**Technical assessment and decision making for the environmental recovery of waterways and their banks: a science-based protocol**



**Citation:**

Silva, R.A, de Oluveira Afonso, Francesconi, Wendy, da Silva, A.M. (2018). Technical assessment and decision making for the environmental recovery of waterways and their banks: a science - based protocol. International Journal of Environmental Science and Technology, 1-8 p.

**Publisher's DOI:**
http://doi.org/10.1007/s13762-018-1873-x

**Access through CIAT Research Online:**
https://hdl.handle.net/10568/93395

# International Journal of Environmental Science and Technology

## Technical assessment and decision making for the environmental recovery of waterways and their banks: a science-based protocol

--Manuscript Draft--

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|---|---|
| Manuscript Number: | JEST-D-16-02276R2 |
| Full Title: | Technical assessment and decision making for the environmental recovery of waterways and their banks: a science-based protocol |
| Short Title: | Technical tool for the environmental recovery of waterways and their banks |
| Article Type: | Original Paper |
| Keywords: | Aquatic ecosystems reclamation; ecological restoration; ecosystems repair; river ecotechnology |
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| Order of Authors Secondary Information: | |
| Funding Information: | |
| Abstract: | The poor management of aquatic ecosystems often results in environmental degradation, which requires actions for its recovery. A field protocol was elaborated to guide users (restorationists) to assess degraded areas and provide site and situation specific interventionist actions. The protocol was developed following the plant or animal taxonomy framework by Linnaeus, considering that the first character has two mutually exclusive possibilities. It was elaborated in three parts: (i) a technical glossary, (ii) a hierarchical key, and (iii) a set of intervention actions that are indicated according to the case. Complementarily, ten degraded sites (lentic or lotic ecosystem), all located in continental regions of the Brazilian territory were evaluated using this key. The protocol was thought to be applied to continental and superficial water bodies. It starts separating the lotic and lentic ecosystems, and after each part goes for specific ways, all of them finishing in one or more interventionist action(s). The set of actions presented is composed of fourteen scenarios, seven of them to be implemented on-site, five to be implemented off-site, and two to be implemented on- and/or off-site. The intervention actions range from simply monitoring, to re-vegetation of the riparian zone, to activities that target the re-oxygenation of hypolimnion. The study cases exemplify the use of the key and provide insight into the required adjustments for the implementation of intervention actions. The protocol and guidelines presented here will allow in a systematic manner, assess and compare the outcomes and efficiency of river restoration projects, locally, regionally and internationally. |

Sorocaba, SP Brazil June 11th, 2018.

Respected Editor in Chief of the
International Journal of Environmental Sciences and Technology

Ref. Paper JEST-D-16-02276**R1**

After receiving the reviewers and editorial remarks and recommendations, we began to work on the adjustments and improvements to the document.

All parts of the manuscript were revised (the main document and also the supplementary file). We made corrections and improvements in all parts, including several extra grammatical corrections that were not pointed by the reviewers. To avoid confusion, the parts of the text that were red-painted in the second version were converted into black, and the parts were modified in this version (3rd version) were all red-painted, following the instructions of the editorial team. In the following pages, you will see the responses given to the reviewers' comments.

We believe that the paper gained quality to be accepted for published in your prestigious journal. But, we are fully available to review it again if necessary.

We want to appreciate the efforts of the editorial team and the reviewers in elevating the quality of our paper.

We would be very pleased if you would consider our manuscript for publication in this very prestigious journal.

I am looking forward to hearing responses from you regarding the analysis of the second version of the paper.

Thank you for your time.

Yours sincerely,

Professor Alexandre Marco da Silva
Corresponding author.

Initially, we desire to thank the interest, efforts, and patience of the reviewers (especially the R6), to accomplish the arduous mission of reviewing a paper that is in the 2nd version.

<table>
<tr><th colspan="2">Author Query Form</th></tr>
<tr><th>Reviewers comments (Reviewer R3)</th><th>Author(s) response</th></tr>
<tr><td colspan="2">(*) We must say that the two comments made by the reviewer R3 are the same comments made for the 1st version of the paper. Below are the responses provided for the comments and we say that in the 2nd version the parts were red-painted. If in the opinion of the reviewer and /or the editor the comments are not yet sufficiently answered or the improvements in the text are not sufficient yet, please let us know. Thank you.</td></tr>
<tr><th>Reviewers comments (Reviewer R3)</th><th>Author(s) response</th></tr>
<tr><td>The manuscript covers an interesting and very relevant area of concern in today's context. It is well written and well organized. The only major concern is that related policies, proposed by regulatory bodies worldwide, are already in place. How relevant, significant, and adaptable will the proposed guidelines and corresponding protocols be in the present scenario?</td><td>Thank you for your eulogies. Our goal was to generate a paper as excellent as we could.<br>Regarding the policies: we agree with the reviewer and we inserted some details along the text and in the supplementary file (glossary and key) so that permits the use of the key worldwide. Thank you.<br>Regarding the relevance: the guidelines are relevant due to feasibility and speed of manipulation (this is discussed in the paper). However, we also inserted additional information (especially related to the paper from McDonald et al (2016 – please, see the list of references) that support the relevance of the tool presented in the manuscript.</td></tr>
<tr><td>Also, variations in protocols need to be emphasized upon keeping in mind the policy variations arising in response to different geographical areas.</td><td>Yes. We agree, and in several parts of the paper, we have done this.</td></tr>
</table>

