Ecological responses of three urban watercourse stretches after implementation of one-off recovering interventions: an integrated assessment

Assessment of three brazilian urban stream streches interventions

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Conflicts of Interest

The authors affirm no conflict of interest. The funding agency had no participation in the design of the project; in the sampling, analyses, or treatment and interpretation and of data; in the elaboration of the paper, as well as and in the predisposition to publish the results.

Abstract

Faced with the anthropic activities of urban streams stretches through rectification with concrete, there is a concern about the modifications of the aquatic habitats and consequent ecological damages to the ecosystems. Based on biophilic engineering, there is a great opportunity to idealize and test interventions to revitalize such hampered ecosystems. Hence, we verified the performance of biological and organic factors, after the implementation of one-off interventions in three rivers using biophilic handmade materials and structural elements in their fixation. We carried out the project in urban stretches of concrete bed streams, located in Sorocaba-SP, Southeast of Brazil. In two years, we conducted biweekly in situ and laboratory measurements to characterize the study sites, idealize, scale, implement the projects, and, evaluate the ecological responses of the implementations. We collected sampling in two points: upstream and downstream interventions. We evaluated the performance of the interventions through the analysis of SWOT (Strengths, Weaknesses, Opportunities, and Threats) factors and by using the Analytic Hierarchy Process (AHP). We presented the results through a decision-making matrix for stakeholders, which indicated that our ideas are of low cost and easy to implement. Then, we got the following scenario of SWOT priorities: opportunity (58.55%), strength (24.71%), threat (10.74%), and weakness (6.00%). They demand constant efforts for maintenances and they need adjustments to a better understood by residents and the watershed management. We concluded that the strengths observed in the project turn our idea replicable in any part because it attaches the idea of caring about the environment through biophilic techniques, and the weaknesses are liable to modifications (improvements) in future projects that consider such proposal.

KEYWORDS

Stream revitalization, one-off intervention, watershed management, analytic hierarchy process (AHP), biophilic techniques.

1 INTRODUCTION

Urban development has major effects on aquatic ecosystems, due to the combination of the factors: increasing in the impermeable surface of the catchment areas, alterations in the channel (including channel rectification), impermeabilization (concrete) of the channels, disconnection of channels, and problems of contamination (Everard & Moggridge, 2012; SNIS, 2018). Developing countries have especially suffered from this problem. Exemplifying, in Brazil, 53.2% of the population has access to wastewater collection, and the services of treatment of sewage processes (treat) less than half of the total of sewage generated (SNIS, 2018; Cerqueira *et al.*, 2020).

For better understanding the stream ecology restoration in urban areas, there are recommendations to integrate the stream ecological with social, economic, and political drivers of the urban environment (Walsh *et al*., 2005). Illustrating, Darwiche-Criado *et al.* (2017) carried out a study for prioritizing wetland restoration not only with environmental and biophysical but also, socio-economic factors through the comparison of two multi-criteria methods.

Past engineering practices encouraged flattening, hardening, and enlarging pristine waterways to diminish flooding and erosion complications in peopled areas (Gomes & Wai, 2019), implicating several kinds of ecological imbalances and loss. Such interventions receive the name of "grey" interventions (Ourloglou*et al*., 2020). Nowadays, one way to reestablish the local, ecological conditions is the use of bioengineered products. Such products might be a useful option to help to manage water resources, especially if we generate low-cost alternatives. This kind of technology incentives the use of products and actions of naturally-elaborated products and a multi-dimensional approach, aiming to attend needs of society, preserving the urban infrastructure, and improving the environment through aesthetics enriched by landscaping (Koepke, 2017; Chen and Ku, 2018).

Hence, we might implement restoration activities to repair hampered environments, reduce point-specific problems, and improve ecosystem functions (McDonald *et al.*, 2016). Such an approach (point-specific) may help to define actions for restoration personalized to socioecological contexts. Restoration projects have the objective of one-off interventions, while for others the goal is implementing ongoing interventions (Hobbs & Cramer, 2008; Hobbs *et al*., 2011). Cities and towns offer important and interesting opportunities for the conservation and/or recovery of biodiversity (Parris*et al.*, 2018; Primo, 2020; Silva *et al.*, 2021).

