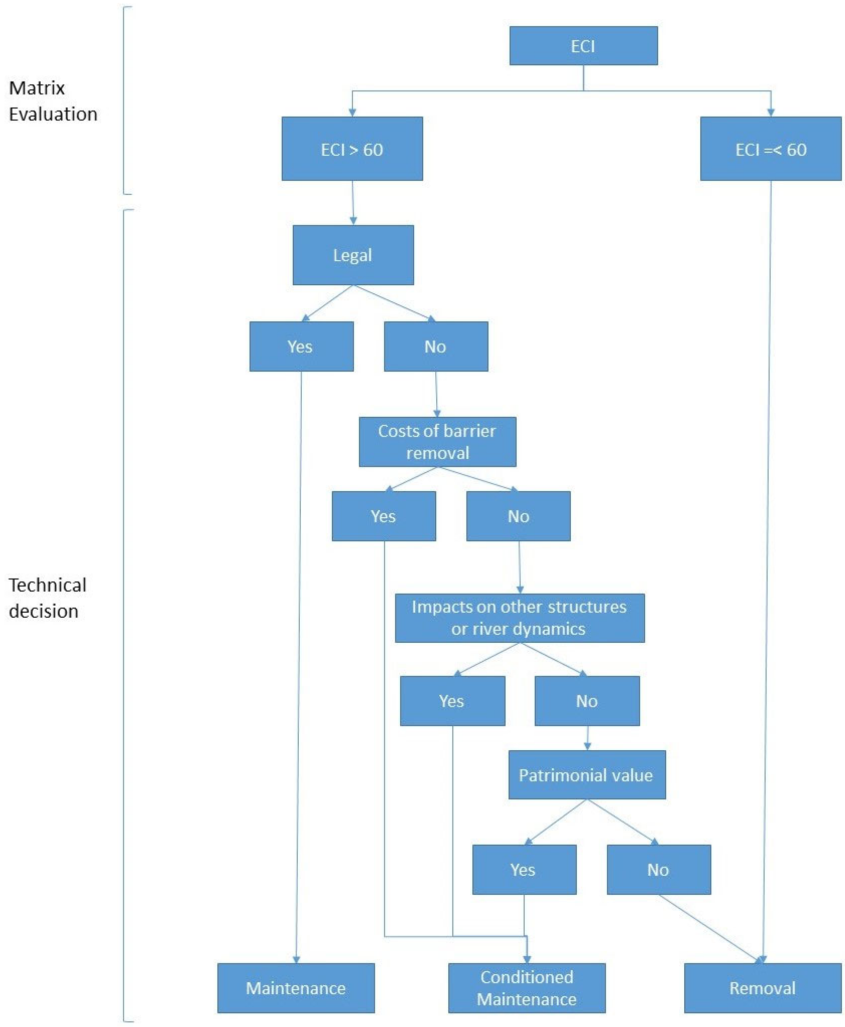

Figure 3. Workflow for the assessment of the barrier removal decision.

3. Results and Discussion

Based on the inventory, we defined the main characteristics of the weirs:

1—The weirs were of small height and with simple permanent structures of rockfill, sill, or spillway; 25 were inactive (Figure 4).

Accepted were the dams at Carvalho do Moinho (nº. 38, 7.5 m) for hydroelectric exploitation and at Moinho do Buraco (nº. 39, 13 m), belonging to a textile industry already abandoned (Figure 5).

The remaining weirs (41), which were mostly used for irrigation and mill operation, were very small (less than 0.5 m high) (Figure 6).