| **Reviewers comments (Reviewer R6).** *The comments were found in the yellow balloons spread out in the pdf file (most of the questions were in Portuguese, they were translated into English, and transcribed below).* | **Author(s) response** |
| --- | --- |
| *Abstract – What were the methods used in the study?* | Ok. We understand that some information about this topic was missing in the Abstract, and we complemented it. |
| *Abstract – could you point out how many examples are and cite such examples?* | Ok. Same response as above. |
| *Introduction (2nd paragraph) – a suggestion to replacing a word.* | Ok. Done. |
| *Introduction (2nd paragraph) – a suggestion of including a bibliographic reference.* | Ok. We searched and found the suggested reference and we inserted it in the text and in the list of references). |
| *Introduction (5th paragraph) – insert the preposition "of".* | Ok. Done. However, the paragraph is entirely red-painted because we found inconsistences in the text and we rewrote parts of the text to improve it. |
| *Material and Methods (The intervention actions – 1st paragraph) – a restoration action for the benefit or favor the community of macroinvertebrates, periphyton, and fishes.* | Ok. We understand that the actions for improving the bottom of channels to provide suitable habitats for macroinvertebrates, periphyton and fishes are already presented (please, see actions AC1, AC2, AC5). For AC4 (Dredging of sediment): following the comments of the reviewer, we added the word "selective", resulting in: "AC4: Selective dredging of sediment". |

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**Full title:**

Technical assessment and decision making for the environmental recovery of waterways and their banks: a science-based protocol

**Short Title:**

Technical tool for the environmental recovery of waterways and their banks

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# Technical assessment and decision making for the environmental recovery of waterways and their banks: a science-based protocol

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Technical tool for the environmental recovery of waterways and their banks

**Abstract** The poor management of aquatic ecosystems often results in environmental degradation, which requires actions for its recovery. A field protocol was elaborated to guide users (restorationists) to assess degraded areas and provide site and situation specific interventionist actions. The protocol was developed following the plant or animal taxonomy framework by Linnaeus, considering that the first character has two mutually exclusive possibilities. It was elaborated in three parts: (i) a technical glossary, (ii) a hierarchical key, and (iii) a set of intervention actions that are indicated according to the case. Complementarily, ten degraded sites (lentic or lotic ecosystem), all located in continental regions of the Brazilian territory were evaluated using this key. The protocol was thought to be applied to continental and superficial water bodies. It starts separating the lotic and lentic ecosystems, and after each part goes for specific ways, all of them finishing in one or more interventionist action(s). The set of actions presented is composed of fourteen scenarios, seven of them to be implemented on-site, five to be implemented off-site, and two to be implemented on- and/or off-site. The intervention actions range from simply monitoring, to re-vegetation of the riparian zone, to activities that target the re-oxygenation of hypolimnion. The study cases exemplify the use of the key and provide insight into the required adjustments for the implementation of intervention actions. The protocol and guidelines presented here will allow in a systematic manner, assess and compare the outcomes and efficiency of river restoration projects, locally, regionally and internationally.

**Key-words** Aquatic ecosystems reclamation; ecological restoration; ecosystems repair; river ecotechnology

## Introduction

Several ecosystem services, essential to the environmental and human wellbeing are dependent on healthy water resources. On the other hand, water resources globally are degraded by a multifaceted combination of stressors, resulting from a variety of drivers (Beechie et al. 2010). Problems of degradation in rivers and their adjacencies can be physical, chemical and/or biological, and the degradation process is usually linked to soil erosion, pollution, missing of riparian vegetation and excessive fishing (Le et al. 2014). These can occur at different intensities, because of both the nature of the degrading activity and the local environmental factors.