There are several options for analyzing and evaluating the outcomes of a project or campaign concerning restoring watercourses. One alternative is the TOWS matrix. A TOWS analysis is an alternative form of a SWOT analysis, being an acronym for Threats, Opportunities, Weaknesses, and Strengths. In its turn, the SWOT Analysis is an evaluation method used to assess the 'strengths', 'weaknesses', 'opportunities' and 'threats' involved in an association, a proposal, a project, an individual, or a company (Gürel & Tat, 2017). The TOWS might be based on the criteria listed in the SWOT step so that the combination of factors could provide a solution with the best strategies for a project with an integrated approach (Table 1).

The Analytic Hierarchy Process (AHP) is a technique to assist people in making complex decisions. More than determining which decision is correct, AHP helps people choose and justify their choice. Following this idea, as an example, Yavuz and Baycan (2014) applied the Analytic Hierarchy Process (AHP) method with the Strengths-Weaknesses-Opportunities-Threatens (SWOT) analysis and TOWS matrix in a study conducted at Lake Beyşehir in Turkey.

TABLE 1 TOWS matrix representation

Hence, after implementing a set of experimental interventions designed to repair some ecological features of impacted river stretches, we monitored the evolution of some environmental properties and used the SWOT approach to investigate the external opportunities and threats, as well as the internal strengths and weaknesses for evaluating the success of such interventions, and developed a TOWS matrix based on the criteria listed in the SWOT components.

2 STUDY SITES AND METHODS

2.1. The study sites

We carried out this project in three urbanized rivers located at Sorocaba. This is a metropolitan city located approximately 100 km from the capital São Paulo (Lat 23°30′0″ S, Long 47°27′29″ W) with an approximated area of 450 km^2 and 700,000 inhabitants (Figure 1). The regional climate is predominantly humid and warm, with dry winters. The average rainfall in the study region is 1,339 mm y^{-1} and the average annual temperature is 21.2°C (Abreu & Tonello, 2017).

FIGURE 1 Left: Location of São Paulo state in Brazil and Sorocaba. Right: Geopolitical boundaries, river network and digital elevation model of Sorocaba, and study site

The three stretches remain in different catchment areas (watersheds), named here as R1, R2, and R3 (Figure 2).

FIGURE 2 Shapes of the streams sub-basins R1, R2, and R3

2.2Design of the structures and arrange of them in the locals of the experiment

Considering that the three selected rivers have the studied stretches the bottom impermeabilized with concrete to avoid problems with erosion (Figure 3), we tried to design structures to influence the water dynamic (flow and quality) to create an environment appropriate to recolonization by plant species. We decided to use low-cost materials considered to be ways of bioengineered and biophilia, with the intention of not causing damage to the current ecosystem (Silva *et al*., 2018; Primo, 2020).

FIGURE 3 Illustration of the structures manufactured and installed in the three studied river channels (above: photographs and down: upper view): (a) Stream R1; (b) Stream R2 and (c) Stream R3

For stream R1, we used seven jute bags (normally used to transport vegetables like potato or onion) filled in with gravel (approximately 26 kg each bag). We arranged them aiming to create a surface of the anastomosed pattern.

For the stream R2, we used six rolls (6.5 m long × 13 cm∅) manufactured with tulle and jute and filled in with gravels (approximately 35 kg of gravels each roll). We named such structures "sausages" and we placed them parallel to the water flow. We installed two of them in direct contact with the water, and the other four parallel to such flow.

Finally, in-stream R3, we manufactured four "sausages" of identical dimensions to those used in stream R2, and we also arranged them parallel to the water flow. Following the same principle as the previous stream, we placed two of them in direct contact with the water, and the other two ones, we fixed on the concrete margin of the stream to remain above the water level most of the time. Also, we manufactured another additional cylindrical piece of plastic mesh used in civil constructions (geotextile), and we filled it in with gravel (approximately 40kg of gravels). Such structure had approximately 15 cm in diameter and 4 meters long. We placed this one perpendicularly to the water flow, thus serving as a small dam for sediment retention.