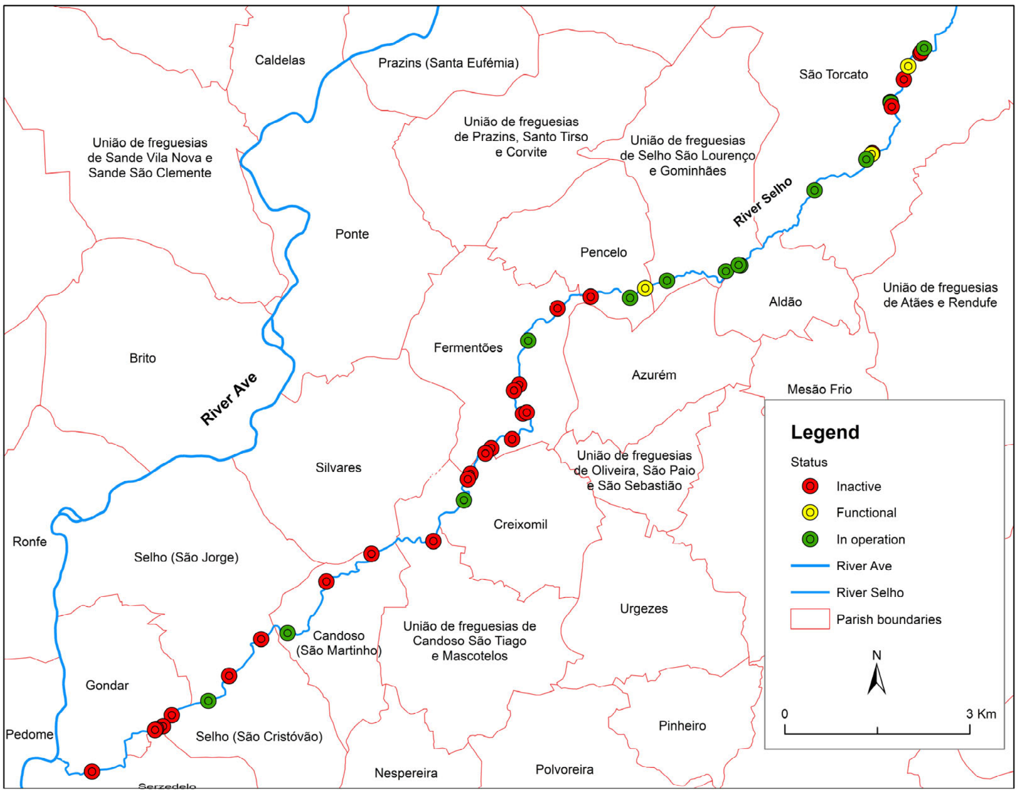

Figure 4. Weir status classification.

Figure 5. The dams of Carvalho do Moinho (**left**) and Moinho do Buraco (**right**).

Figure 6. Two examples of small weirs on Selho River (nos. 39 and 14).

2—Barriers created by permanent structures caused backwater effects in most cases (27), with significant environmental impacts, mainly because these weirs created a physical barrier to fish passage (Figure 7). In 18 of the 43 weirs, fish passage was unfeasible.

Figure 7. Backwater effects, revealing environmental impacts, and incapacity of transposition by fish species (nos. 38 and 16).

3—The main hydrological impacts related to sedimentation processes (Figure 8), with prevalent or very high effects in 32 weirs.

Figure 8. Two examples of significant sedimentation processes on Selho River (nos. 32 and 40).

The fluvial dynamics were greatly influenced by low water velocity due to the reduced hydraulic gradient along the watercourse, which was the case for the predominant laminar flow and the balance between erosion and sedimentation.

4—The environmental and hydrological impacts were reflected in the physical–chemical quality of the water (Figure 9), namely, in the alteration of the dissolved oxygen value, considered bad in 23 weirs.

5—From a biogeographic point of view, the low quality of riparian vegetation stood out, with a predominance of invasive/infesting species occupying the banks of most areas where the weirs were located. The aquatic vegetation presented very low occupation and diversity by native plants, with herbaceous plants occupying the bed of the watercourse (Figure 10).

With the data from the inventory, we filled in the matrix and obtained the ECI results, which showed that 95% of the weirs had a status lower than "Good". No barrier scored excellent, and only weirs 14 and 42 had a good condition (Figure 11).

Consequently, Table 5 shows the results of the ECI calculation for each barrier considered. Based on the environmental assessment and removal feasibility sheets, it is possible to present the most appropriate technical decision for each barrier (Tables 5 and 6).

Figure 9. Environmental and hydrological impacts occurring in the Selho River, revealing very low values of physical–chemical criteria for these two examples (nos. 12 and 43).

Figure 10. Examples of the occupation of riverbanks by invasive/infesting species (nos. 17 and 36).

Table 5. Results of the Environmental Condition Index and Technical Decision for all weirs.