For example, typical urbanization-induced intensifies in peak flow magnitudes may result in very different variations to flood frequencies in different regions, influencing on the frequency and magnitude of high-flow events. Others modifications are usually reported, as increasing in channel cross-section, diminution in fish and benthic macroinvertebrates, being that more urbanized streams showed more damaged biological assemblages (Booth et al., 2015). On the other hand, the unplanned expansion of the agricultural also degrades the river, being the degradation of riparian vegetation results one of the major concerns, besides of contributing to the formation of extensive open areas, featured by grassy and herbaceous vegetation. A qualitative and quantitative change in the riparian forest affects the litter input to streams and thus modifies the structure of the whole biotic community (Afonso et al. 2000, Barrella and Smith 2000).

Waterways degradation due to human activities on many occasions requires interventions. In general, the interventions are necessary in order to reach simultaneously three goals: 1 – stop the degradation process, 2 – accelerate the restoration process, and 3 – drive the restoration process (assisted restoration), aiming to reestablish the ecological interactions that are vital to maintaining the ecosystem integrity of a watershed (Palmer et al. 2014). Restoring and/or revitalizing rivers or stretches of rivers and streams is a difficult task (Palmer et al. 2014, Walsch et al. 2016). A successful restoration project will depend on an adequate evaluation of the site to be restored (Cooke et al. 2016).

Progress towards more sustainable manners of water management is hampered by a lack of quantitative, transparent tools to simplify critical decision making (Poff et al. 2015). Establishing criteria to recover the ecological properties of water resources would be helpful to decision makers, especially in cases where little data and financial budgets limit the development of appropriate management plans, and consequently, result in the degradation of many rivers (Le et al. 2014).

Projects of river restoration are conducted normally through ad hoc methods (Bernhardt et al. 2005). Especially in the last twenty years, some devices and/or protocols have been created to facilitate the task of identifying the elements considered essential, ranking them, and also guiding decision-makers, technicians, and researchers to execute more efficiently the restoration project (Arthington 2015, Paillex et al. 2017). However, some methods are very complex and require a comprehensive database, or are limited to a specific type of ecosystem (only rural, or only urban, for example).

A comprehensive protocol that establishes a hierarchical approach to examining the degradation processes in the waterway and their banks, taking into account the causes, intensity, and historic conditions, is still missing. Such a tool could be valuable for decision making by government institutions (such as environmental agencies) and for other academic and public organizations, such as river-related technicians and for recreational purposes (Lange et al. 2015).

Here the facts are being considered: (1) waterway ecosystems are governed by hierarchical spatial arrangements that include catchments, floodplains, reaches, aquatic ecosystem's, and others (Beechie et al. 2010, Paillex et al. 2017), (2) the dynamics of aquatic ecosystems are governed not only by internal structural or functional elements of a water body, but also by an array of external elements that constitute the riverine landscape (Ward et al. 2002, Booth et al., 2015), and (3) there is no device like these and, on the other hand, such two devices described do not contemplate aquatic systems, because they were both elaborated to be used in projects of forest restoration.

Thus, in this project, a technological device was elaborated to be used in field works to assist the diagnostic of degraded water bodies and provide alternatives for restoring the stretch of the river according to the situation of degradation of the local. Complementarily, results of ten study cases developed to test and calibrate the key are also presented.

## Materials and Methods

The waterway environmental assessment protocol was divided into three segments: a first segment composed of a technical glossary terminology associated with river restoration, a second segment composed of a key to guide the assessment of waterway environments for the identification of restoration actions, and a third and final segment structured of a set of case studies and intervention actions identified through the key.

**The Glossary**

To avoid misunderstandings during the application of the waterway assessment key, a brief glossary was elaborated. While the glossary is not a comprehensive dictionary of terms, it does provide clarify during the interpretation of ambiguous concepts during assessments. Definitions were provided for forty one waterways concepts. The meaning of each technical term was obtained from laws, decrees, environmental agencies, academic papers and scientific organizations.

**Criteria for the elaboration of the key**

The waterways assessment protocol key was developed following the plant or animal taxonomy framework by the Swedish naturalist Carolus Linnaeus in the 18$^{th}$ century. The strategy for structuring the key considered, at most times, that the first characteristic has two mutually exclusive possibilities. The following steps considered might be another diagnostic item of or a potential restoration action. In some cases, the key could offer three options, which are also mutually exclusive. It was considered the broader features of the water resource setting, in a manner equivalent to the kingdom level in a traditional biological taxonomy key. According to the response provided by the user, the key takes you to the following classification step, which is more specific than the previous, and so on.

An important aspect to point out is that the key was elaborated to be applied to superficial and continental water resources. Given the variety of influencing factors and their levels of intensity at different points within the waterway, several analyses within a river channel were conducted. This was made by dividing the channel into stretches of 50 meters. Moreover, the application of the waterway assessment key predominantly required visual observations that were conducted in order to avoid the use of complex and sometimes expensive equipment or sampling collection efforts for posterior analyses.

