



Environmental degradation and opportunities for riparian rehabilitation in a highly urbanized watershed: the Matanza-Riachuelo in Buenos Aires, Argentina

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Received: 25 March 2018 / Accepted: 17 January 2019 / Published online: 12 February 2019
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Abstract The growth of human societies worldwide has been associated with the degradation of natural resources; in particular, freshwater ecosystems are among the most seriously threatened. Riparian restoration has received much attention due to the importance of ecological functions and ecosystem services sustained by watercourses. The objective of this paper was to assess the environmental quality of riversides in a highly urbanized watershed in the Buenos Aires metropolitan area (Argentina) in order to identify

rehabilitation opportunities. We conducted a stratified random sampling of 82 sites where we recorded 33 variables regarding geomorphologic traits, vegetation attributes and anthropogenic impacts. Pristine riparian habitats are almost completely extirpated throughout the watershed and most of the streams sampled showed signs of degradation related to multiple threats. We detected a degradation pattern that follows the urban–rural gradient occurring in the watershed which enabled the definition of four types of riversides. In order to identify potential river rehabilitation alternatives in accordance with each degradation driver detected, we performed a systematic review of the literature. We identified the fluvial rehabilitation techniques implemented and we grouped them into four types of measures: passive restoration, active abiotic techniques, active biotic techniques and active social techniques. We also recognized the reported

This research was funded by the National Agency for Science and Technology of Argentina (PICT-2009-0125 and PME funds granted to GZ and PFDT doctoral scholarship granted to BGJ at the National University of Lomas de Zamora).

Electronic supplementary material The online version of this article (<https://doi.org/10.1007/s11273-019-09656-5>) contains supplementary material, which is available to authorized users.

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social, ecological, economic and/or political constraints which were encountered in those experiences. All possible dimensions of the potential constraints should be recognized during the planning stage of rehabilitation and then properly addressed before and during the implementation of measures in order to make the interventions successful.

Keywords Environmental management planning · Exotic species invasions · Land use impacts · Rehabilitation needs · Urban–rural gradient

Introduction

The growth of human societies worldwide has frequently been associated with the degradation of different types of ecosystems due to intensive exploitation and unsustainable development. In particular, freshwater ecosystems are among the most seriously threatened since humans usually settle near watercourses and, therefore, riparian zones become extensively modified for different reasons (Sala et al. 2000). Direct anthropogenic impacts include channel modification, manipulation for transportation or energy generation, river diversions, water extraction or dam construction; whereas other activities, such as livestock grazing, timber harvesting, mining or road construction, generate indirect impacts (Kauffman et al. 1997; Groffman et al. 2003; Walsh et al. 2005; Gregory 2006). Indeed, the management of watercourses and riverbanks, as well as wetlands in general, has been traditionally oriented towards increasing the social well-being or material wealth of societies (Kauffman et al. 1997), regardless of the geomorphologic, hydrologic and/or ecological processes that sustain these environments. Consequently, a long history of use and degradation has been imposed on this type of ecosystems (Nienhuis and Leuven 2001).

Specific impacts found on streams and their banks are usually related to the type of land use occurring on adjacent floodplains. Urban land use tends to have disproportionately large effects on streams, both nearby and over distance, even though it commonly represents a low proportion of the total watershed area (Allan 2004). Major changes associated with urbanization include the engineering of stream channels, replacing natural features with concrete structures;

stream bank stabilization efforts, designed to resist increased flood flows; and extensive piped storm drainage networks, which often completely bypass riparian zones, channeling large amounts of water from impervious surfaces directly into streams (Groffman et al. 2003; Allan 2004). These transformations usually result in various types of impacts, such as, changes in hydrology owing to an increase in the impervious surface area, which in turn reduces rainwater infiltration and increases storm water runoff (Jacobson 2011); stream incision combined with reduced infiltration, which can lower riparian groundwater levels and have dramatic effects on soil, plants and microbial processes (Groffman et al. 2003); an increased amount and variety of pollutants in the runoff (Sliva and Williams 2001); a reduction in channel and habitat complexity due to sediment inputs, bank destabilization and channelization, as well as disconnection between the river and its floodplain (Allan 2004; Walsh et al. 2005). Moreover, urban and suburban land uses impact on the riparian seed banks, altering species composition, diversity and density (Moffatt and McLachlan 2003).