2.3 Field experiments - monitoring

After implementing all previously planned interventions, we carried out data and sample collections through one entire year, including the two typical seasons of the region. We conducted the field works always beginning at 8:00hAM and following systematically the same routine to avoid differentiation of the data as an effect of the time.

To verify the efficiency of the interventionist activities implemented, we adopted two sampling points in each studied river stretch: (i) upstream the intervention and (ii) in the intervention. In all sampling points, we collected data in triplicate to permit statistical analyses (Figure 4). Table 2 summarizes the procedures adopted to collect the data of each indicator.

FIGURE 4 Illustration of the data and sample collection strategy (not to scale)

TABLE 2 Description of the procedures for determining the investigated variables

2.4. Data interpretation and matrix-basedanalyses

Using the statistical package BioEstat 5.0 (Ayres *et al.*, 2007), we applied the non-parametric Wilcoxon test to check the possible significance in terms of statistics for all analyzed parameters. For all parameters, we assumed as null hypothesis (H_0): there is no difference between the upstream and at the local with intervention, and an alternative hypothesis (H_1) there is a significant difference between the upstream and at the local, with intervention. The decision level we used for the Wilcoxon test was $\alpha = 0.01$ and $\alpha = 0.05$ for the Student's t-test.

Initially, we conducted a SWOT analysis to identify the strengths and weaknesses of the implemented project, as well as opportunities and pressures in the environment. Considering that for conducting a SWOT-based analysis, the analyzers create a procedure or method of getting information concerning each part of the SWOT's context, i.e., information concerning Strength, Weaknesses, Opportunities, or Threats (Silva *et al*., 2018; Primo, 2020), for the current study, we considered to relate and the understandings experienced by the participants of the project during the period of execution of the project. Such understandings and experiences were that one viewed, described, and shared in and after the field incursions.

Hence, we created a Threatens-Opportunities-Weaknesses-Strengths (TOWS) matrix model containing restorative actions such as improving the environment and avoiding the degradation of rivers in urban centers. We used the fundamental scale of priorities proposed by Saaty (1977) for the elaboration of the priority matrix to compare the pairs of criteria. The scale of importance varied from 1/9, meaning the minimum scale of importance, until 9, the maximum scale of importance. We followed the consistency ratio of each judgment matrix and the normalization of the criteria vectors. Finally, we applied the A'WOT method, called by Kurttila *et al.* (2000), in four steps following the propositions published by Kisi (2019):

Step 1: Observing and reporting the internal (strengths and weaknesses) and external (opportunities and threats) factors for the SWOT matrix building.

Step 2: Applying pair comparison between the SWOT groups factors to build-up a 4 x 4 order matrix.

Step 3: Calculating the priority of each factor, within the SWOT groups, by making four n x n matrices (depending on the number of factors in each group).

Step 4: Obtaining the total factor priority by multiplying the group's priority by the factor's priority within each group.

As a result, we developed the TOWS matrix based on the criteria listed in the SWOT step so that the combination of factors could provide a solution with the best strategies for a project with an integrated approach.

To improve the planning information contained in the SWOT analysis, we used the AHP method to verify the priority between the attributes in a global (comparing the four pillars or groups of the SWOT matrix) and local way (the criteria within the groups).

3 RESULTS

3.1. A general view of the study areas and the structures

The catchments R1 and R2 have a greater tendency to a higher peak flow due to the compactness coefficients (1.2 for both) being closer to the unit (1.0). The R3 lower value of shape factor (0.3) evidences that this catchment has a lower tendency to flood, concerning to the others. The value also indicates that is a typical basin with an elongated shape. In terms of hydrographical hierarchy, the stretches where we implemented the restoration works are of second-order in streams R1 and R2 and third-order in the R3 stream (Table 3). Two of the three catchment areas present a high percentage of urbanization (Silva, 2019; Silva *et al.*, 2021): R1 75% and R3 (82%), whereas in stream R2, the urban occupation is almost 38%.Both the R1 and R2 catchments present a topographic range higher than 100 meters and average slope higher than 4.0 $m.m^{-1}$, while in the R3 the topographic range is 60 meters and the average slope is low (2.6 $m.m^{-1}$).