**The intervention actions**

The intervention actions proposed were meant to improve the river's ecological condition, leading the ecosystem to a condition more self-sustaining and resilient (Palmer et al. 2014, Paillex et al. 2017). Such actions were elaborated taking into account that desirable ecological standards river environments should provide the seven major ecosystem services: (i) supply nutrients for plants, (ii) supply foods for local animals species, (iii) improve the physical and chemical quality of water, (iv) regulate local climate, (v) provide suitable local recreation, (vi) waste processing, and (vii) provide local landscape harmony and aesthetics (Esteves 2011).

Reaching the mentioned ecosystem services in a simultaneous and satisfactorily manner may be difficult in some cases (for instance in urban rivers). On the other hand, it is understood that such services are possible when the ecosystems components interact in a balance and integrated manner. Thus the key was developed in order to permit the user developing clear, achievable, and measurable goals for the intervention. The proposals were formulated in order to assist the user to use local species (when biological interventions are suggested) in order to favor the conservation or restoration of the local biodiversity.

**Using the key – study cases**

In order to calibrate the key and present the potential outputs of implementation activities, ten evaluations in eight sites were conducted. Such sites were previously chosen in order to have distinct environmental conditions (characteristics of the relief, land use, land cover, level of degradation).

For each one of the locations used as a case study, the location was reported, as well as the assessment following the key, and the recommendation of actions also following the criteria of the key. Along with the key, ground photos of the site were suggested as a way to enhance the registers and development of the restoration project, such as to register the level of degradation, progress, hydrologic situation (flood or drought), and other features of interest (Palmer et al. 2014). Hence, ground photos were taken in each study site and the user is oriented to take digital, georreferenced ground photos in field works.

## Results

### The technical concepts

The Glossary was composed of forty one terms alphabetically arranged (see Appendix I), some of them were water quality related, while others were associated with land cover, or related to restoration actions. Furthermore, it was noted that while some terms are common and easily defined in various sources, other terms or concepts, are made up of two, three or more words, being composite terms. Such composite terms tend to be more specific and scant in the popular literature. In addition, the explanation of some terms was also graphically illustrated.

### The key

The key could be presented as a flowchart or text (Silva 2015). Here, it is presented as a text (see Appendix II). It was observed that use of the key is more appropriated for stretches up 50 meters long, since that for larger areas the hydrologic, geomorphologic and ecological features of the stream or river might change considerably. Therefore the necessary restoration activities will probably not be the same.

For restoration actions of waterways longer than 50 meters, which is a very common situation in many projects (Morandi et al. 2014, Cookie et al. 2016), it was noted that dividing the perimeter into stretches of up 50 meters long could achieve the results more accurately. Given that the evaluation of the waterway through the key is visual, if the stretch is sinuous, it was perceived that the analysis might be especially difficult for stretches longer than 50 meters. For lentic ecosystems (lakes, dams, reservoirs or similar), the same approach is recommended.

In lotic ecosystems, when the stretch to be analyzed is located in the middle or lower regions of the watershed, and there is siltation problem, we suggested considering a complementary analysis of the environmental features at the upper portion of the watershed that may be causing the problems. For example, features such as total catchment area, relief, the number of headwaters and location of each one, and land cover, may be having degradation problems on their own. It is common for projects that aim to restore rivers to fail since the environmental features at the upper region of the watershed were not assessed (Palmer et al. 2014).

It was also suggested the use of the key preferably on headwater streams (First through third order streams considering Strahler's system of classification). The hierarchical ranking can be measured by using a map that depicts the river network (scale 1:50,000 or more detailed) and considering the Strahler's system of classification for ranking streams (Britney 2015). We though that if interventionist actions were effectively and correctly implemented in the headwater streams, the waterways of higher ranking (4$^{th}$ or superior), consequently will be benefited in ecological terms.

**The interventionist actions**

The fourteen applicable actions (henceforward AC) are presented in Part II of Appendix I. They were coded as AC1, AC2 and so on. The set is constituted by actions elaborated to be implemented at local scale. From the total, seven options of actions were selected to solve in-site degradation problems (AC4, AC6, AC10 through AC14). Five options (AC2, AC5, AC7, AC8, and AC9) were chosen to solve off-site problems, and two actions (AC1 and AC3) might be applied to solve both in- and off-site problems.

It was mentioned the ACs on 43 occasions along the key. The most common action was AC3, which was mentioned on ten occasions (Fig. 1). Although the AC3 is not exactly an interventionist action, the monitoring is one of the most common environmental policies devoted to restore water streams and maintain the quality (Wohl et al. 2015). This is because a catchment and its respective river network is a continuous and dynamic system, both in natural (climatic, ecological) and human (land cover, land use, and water resources use) terms, both monitoring and punctual adjustments constitute a set of essential activities.