Urbanized watersheds also encompass rural surroundings from where key resources for the city are taken. In this environment, agricultural land use has been associated with declines in freshwater biological assemblages as well as water and habitat quality. This type of land use degrades streams by increasing non-point inputs of sediments, nutrients and pollutants, such as herbicides or pesticides (McKergow et al. 2003), altering flows and bank stability (Allan 2004), and affecting the composition of riparian vegetation due to the invasion of exotic species (Meek et al. 2010). In particular, uncontrolled or unmanaged livestock grazing in riparian ecosystems also affects stream channel morphology causing streambeds to become wider and shallower, as well as the soil structure of the riverbank (Kauffman and Krueger 1984), the shape and quality of the water column by increasing water temperature, nutrient concentration, suspended sediments and bacterial counts (Vidon et al. 2008), and the composition of riparian vegetation communities due to overgrazing (Kauffman and Krueger 1984).

The restoration of riparian environments has received much attention due to the importance of ecological functions and ecosystem services sustained by watercourses, especially in the last 20 years

(Palmer et al. 2007; Roni et al. 2008). However, restoration feasibility could be questioned in riparian areas subjected to great environmental degradation (Harris 1999), such as urban–rural gradients. In these cases, the rehabilitation of riversides is a more appropriate final goal. Rehabilitation is defined as the action of returning a site to a previous condition or status, with little or no implication of perfection (Bradshaw 1996). The selection of specific rehabilitation techniques must be guided by the impacts that occur, as well as the degradation drivers identified, which are usually of a multiple and interactive nature in urbanized watersheds. In fact, degradation gradients have been detected along urban–rural gradients influencing, for instance, the composition of riparian vegetation (Moffatt and McLachlan 2004), macroinvertebrate communities (Tavzes et al. 2006) or benthic communities (Hepp and Santos 2009). Therefore, rehabilitation techniques must be selected by recognizing and following these gradients. Finally, one key aspect to consider is the existing constraints: whereas ecological constraints define what is possible and economic constraints determine what is realistic, the social constraints determine whether a project or a technique is acceptable (Miller and Hobbs 2007). Political constraints are a fourth type of limitation that should be considered in order to fully assess the potentiality of a measure in a particular context. All these constraints should be taken into consideration in order to achieve success in any rehabilitation project.

The objective of this paper was to assess the environmental quality of riversides in a highly urbanized watershed subjected to multiple anthropogenic threats in the Buenos Aires metropolitan area (Argentina) in order to identify rehabilitation opportunities. We hypothesized that we will find a degradation gradient imposing different changes on the geomorphology and vegetation structure of riversides, and that this gradient will follow the urban–rural gradient that occurs across the watershed. From the identification of riparian degradation drivers and a review of the literature, we will detect possible rehabilitation techniques and the potential constraints (ecological, economic, social and/or political) which could be expected.

Materials and methods

Study area

The study area is the Matanza-Riachuelo watershed (CMR, acronym in Spanish for *Cuenca Matanza-Riachuelo*), which is located in the NE of Buenos Aires province and lies between latitudes 34°37'9.31" S and 35°7'25.07" S and longitudes 58°21'2.06" W and 59°3'1.21" W (Fig. 1), comprising approximately 200,000 ha. According to official estimates (INDEC 2010), more than 8 million people live in its area of influence. The CMR is an emblematic case study since it is the most polluted in Argentina and one of the most polluted in the world. The main environmental problems include soil, air and water (surface and groundwater) pollution, anthropogenic alteration of the drainage system, flooding of urbanizations and settlements which occupy the floodplains and low river terraces, open rubbish dumps which constitute a risk to human health, and the loss of biodiversity associated with the transformation and destruction of habitats, as well as the invasion of exotic species (Pereyra 2004; Ratto et al. 2004; Nápoli 2009; Zuleta et al. 2012).

The drainage system in the CMR was extensively and severely modified long ago. Construction of the Buenos Aires port began in 1876 which included the dredging and rectification of the main watercourse, the Riachuelo, which also constitutes the southern border of Buenos Aires City (Brailovsky and Foguelman 2009). There are practically no intact streams in the urban region of the basin and some watercourses have been piped underground (Pereyra 2004). Likewise, many streams located in the rural sector also show evidence of transformation. With respect to the riparian vegetation, the streams in this region are characterized by rich macrophyte communities and the lack of woodland, except for two tree species (*Celtis tala* and *Salix humboldtiana*) that develop isolated in areas with particular soil conditions (Cabrera 1971; Giorgi et al. 2005; Feijoó and Lombardo 2007). However, many riverbanks have been invaded by exotic species during recent decades and they are now occupied by riparian forests. The invasive woody species include *Gleditsia triacanthos* (honey locust) from eastern North America, *Morus alba* (white mulberry) from central and eastern Asia, *Populus* sp. from the North Hemisphere and *Melia*