TABLE 3 Morphometric and land cover properties of the three studied catchments
Sources: Silva (2019) and Silva*et al.* (2021) - modified.

We described the shapes and dimensions of all structures used in the experiments earlier, in the section Material and Methods. Here we report that the bags were the pieces that we experimented with more easiness and convenience to transport from the local manufacturing to the experimental place. We consider that all structures are of easy installation. We always fixed the structures with metallic wires. The point of difficulty was that we did not make holes in the concrete (to avoid damage to the concrete), and we tried to nail the iron piles in the interstices between the concrete plates of the stream floor.

It is worth observing that, during the implementation phase of the structures in the R1 stream, we went through a flood event that, due to river flow increased, the bags were carried about 100 m downstream. At this stage, therefore, we had to relocate them properly again. Another interesting point to mention, which also happened in the R1 stream, was that in a certain period of the study, some residents felt uncomfortable with the growth of vegetation in the stream bed and ended up pruning the species due to the lack of knowledge of the experiment.

3.2. The evaluated indicators

Total organic carbon (TOC) of the sediment and Biochemical oxygen demand (BOD)

For the organic carbon data of the R1 stream sediment, we chose the non-parametric Wilcoxon's test, which considers paired and related data. As a result, we reached a value of $p > 0.01$, so there was no difference between the amount and intervention measures (Table 4). For the R2 stream, the sample series did not show significant differences according to the Shapiro-Wilk test (p>0.05), therefore, it was plausible for us to apply the student T distribution. We could infer from the unilateral p-value (p<0.05) that the hypothesis was acceptable, that is, there was some difference between the amount and intervention values. Finally, for the R3 stream, we achieved from the Wilcoxon non-parametric test the value of p>0.01, therefore, there was no difference between the amount and intervention data.

TABLE 4 Statistical results comparing the variables upstream and at the intervention site
[b]Wilcoxon signed-rank test; [a]Paired sample *t*-test.

For the statistical analysis of the BOD content of the R1, R2, and R3 streams, we chose the Wilcoxon non-parametric test that considers the paired and related samples. As p>0.01, we could say that there were no differences between the BOD values upstream and in the intervention in all rivers, that is, we considered the nullity hypothesis.

Through Figure 5 we observed outliers for the total organic carbon (TOC) of the sediment and biochemical oxygen demand (BOD) data measured in rivers R2 and R3, which may have negatively influenced the statistical study.

FIGURE 5 Boxplots of total organic carbon (TOC) and biochemical oxygen demand (BOD) for the streams R1 (top), R2 (center), and R3 (below)

Invertebrate animals

The main macroinvertebrates identified were *Chironomus* spp. (Diptera, Chironomidae) and we found them in streams R1 and R2. We found almost four times the amount of specimens in the R1 stream, the most urbanized one, concerning stream R2 (197 versus 56),corroborated with Riente (2017) who found out there was a significant increase in the number of Diptera larvae in the medium course, downstream of the inflow of the urban watershed. We captured them most of the times together in the sediment (Figure 6), always in the bottom of the stream, because the fixation of O_2 in the water happens in an easier mode, without the necessity of the larva climbing to the surface of the water body to breathe (Gomes *et al.*, 2018).

FIGURE 6 Specimen of *Chironomus* spp. (Diptera, Chironomidae) found in streams R1 and R2, placed in an Imhoff cone

Emergence and development of vascular plants

By the succession of photographs, throughout the project period, we could notice that the projects implemented in streams R2 and R3 did not show the emergence of vascular plants. On the other hand, after interventions made in the R1 stream, some plant species emerged on the artificial substrate (jute and gravel) placed on the stream bed and remained effective, for at least one year, after the beginning of the project, evidenced by pictures (Figure 7).