In lotic systems, the AC2 (Increment of the native forest vegetation by means of planting of seeds or saplings, or use of nucleation technique) occurred the same number occasions as AC3. In fact, even being an off-site action, the re-establishment of riparian vegetation is one of the most common restoration activities requested regardless of the region of the world (Moore and Richardson 2003). The riparian vegetation influences the health and equilibrium of waterways, because of its regulating effect on the river attributes such as: physical (temperature, light filtration), chemical (filtration of nutrients and pollutants, providing detritus), hydro-geomorphologic (regulation of floods, minimize riverbank erosion, reduces its sediment carrying capacity) (Moore and Richardson 2003). Moreover, the diversity of aquatic ecosystem in low hierarchical order rivers (or headwater waterways) depends critically on coarse woody debris which plays a major role in waterway geomorphology and gives a major supply of fish cover (Cowx and Welcomme 1998). This stresses the importance of the riparian vegetation, especially for small-sized streams.

The AC4 (dredging of silted sediment) was cited twice. It is a technique mostly used to meet economic and/or social demands (Esteves 2011). However, it is costly, and usually, its application generates some adverse disturbances, including large volumes of detritus (Barbosa and Almeida 2001), with a large part of the total cost related to management and disposal of the material (sediment) removed from the waterway (Mohan et al. 2016). This technique has potential to be more suitable for large rivers and/or shoreline regions. Alternatively, especially for small creeks and streams, the use of some techniques of bioengineering, as the creation of wetland systems in appropriate places, might return more interesting results. This means more of an ecological, adaptive use than a physical manipulation for altering the ecosystem (Palmer et al. 2014).

It was not considered actions that involve the reintroduction of wild animals in the CAs since that during the development of the restoration activities, the habitat (terrestrial or aquatic) is being modified and so, it may not be favored by wildlife. For riparian terrestrial species, once the natural adjacent vegetation is reestablished, the native wildlife tends to reappear. Hence, it was recommended using nucleation techniques (Corbin and Holl 2012) rather than re-introducing specimens of animals.

**The study cases**

Through the field visits and following the criteria established for the key, we surveyed information regarding the waterways sites and their immediate surroundings. The case study tables contain the following information: description of the environment, the aim of the interventions, using the key, main actions recommended, and photographic documentation.

Exemplifying, for the study cases 1A and 1B two stretches of 50 meters length each were chosen (see Table 1 and Appendix III). Is was observed local waterways with slow flowing and with degraded or missing riparian vegetation. By applying the key to these sites, two of them resulted in step 5b (cases 7 and 8), while other two (cases 1b and 3) in the step 15a.

In general, twenty three ACs of eight different categories were cited across the ten study cases. The predominant action recommended was AC5 (Artificial Protection of Margins). However, a complete re-vegetation effort is sometimes difficult due to the use of the floodplain region. Thus, the AC2 (Increment of the native forest vegetation by means of planting of seeds or saplings, or use of nucleation technique) is an activity ranked in second as the most suggested.

## Discussion

The costs of implementation for each CA can differ greatly given the complexity of the action and according to the intensity of the problem. For instance, removing of solid waste might be inexpensive or very costly, it will depend on many other things, access, technology to be used, the cost of labor. There are multiple socioeconomic, environmental, and logistical factors that affect the cost of restoration interventions (Paillex et al. 2017).

In many cases, there are reasons to restore a waterway as quickly as possible, but there are other situations where immediate action is not required, allowing for passive restoration elements to be implemented. Hence, understanding the level of urgency for implementing restoration action, it is important to keep in mind when engaging in activities.

Some CAs can be implemented by governmental institutions in projects and others might be implemented jointly with the local population. For some CAs achievements can be obtained almost immediately, while for other the outcomes might take a long time to be evidence. It is expected that several crucial problems are solved in order to provide ecological conditions of a self-reestablishment of the local ecological conditions (NRC 1992).

The use of the key in large rivers should be careful or even avoided. Projects aiming to restore rivers of small or medium size are common across the world. However, restoring large water bodies is a very difficult task, since large water bodies have large catchment areas (river basin) and restoration projects of large river might be overruled if headwater rivers are not restored and/or if the upstream land cover is mismanaged in order to improve the runoff's quality (Lorenz and Feld 2013, Angrill et al. 2017).

Specifically for interventionist action AC3: "Environmental monitoring and occasional, punctual adaptation", we suggest the adoption of this technique when the place to be restored (or after some early intervention) is a degraded system that appears to have the capacity to continue its trajectory unaided, being similar to principle "do nothing", meaning no intervention (Cookie et al. 2016). However, monitoring activities are always necessary for analyses and, when necessary, add punctual adaptations.