BN	S001	S002	S003	S004	S005	S006	S007	S008	S009
ECI	40	33.125	21.875	42.5	43.125	48.125	33.75	26.875	51.25
TD	CM	CM	CM	CM	R	CM	CM	CM	R
BN	S010	S011	S012	S013	S014	S015	S016	S017	S018
ECI	56.875	53.125	41.25	41.25	74.375	50	43.75	41.25	43.75
TD	CM	CM	CM	CM	CM	CM	CM	CM	CM
BN	S019	S020	S021	S022	S023	S024	S025	S026	S027
ECI	45	35.625	54.375	48.125	48.125	35	34.95	25.625	46.875
TD	R	R	CM	R	R	CM	R	CM	R
BN	S028	S029	S030	S031	S032	S033	S034	S035	S036
ECI	32.5	26.875	55.625	50	60	33.125	35	35	43.125
TD	R	CM	R	CM	R	CM	CM	CM	R
BN	S037	S038	S039	S040	S041	S042	S043		
ECI	53.125	40.625	21.875	24.95	58.75	63.75	30		
TD	CM	M	CM	R	R	R	R		

BN—Barrier Number; ECI—Environmental Condition; TD—Technical Decision; M—Maintenance; CM—Conditional Maintenance; R—Removal.

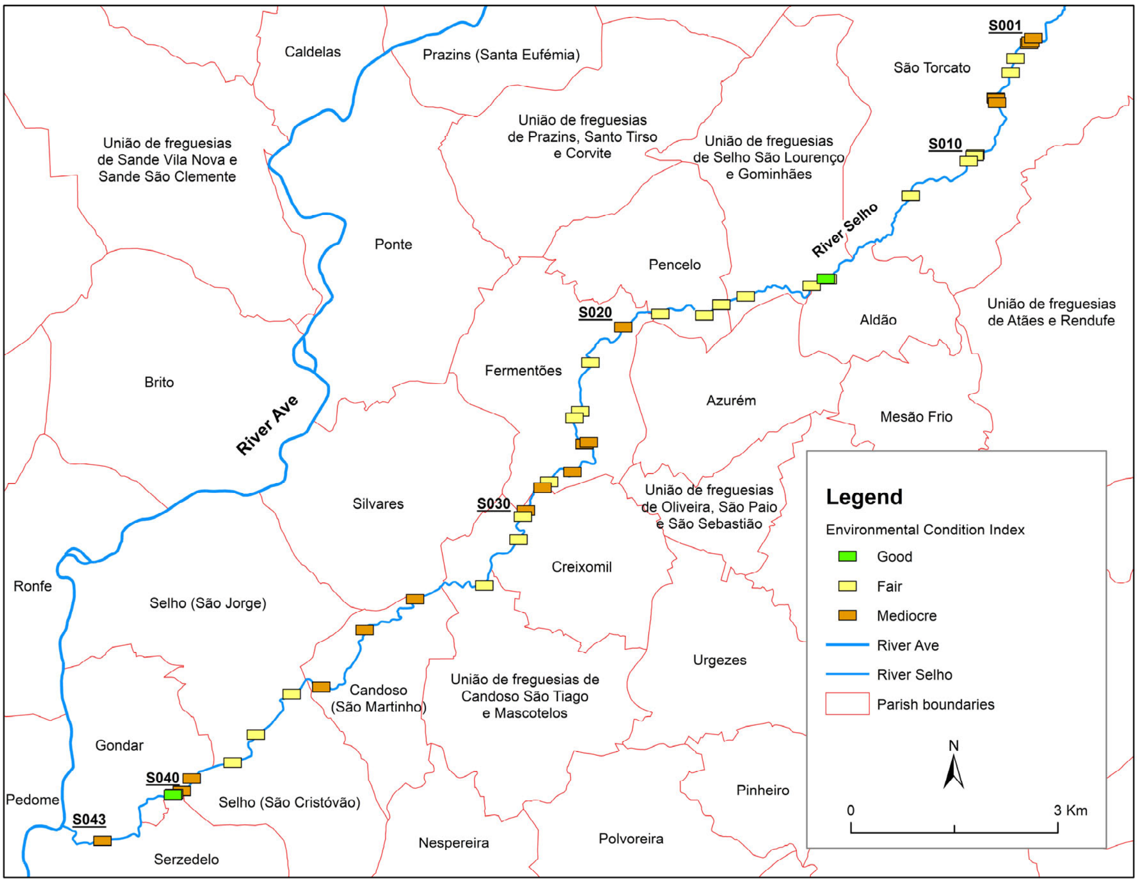

Figure 11. Classification of weirs following the ECI.

Table 6. Synthesis of the analysis performed on the weirs, considering the three possible technical decisions.