FIGURE 7 Status of the projects after three months of intervention: (a) Significant amount of vascular plants growing in stream R1 (in the photo, water flow: from up to down); (b) Low retention of sediment in stream R2 (in the photo, water flow: from the right to left); (c) Retention of sediment and coarse solids in-stream R3 (in the photo, water flow: from right to left)

Supported by books, booklets, manuals, and the supplementary technical collaboration of taxonomists, we identified four plant species growing in the structures implemented: *Heteranthera reniformis* (Ruiz & Pav.), *Polygonum acuminatum* (Kunth), *Ludwigia grandiflora* (Michx.), and *Rumex crispus* (L.) (Figure 8) (Olimpio, 2019). We reported all these species in the R1 stream. They are all ruderal species, able to develop in wetlands, and/or humid environments, and prefer a high light and temperature environment. Their growth is fast and in our experiment, we noted that they reached significant heights like those generally found in the consulted bibliographies.

FIGURE 8 Plant species found in stream R1 in less than a year later the implementation. (a) *Heteranthera reniformis* (Ruiz &Pav.), (b) *Polygonum acuminatum* (Kunth), (c) *Ludwigia grandiflora* (Michx.), and (d) *Rumex crispus* (L.)

3.3. Results of the matrix-based analyses

We based the factors within the pillars of the SWOT matrix on the experience of the type of project carried out mostly in the R1 stream, which showed clear ecological responses, including the physical characteristics of the stream, types of works implemented, layout and quantity, as well as the barriers and positive points observed (Table 5).

We present the results of the SWOT analysis with the priority analysis in Table 6. The result of the consistency of the matrix containing the four SWOT pillars was a consistency ratio of 0.015, which is a consistent matrix because this value is less than 0.1 (Podimata & Yannopoulos, 2013).

TABLE 5 The SWOT analysis based on the R1 stream intervention works. We codified each subtopic of the table (S1, S2, W1, W2, etc.) to facilitate the subsequent explanations in the text and Table 6

TABLE 6 Priorities and consistency index of the SWOT analysis groups and the factors within the group and globally

[1]Consistency ratio. [2]The greatest weight concerning each SWOT group is underlined.

As a result of the A'WOT analysis (AHP-SWOT), we obtained the attributes with the highest degrees of importance in this type of project. They are: "low-cost projects", "scarcity of people minimally trained to execute successfully the tasks", "water quality improvement with simple work" and "risk of loss of work due to the very aggressive weather" (Figure 9).

In Figure 9, the lengths of the lines in the different sectors show that the threats and opportunities prevail over the other attributes, therefore, it is necessary to pay more attention to external factors for the development of this sort of project.

FIGURE 9 Result of the A'WOT method for the intervention project (priority indexes of the SWOT factors based on the R1 stream experiment). Note: negative values are symbolic and should be ignored

Moreover, it was feasible to direct the result of the intervention project carried out to obtain a TOWS matrix, rich in an ecosystem approach (Table 7). We created sucha matrix based on the criteria listed in the SWOT analysis that received the most degree of importance according to the AHP method. This matrix will serve as a tool in future projects to revitalize urban stretches of streams in regions with characteristics like those of the studied locations.

TABLE 7 TOWS matrix of the project to revitalize urban stretches of streams

4 DISCUSSIONS

The interpretation of the outcomes of a project of ecological restoration should not be simply "successful" or "unsuccessful", but rather analyzed if they accomplished the main goals or not, and if there were indications of progress after the project implementation (Zedler, 2007; Primo, 2020; Silva *et al.*, 2021). Hence, we analyzed the post-intervention progress in the studied streams separately, without the goal of comparing the three models employed, but rather describing them in terms of ecological responses, according to the statistics tests results and data collected (see Supplementary file).