Hence, evaluating the effects of river restoration projects is important for adaptive management, evaluating project efficiency, for optimizing future programs, and for gaining public reliability and acceptance (Woolsey et al. 2007, Poff et al. 2015). After implementation, some kind of project evaluation is crucial in order to produce a critical analysis of the activity and for future planning and replication (Bernhardt et al. 2005). The key here presented does not provide a method to evaluate the suggested restoration actions to be implemented. One way to address this is to take systematic photos during pre-established periods throughout the assessment and implementation phases (for example, quarterly or half yearly) from the restoration site using a fixed photopoint (McDonald et al. 2016).

Photographic records can help observe the impact of the restoration activity overtime. For larger sites, aerial photography might also provide favorable before and after imagery (McDonald et al. 2016). For example, the re-establishment of natural vegetation might be easily assessed by means of systematic and chronological photos, as well as by the presence of solid wastes on waterways and/or in the riparian zone. In a complementary manner and depending on the site, interviews and questionnaires can provide evidence of a project's success by the level of satisfaction of people, or through documenting the number of visitors to a location for recreational or commercial purposes (Woolsey et al. 2007). Another evaluation approach could be to carry out the same monitoring method in a pristine area in order to compare the performance of the place in terms of its recovery. Monitoring methods could also involve the collection of samples for chemical analysis to quantify changes using a particular biophysical indicator(s).

Although it may be obvious, it is important to reinstate to consider indigenous species in environmental restoration projects. It may not be possible in all cases due to the need for species with particular attributes (i.e. bioremediation, increase water evapotranspiration, etc.), but the implementation of natives tend to increase the probability of success of a project (Poff et al. 2015). Native species (microorganisms, plants, and animals), are genetically conditioned to withstand local climatic extreme events (sunlight exposure, temperature variations, drought periods, flooding events, resistance against local pests, etc.), and be part of the local ecological food web. Furthermore, when promoting natural habitat for indigenous species the user is meeting an important goal in environmental restoration, that is, re-establishing the local terrestrial and aquatic biodiversity, and usually accomplishing local environmental legislation. Healthy riparian areas that are characterized by having native vegetation are critical to healthy aquatic community dynamics (Schiemer et al. 2013).

**Conclusions**

Waterways degradation due to human or natural drivers have to lead to an increased demand for interventionist efforts aiming river restoration and diagnosis works are conducted in a poorly systematized way. Through this paper, a protocol is here presented. It was developed as a key in order to support the systematized assessment of the river-related environmental problems.

The key was initially thought considering scientifically-based concepts to be easily applied and it was elaborated considering a hierarchical order of environmental characteristics, starting from the generic characteristics and going to more specific features. After the diagnostic, the user is oriented to use some interventionists actions that will help the local ecosystem improve the ecological features and achieve a status of resilience.

In the ten study cases conducted to test the key and to illustrate the use, it was concluded that the employment of the key helped us quickly evaluate the locals, and decide about the interventionist actions. Some of the investigated places presented similar levels and modalities of degradation. As consequence, the key indicated similar actions for such locals.

After the tests showed here as study cases, it was demonstrated that this tool has good potential to be successfully used worldwide. It can be transformed into an App or software and broadly disseminated towards the improvement of the environmental quality.

**ACKNOWLEDGMENTS -** We thank CAPES (Federal Brazilian Agency for Betterment of Human Resources of Higher Education) for providing a scholarship for the first author (grant number not provided).

## REFERENCES


Afonso AAO, Henry R, Rodella, RCSM (2000) Allochthonous matter input in two different stretches of a headstream (Itatinga, São Paulo, Brazil). Braz Arch Biol Tech 43: 335-343

Angrill S, Petit-Boix A, Morales-Pinzón T, Josa A, Rieradevall J, Gabarrell X (2017) Urban rainwater runoff quantity and quality – A potential endogenous resource in cities?. J Environ Manag 189: 14-21

Arthington AH (2015) Environmental flows: a scientific resource and policy framework for river conservation and restoration. Aquatic Conserv 25: 155-161

Bakker K (2012) Water security: research challenges and opportunities. Science 337: 914-915

Barbosa MC, de Almeida MDSS (2001) Dredging and disposal of fine sediments in the state of Rio de Janeiro, Brazil. J Hazard Mater 85: 15-38

Barrella, W. Smith WS (2000) The ichthyofauna of the marginal lagoons of the Sorocaba River, SP, Brazil: composition, abundance, and effect of the anthropogenic actions. Rev Bras de Biol 60: 627-632

Beechie TJ, Sear DA, Olden JD, Pess GR, Buffington JM, Moir H, Roni P, Pollock MM (2010) Process-based principles for restoring river ecosystems. BioScience 60: 209-222

Bernhardt ES, Palmer M, Allan JD, Alexander G, Barnas K, Brooks S, Carr J, Clayton S, Dahm C, Follstad-Shah J, Galat D (2005) Synthesizing U.S. river restoration efforts. Science 308: 636-637

Booth DB, Roy AH, Smith B, Capps KA (2016) Global perspectives on the urban stream syndrome. Freshw Sci 35: 412-420.