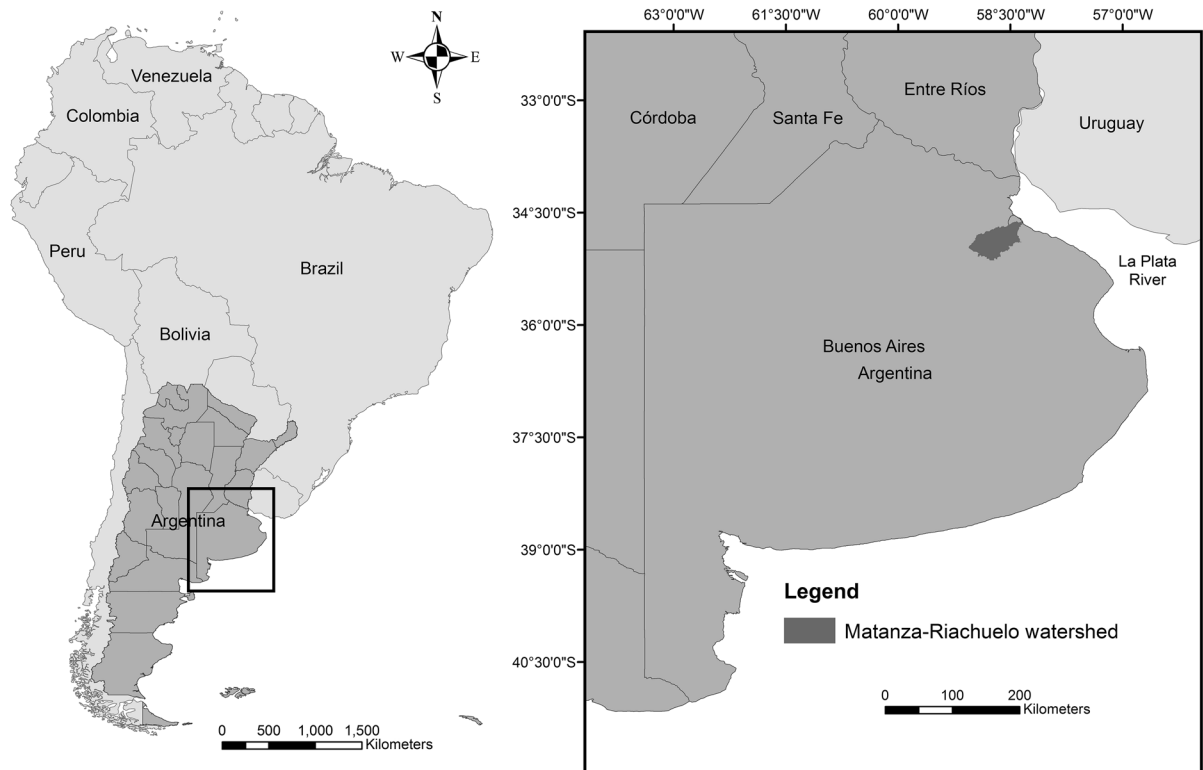


Fig. 1 Location of the Matanza-Riachuelo watershed in Buenos Aires (Argentina)

azedarach (chinaberry tree) from southeastern Asia (Ghersa et al. 2002; Bilenca et al. 2009).

The CMR presents two main types of land use, urban and rural, which are spatially arranged as a gradient (Laffitto et al. 2011). The lower part of the watershed is occupied by one of the megacities of the world (Buenos Aires City), while peri-urban land use prevails in the middle sector (Fig. 2). Rural land use, which includes agriculture and cattle ranching, is mainly located in the upper part of the basin and, to a lesser extent, in the middle sector. In order to encompass the heterogeneity of the conditions associated with this gradient, we defined two general riparian rehabilitation objectives in a previous study: ecological and socio-environmental (Guida-Johnson and Zuleta 2017). The first objective entailed the recovery of ecological processes and functions which could be best pursued in a rural context; whereas the second objective involved the creation of urban green spaces which could improve human welfare and thus it could be sought in urban and peri-urban areas.