4.1. A general view of the study areas and the structures

In stretch R1, the system installed allowed a spontaneous plant emergence in the apparatus implemented in the river, with a substantial amount of individuals of four different plant species, and they remained, according to our monitoring and photographic record, for more than a year after the end of sample collections (Olímpio, 2019). Additionally, the bags containing gravel allowed not only the establishment but also the harmonic coexistence of the emerging vascular plants. The root system of the plants was able to penetrate the tissues of the bags and the plants were sufficiently sustained (fixed) to not be washed away by the water during times of river flooding. We concluded, then, that the emergence of plant species was better than our expectations.

However, the ecological succession of plant species, in the works' substrate in streams R2 and R3 unfulfilled our expectations. We had greater difficulty in implementing the intervention project in the river with the largest channel (stream R2), due to the greater hydrological disturbance resulting from the processes that occur upstream of the intervention point. Beechie *et al.* (2010) also reported this fact. Comparatively, England and Wilkes (2018) attributed the failure in river restoration projects to the lack of effective monitoring. Also, due to the high energy of the waters that occur over the stream R2, in times of heavy rains, certainly the nature of the interventions should be ongoing profile, not a one-off as we have done on that stretch. Summarizing, hydropeaking may restrict germination and the establishment of riverbank vegetation (Bejarano *et al*., 2020).

Hence, we might infer that, besides the physical characteristics of the sub-basins, the high flow speed, in this case, R2 and R3 (5.01 and 3.98 $m.s^{-1}$, respectively) concerning the stream R1 (0.26 $m.s^{-1}$), may have limited the development of macrophytes and/or riverine plants.

Filoso *et al.* (2015) presented that the frequency and intensity of upstream rain influence the results of solids retention in lotic environments. Associatedwith this, we identified other variables, which may consider: the area of the hydrographic basin and the use and land use. Therefore, as river R2 reached higher peak flow values, followed by R3 and finally by R1, the hydrodynamic characteristics of the streams connected with this variable could then, interfere in the response of intervention projects in a non-desirable form.

In this way, a variable that connected with R3 stream characteristics, and that justified not to appear species in it, was the water level of the stream, a physical type characteristic. From the data collected, we concluded that the water level in R1 was on average of 2.49 cm, while R3 was 3.98 cm (almost half of the height of the bag), which could have negative effects and harm the biophilic work, not allowing spontaneous germination of species easily. We evidenced this fact by the constant need to maintain this work fixed in the river, notably in the post-rain period (Primo, 2020).

As also reported by Silva *et al.* (2018), some months after the implementation of the biophilic works, we noted an accumulation of approximately 18 m^3 of sediment in the "upper river" part of the device used in the intervention work of stream R3. The constitution of such accumulated sediment was mainly of waste of civil constructions (gravels, sand, bits of bricks), although we also detected some organic materials, plastics, and small pieces of glasses.

4.2. The evaluated indicators

According to statistical tests, it was not plausible to state that there were differences between the upstream and intervention data for BOD of the water and TOC of the sediment in stream R1. Therefore, it was not possible to state that the plant species contributed to the reduction of the TOC of the sediment and BOD of the water.

On the other hand, the macroinvertebrate species identified in this stream, which exceeded BOD limits for a class 2 river established by Brazilian Federal Law [Conselho Nacional do Meio Ambiente - CONAMA] (Brasil, 2005), could reiterate the statement found in the literature (Barros *et al*., 2016; Li *et al*., 2010; Lu *et al*. 2019) that such communities can be used as indicators of the conditions of aquatic systems, more precisely the species of Chironomidae, corroborating researches carried out by Machado *et al*.(2015) and Johann *et al.* (2019). The TOC of the sediment proved to be well above the other streams, reaching values of 2.5%, being the main reasonable factor for the emergence of plant species on this substrate richer in organic matter.

Regarding the statistical analysis of data in stream R2, the TOC of the sediments at the sample points upstream and in the intervention indicated that there was a difference between the data collected, however, once this stream did not present plant species, the information above was less relevant. Regarding the statistical tests of the BOD values sampled at the points upstream and at the intervention, there was no significant difference between the data.For stream R3, the statistical tests of the TOC of the sediment and BOD variables, returned for both, a null hypothesis. For stream R3, the statistical tests of the TOC of the sediment and BOD variables, returned for both, a null hypothesis.