Britney A (2015) Stream Order - A Classification of the Rank of Streams and Rivers, http://geography.about.com/od/physicalgeography/a/streamorder.htm (accessed November 2015)

Corbin JD, Holl KD (2012) Applied nucleation as a forest restoration strategy. Forest Ecol Manag 265: 37-46

Cooke GD, Welch EB, Peterson S, Nichols AS (2016) Restoration and management of lakes and reservoirs, 3rd Edition. CRC Press

Cowx IG, Welcomme RL (1998) Rehabilitation of rivers for fish. Food & Agriculture Org. FAO Books, Victoria, Australia

Esteves FA (2011) Fundamentos de Limnologia. 3rd Edition. Interciência, RJ, Brazil

Haan CT, Barfield BJ, Hayes JC (1994) Design hydrology and sedimentology for small catchments. Academic Press, USA

James AB (2013) A review of the ecological effects of macrophyte management in soft-bottomed waterways. Waikato Regional Council Technical Report 2013/03. EOS Ecology, Christchurch, New Zealand

Jelte A, Aronson J (2006) Restoration Ecology: the new frontier. Blackwell Publishing

Kauffman JB, Beschta RL, Otting N, Lytjen D (1997) An ecological perspective of riparian and stream restoration in the western United States. Fisheries 22: 12-24

Lange C, Schneider M, Mutz M, Haustein M, Halle M, Seidel M, ... and Hinkelmann R (2015) Model-based design for restoration of a small urban river. J Hydro-Environ Res 9:226-236

Le AH, Tokai A, Nakakubo T (2014) Applying value of information methods to prioritize elements for water quality management with an example of linear alkylbenzene sulfonate in the Yodo River, Japan. Environ Syst Dec 34: 110-123

Lorenz, A. W., Feld, C. K. (2013). Upstream river morphology and riparian land use overrule local restoration effects on ecological status assessment. Hydrobiologia 704, 489-501

McDonald T, Jonson J, Dixon KW (2016) National standards for the practice of ecological restoration in Australia. Restor Ecol 24: S4-S32

Mohan R, Doody JP, Patmont C, Gardner R, Shellenberger A (2016) Review of environmental dredging in North America: current practice and lessons learned. J Dredging 15: 29-50

Moore RD, Richardson JS (2003) Progress towards understanding the structure, function, and ecological significance of small stream channels and their riparian zones. Can J For Res 33: 1349-1351

Morandi B, Piégay H, Lamouroux N, Vaudor L (2014) How is success or failure in river restoration projects evaluated? Feedback from French restoration projects. J Environ Manag 137:178-188

NRC - (National Research Council (1992) Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy. Washington, DC: National Academy Press

Paillex A, Schuwirth N, Lorenz AW, Januschke K, Peter A, Reichert P (2017) Integrating and extending ecological river assessment: Concept and test with two restoration projects. Ecol Indic 72: 131-141

Palmer MA, Hondula KL, Koch BJ (2014) Ecological restoration of streams and rivers: shifting strategies and shifting goals. Annu Rev Ecol Evol S 45: 247-269

Perrow MR, Davy AJ (Eds.) (2002) Handbook of Ecological Restoration. 2nd version. Cambridge: Cambridge University Press

Poff N. et al. (2016) Sustainable water management under future uncertainty with eco-engineering decision scaling. Nat Clim Change 6.1: 25

Roni P, Beechie TJ, Bilby RE, Leonetti FE, Pollock MM, Pess GR (2002) A review of stream restoration techniques and a hierarchical strategy for prioritizing restoration in Pacific Northwest watersheds. N Am J Fish Manage 22: 1-20

Schiemer F, Zalewski M, Thorpe J.E. (eds.) (2013) The importance of aquatic-terrestrial ecotones for freshwater fish (V. 105). Springer Science & Business Media

Silva RA (2015) Criação e desenvolvimento de uma chave para apoio no diagnóstico e na tomada de decisão de ações de restauração ecológica de cursos d´água e adjacências. Master Science Dissertation. Sao Paulo State University, http://www2.feb.unesp.br/pos/bibliotecavirtual/documento.php?COD=2421fcb1263b9530df88f7f002e78ea5 (accessed September 2016)