Field sampling

We conducted a stratified random sampling in order to evaluate the condition of the riparian areas in the CMR during the summer of 2012. We used two criteria for stratification: the land use on the adjacent floodplain and the position of the stream within the watershed. For the first criteria, a land use/land cover map generated on the basis of visual interpretation of a Landsat 5 TM image acquired in 2010 (Laffitto et al. 2011) was used to determine land use on each floodplain: rural, forest, peri-urban or urban. As already stated, the riparian forest cover corresponds to invasion of exotic species. For the second criteria, the location of watercourses was classified as in the upper, medium or lower sector of the basin. The selection of sites was performed in ArcGIS 10.1, using ten random points for each combination of land use/land cover and position in the watershed. Selected sites were analyzed using Google Earth so as to discard those sites that were either spatially overlapped (threshold distance was defined as 500 m) or inaccessible (this condition was defined as further than

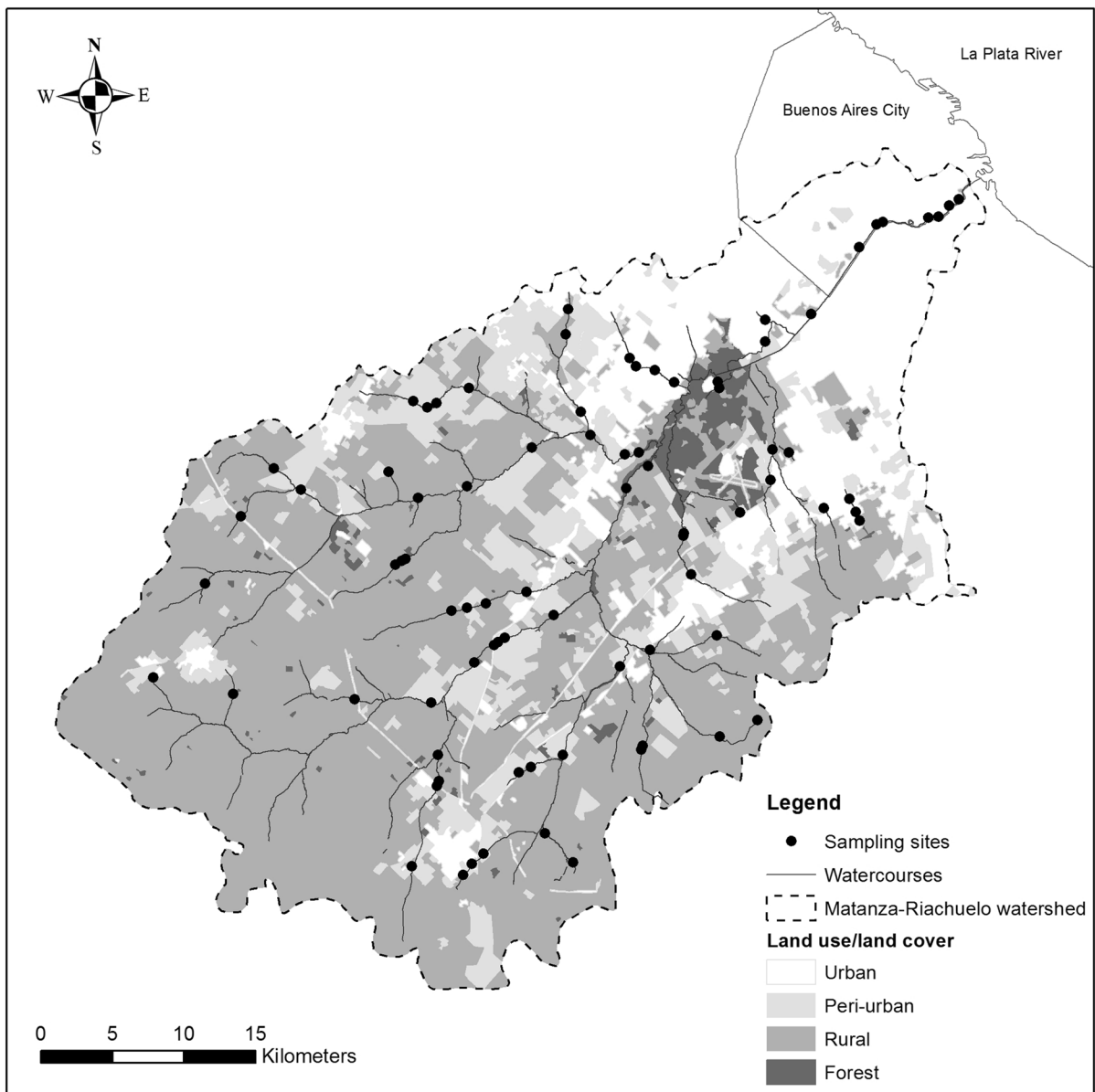


Fig. 2 Location of sampling sites along watercourses in the study area. Adapted from Laffitto et al. (2011)

1 km from roads or within the boundaries of informal settlements due to crime related insecurity). This assessment resulted in 82 sampling sites (Fig. 2).