	Technical Decision			
Classification	**Maintenance**	**Conditioned Maintenance**	**Removal**	**TOTAL**
Good	0	1	1	**2**
Fair	1	14	9	**24**
Mediocre	0	11	6	**17**
TOTAL	**1**	**26**	**16**	**43**

In Figure 11, we show the distribution of the weirs by technical decision classification. The result can be spatialized on the study area (Figure 12) and the distribution of the different weirs according to the technical decision categories, which shows a concentration of weirs with proposal for removal in more anthropized areas (especially close to the city of Guimarães).

The analysis process resulted in the following recommendations:

(a) Removal of 16 weirs. These correspond to barriers whose ECIs are below 61 points or/and abandoned and easy to execute from a technical point of view.

(b) Maintenance of 26 weirs under conditioned form. Additional information is required, such as legal situation and activity, cost and complexity of the intervention, or relationship with the hydraulic heritage. Based on this information, a final decision will be made for removal or maintenance. In the case of maintenance, mitigation measures should be defined. The maintenance work of a preventive character includes a set of works aimed at selective cleaning of riparian and aquatic vegetation, desilting, construction of fish passages, and monitoring and removal of solid waste. Other complementary measures must be analyzed on a case-by-case basis:

- Landscape integration measures that favor the recovery of the riparian gallery with respect to some structures, like pipes, stormwater manholes, and sanitation;
- Removal of illegal abandoned or ruined structures and equipment (manholes, canals, clandestine sewers, pipes, and overpasses).

(c) Maintenance of Carvalho do Moinho weir that feeds an active hydroelectric power plant.

(d) Study cases to consider for intervention:

- Carvalho do Moinho weir—has concessions and measures to consider that should take into account the removal of invasive plants, cleaning the bottom of the dam, and recovery of the existing fish passage device;
- Moinho do Buraco Factory Weir and Roldes Weir—although the technical and financial solutions are demanding, given the environmental and hydrological impacts, removal is the appropriate option for these two weirs. However, taking into account the historical character of the two hydraulic structures, we advise a photographic and video study for future memory on the local industrial heritage;
- Weir and "levada" of Moinhos de Varandas—considering the local conditions that are associated with a high risk of flooding, a hydrological study and a survey should be carried out on the "levada" and the mills that still exist in this area that portray significant local importance.