4.3. Results of the matrix-based analyses

Analyzing the stream that best presented a response to the intervention related to spontaneous vegetation, we met some criteria to achieve the efficiency of the project: the system presented, without damage to the ecosystem, an improved ecological condition, became more dynamic, and finally, provided data for analysis and publication of results.

Using the SWOT analysis in conjunction with the AHP method (A'WOT analysis), we obtained the following ranking of SWOT analysis priorities: opportunity (58.55%), strength (24.71%), threat (10.74%), and weakness (6.00%). According to this analysis, the most important SWOT attribute was “water quality improvement with simple work”, from the opportunity group, with 46.41% of the total priority of this factor. Other criteriaglobally analyzed considered important were: “low-cost projects” (13.34%), “using of recycled materials” (7.68%), “risk of loss of work due to the very aggressive weather” (7.68%), and “easy implementation and execution” (7.34%). Similarly, Chen and Ku (2018) also applying the SWOT analysis in research concerning river ecosystems management under nature-based solutions (providing solutions that integrate both engineering projects and protection or restoration of the natural environment), considered "few and simply engineering measures" as an opportunity (O) that can control some related threats (T) to optimize the ecosystem studied by the authors.

The partial achievement of the objectives and "slow-motion" progress by the bioengineering projects, related to ecological succession, implemented in streams R2 and R3 may be, according to other studies, due to lack of investments, as well as unfamiliarity of risks. These reflections will serve as a lesson for future studies and should not be considered as a failure (Geist and Hawkins, 2016, Gann *et al.*, 2019, Arango *et al.*, 2015).

In a general context, analyzing the three streams, we reported that the ability to restore streams by reducing pollutant loads in the water was inefficient because the release of polluting loads remained unchanged, corroborating the ideas described by Beechie *et al.* (2010), Filoso *et al*. (2011), and Geist and Hawkins (2016). Hence, we suggest that the first step in allowing the recovery of a degraded ecosystem is through the actual impacts identified removal, or reduction (Primo, 2020).

The recent research questions developed about river management and restoration activities studied by Piégay *et al.* (2020) showed that there is continually widening the range of successful projects, with more social factors in addition to ecological ones. As a suggestion from this innovative approach, It would be interesting that some research is carried out before the intervention projects, including interests of the residents with potential for future installation of such works, and besides, a survey with the population would be pertinent after the end of the projects, verifying the gains obtained from the social and economic point of view (Polizzi*et al.*, 2015, Vásquez and Rezende, 2016, Brouwer, 2017). Nicholls and Crompton (2017) investigated the effect of rivers on property values and stated that besides the reduction of damages as a result of a restoration program, recreational and aesthetic benefits to nearby homeowners are an important value to consider in its cost–benefit analysis.

5 FINAL REMARKS

The dynamics of the ecosystem exhibited alterations, evidenced by the spontaneous appearance of plant species with ecological succession in one of the streams, as well as the appearance of macroinvertebrate species.

Each site presented a unique set of challenges that were useful for the team to disseminate the knowledge. Thus, the products generated in the present study will serve as an alternative in possible future urban streams intervention projects. The information collected can support decision-making for choosing the types of technologies to use and the best site to use them.

We could develop a management protocol, for helping decisions involving the revitalization of water resources, through the creation of a TOWS matrix with suggestions for strategies for future projects. The result of this study can be used as a series of priorities suitable for the academic environment and stakeholders.

Finally, we always encourage projects with interventions in urban streams, focused on the improvement of water quality, and aiming to provide habitats for fauna and flora, taking into account consider preliminary studies of land use, flow regime of the water channel that will receive the intervention, the sediment dynamics of the river, as well as the population interests and expectations, with the aim of better biophilic techniques choice, in addition to their positioning and arrangement in the stream bed.

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Data Availability Statement

The authors confirm that the data supporting the findings of this study are available within the article [and/or] its supplementary material.