Summerfield MA (2014) Global Geomorphology. Routledge, USA

Walsh CJ, et al. (2016) Principles for urban storm water management to protect stream ecosystems. Freshw Sci 35: 398-411

Ward JV, Tockner K, Arscott DB, Claret C (2002) Riverine landscape diversity. Freshwater Biol 47: 517 539

Wohl E, Lane SN, Wilcox AC (2015) The science and practice of river restoration. Water Resour Res 51: 5974-5997

Woolsey S, Capelli F, Gonser TOM, Hoehn E, Hostmann M, Junker B, Paetzold A, Roulier C, Schweizer S, Tiegs SD, Tockner K (2007) A strategy to assess river restoration success. Freshwater Biol 52: 752-769

# CAPTIONS

**Table 1** Location of the sites considered in the study cases

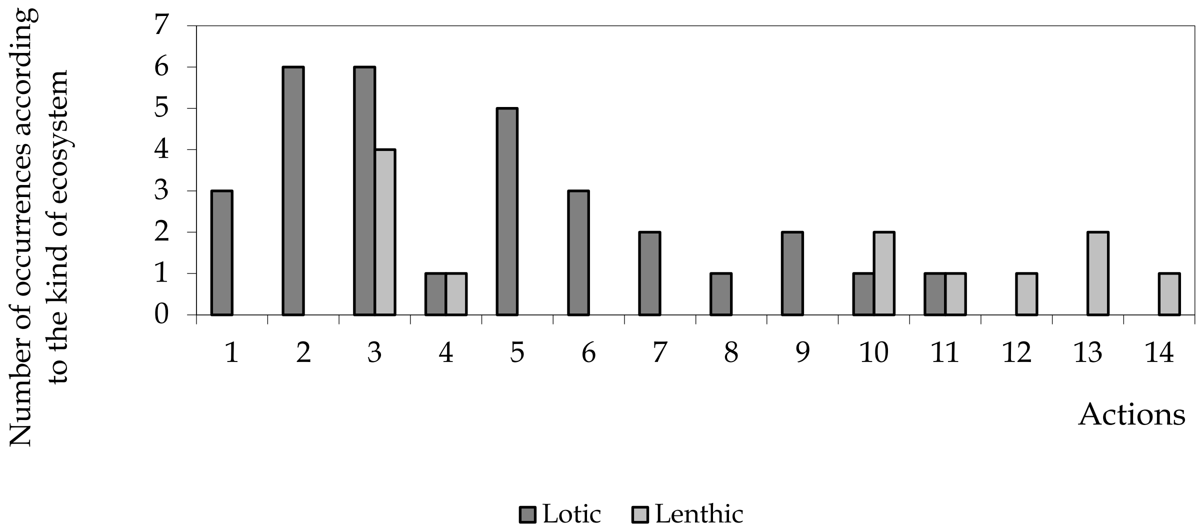
**Fig. 1** Amount of each category of action. For the meaning of each category of action according to the number, see part III of Appendix I

Table

**Table 1** Location of the sites considered in the study cases

| Code of the case study | Geographic coordinates | General features of the place(s) |
|---|---|---|
| 1A | 21°48′36″S 48°10′38″W | It is a bridge that crosses the river located in Araraquara Municipality, Sao Paulo State. The catchment area is 84km² and embraces approximately 45% of the whole area of the Municipality. The main river is 19.9 km length. |
| 1B | | |
| 2 | 22°20′02″S 49°05′25″W | This stream is localized in the Bauru Municipality, the central region of the São Paulo State (Brazil). The land use of the catchment area of this river is constituted mainly by human settlement poorly established in risky areas (subjected to flood). |
| 3 | 22°18′41″S 49°04′02″W | This is the main superficial water curse of the Bauru municipality, highly polluted due to the dumping of untreated sewage (85% residential and 15% industrial). |
| 4A | 23°32′58″S 47°26′43″W | Chave's Waterfall – sited in the urbanized region of the Municipality of Votorantim, Sao Paulo State. |
| 4B | | |
| 5 | 21°35′23″S 48°43′54″W | It is a bridge that crosses the Municipal Freeway of the Itapolis Municipality, São Paulo State. |
| 6 | 23°48′84″S 47°43′64″W | Located in Sorocaba and is approximately 2,550 meters long. |
| 7 | 23°33'47''S 47°29'32″W | Ipanema Stream – located on a highway and within the limits of Sorocaba and another municipality (Votorantim). |
| 8 | 23°53'53''S 47°30'22''W | Lake sited in a small, rural, private property in Tapiraí, SP. Several kinds of land use occur in the property. |

Figure



Number of occurrences according to the kind of ecosystem
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Actions
Lotic
Lenthic