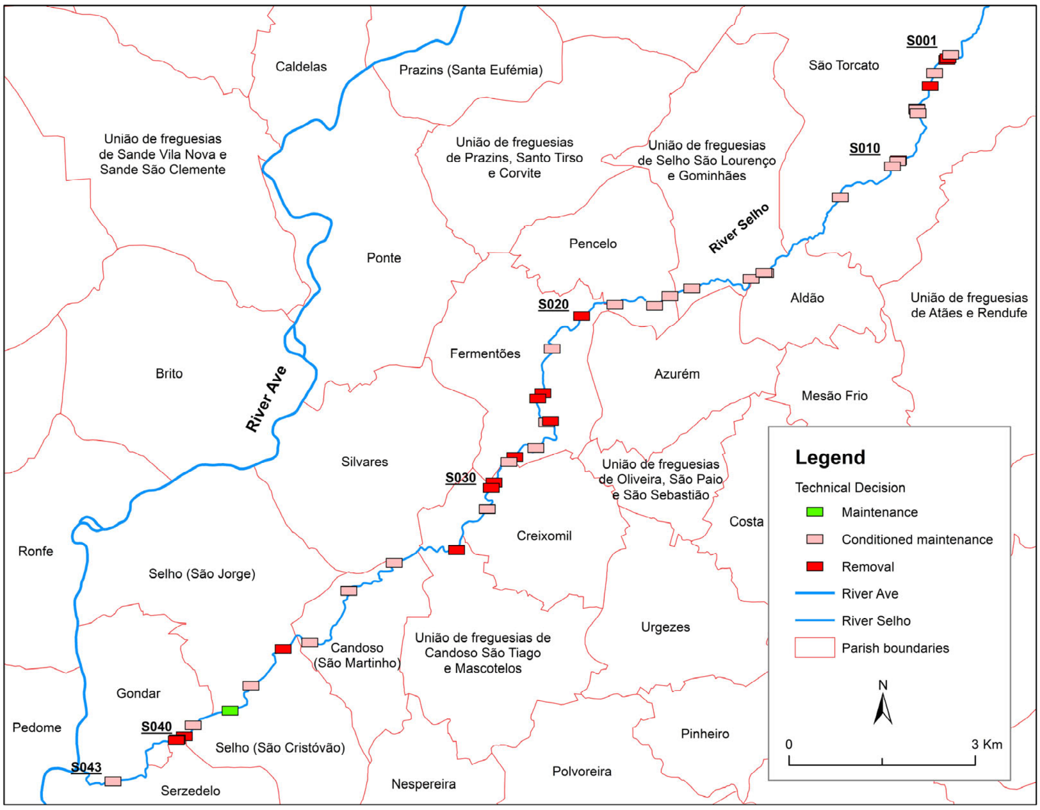

Figure 12. Distributions of the weirs according to technical decision.

4. Conclusions

Flexible, dynamic, and collaborative approaches are currently being implemented [14], focusing their attention on important new challenges in river ecosystem restorations, specifically to find the best solutions based on methodologies appropriate to the scale of the intended interventions.

The project we are developing presents a scoring-and-ranking techniques approach in a combination of physical, ecological, and socio-economic assessment criteria. This method simplifies data [177] and can be applied rapidly [155].

The method was shown to be a rigorous, versatile, and practical tool, based on simple, flexible, and clear guidelines, with standard results that were easy to apply and interpret for the correct and hierarchical management of weir removals at a local level. From this perspective, it is an important instrument in territorial planning and a fundamental tool for knowledge and decision-making, providing a comprehensive evaluation with a clear applicability in management. This project will support the decision-making process after being confirmed with a validation step (technical decision phase) [37,178–181].

The approach presented in this paper can be applied in a straightforward way to any watershed that shows the model's usefulness as a generic restoration planning tool [29]. This tool will be also useful for adaptive management of barriers towards fulfilling the requirements of the European WFD [13]. The expected benefits of the project, and especially the early involvement of the local population and stakeholders, aims to alleviate their concerns and ensure, where possible, compatibility between different activities, and are, therefore, crucial to the success of the project [31]. The most positive aspect was to define a methodology at a local scale and suitable for the management of small rivers with a high number of small barriers. This allows for greater proximity to the regional administration, the municipality, and all local stakeholders.

It is evident that a project of this nature reveals some limitations and constraints. Firstly, the Environmental Portuguese Agency (APA) database that was collected for the purposes of ecological status assessment and monitoring compliance with Water Framework Directive was very incomplete. We tried to address this with complementary sources provided by the Landscape Lab and with preliminary fieldwork. The socioeconomic criterion was the most complex to assess. Data and information on the legal status of the barriers and the activities they carried out were extremely difficult to find and required exhaustive work in the archives of the Environmental Portuguese Agency. Some properties were abandoned, and the current owners were unknown. Another limitation stemmed from the antiquity of many barriers and the difficulty in finding their administrative files since they were not part of the current APA archive. Some of the datasets were still incomplete, so the scores should be treated as provisional and subject to revision as data quality improves. Another aspect to take into account is some mistrust on the part of the local inhabitants whenever we were in the field. Some conflicting situations with landowners who did not have titles for the use of water resources and who were in an illegal situations were to be expected. This showed the complexity of managing barriers, especially given the complexity and scale of each situation and the increasing uncertainty about future conditions.

The method presented not only has methodological significance but also helps policy makers determine river channel restoration priorities based on four key conditions [11]: (1) they provide a meaningful gain in connectivity; (2) they are cost-effective to remove; (3) they do not cause significant or long-lasting environmental damage; and (4) we are dealing mainly with obsolete structures.

The continuity of our project was assured, as it was integrated into an already approved proposal of "REACTivar Guimarães—Renaturalization of the green corridors of the Ave, Selho and Vizela Rivers" with funding of EUR 1.2 million (Operational Program funded by the European Structural and Investment Funds)

The successes and failures of consultation processes, public participation, the roles of local communities, the links between ecological restoration operations and local economic development projects, and the perceived losses of valuable historic landscapes are some of the issues facing this new stage of the project.

Barrier removal projects, when properly sited and carefully managed, can promote highly durable restoration actions that permanently increase habitat connectivity and improve natural river processes and functions important to the health of connected freshwater [12]. The growing number of scientific studies provide an important opportunity to learn how to better manage watersheds and improve our understanding of river restoration science [112,182].

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