In order to include variables that would account for the health of riparian sites, we reviewed environmental quality indexes (Turak et al. 2004; González del Tánago and García De Jalón 2006; Stacey et al. 2009) and we selected 33 variables which characterize the riparian areas according to the geomorphologic traits, vegetation attributes and anthropogenic impacts. The

variables were recorded at each site on 100 m long reaches (González del Tánago and García De Jalón 2006; Feijoó and Lombardo 2007) and, whenever possible, the variables were measured on both banks. Measurements were made by visual estimation, either assigning variables to categories or determining values with 5% precision. A single datum was produced for each site for performing statistical analysis: in the case of categorical variables, the worst condition was selected due to the precautionary

principle, whereas an average was calculated for quantitative variables.

In order to assess the geomorphological traits of the riverbank or bed, we estimated visually and recorded: (1) connectivity between the riparian area and the floodplain (as the proportion of the reach free of embankments or mounds; ranges: 0–25%, 26–50%, 51–99%, 100%), (2) riparian width (m), (3) riparian slope (ranges: < 10°, 10–30°, 31–60°, 61–80°, 81–90°), (4) slope stability (values: stable or unstable), (5) proportion of riverbank with point bars (%), (6) soil composition (values: natural, with debris, replaced by concrete blocks or with presence of garbage). Furthermore, (7) the channel width (m) was measured in Google Earth and (8) the sinuosity was determined in ArcGIS. With respect to the riparian vegetation, we estimated the % cover of (9) trees, (10) shrubs, (11) herbs, (12) grasses, (13) aquatic plants rooted to the bank, or (14) floating in the channel, (15) leaf litter and (16) bare soil. Finally, in order to identify anthropogenic impacts, we recorded: (17) local land use occurring on the floodplain (values: urban, peri-urban, rural, forest); factors that may affect bank stability (values: presence or absence), such as (18) vegetation clearance, (19) erosion by runoff, (20) access by livestock or (21) people, (22) presence of bridges or (23) wire fencing; channel modifications (values: presence or absence), including (24) rectification or signs of channelization or dredging, such as (25) straightened banks or (26) presence of lateral embankments, (27) mounds or (28) rigid structures; and other impacts (values: presence or absence) such as (29) roads, (30) storm water discharges or (31) channels. Additionally, we estimated the % cover of garbage (32) present on the riverbanks or (33) in the stream.

Data analysis

The qualitative variables related to anthropogenic impacts were analyzed by a correspondence analysis (CA) in order to assess the association between local land uses (variable 17) and impacts (variables 4, 6, 18–31). We expected that specific impacts found on streams and their banks would be related to the land use occurring in their surroundings, as predicted by other studies. Furthermore, quantitative variables describing geomorphology (variables 1–3, 5, 7–8), vegetation (variables 9–16) and garbage cover (variables 32–33) were analyzed by a principal component

analysis (PCA) to order the riparian sites according to their level of degradation. We expected to be able to define groups of riversides associated with their level of degradation, which could, in turn, be related to different degradation drivers and, therefore, could be associated with specific management options so as to promote the rehabilitation of those sites. Both statistical analyses were performed with InfoStat version 2015.

Identification of techniques and restrictions

In order to identify suitable urban or rural river rehabilitation alternatives in accordance with each degradation driver detected in the CMR riverside areas, we performed a systematic review of the literature published in the last 10 years and available in Scopus. We used the following search term sequence to find all articles published between 2009 and 2018: “(restor* OR rehabilitat*) AND (floodplain OR fluvial OR riparian OR river OR stream) AND (urban OR rural) AND (action OR measure OR plan OR procedure OR technique)”. On the basis of the abstracts, we only selected articles which reported the outcome of implementing any fluvial restoration or rehabilitation technique in either urban or rural environments. After reading the articles, we identified the implemented measure or measures, as well as the reported social, ecological, economic and/or political constraints which were encountered in those experiences. Considering the results obtained from the assessment of environmental quality of the riversides, possible rehabilitation techniques were then matched to major degradation drivers detected in our watershed.

Results

Local impacts associated with land uses

Nearly all the riparian sites sampled (93%) presented at least one factor that could potentially affect its stability. The most frequent destabilizing factor was the access of people, recorded in 52% of sites, followed by the presence of bridges (38%). Two-thirds of the channels (67%) had been modified which, in most cases, was evident due to the presence of straightened banks (44% of that subtotal), rectified

channels (30%) or lateral embankments (24%). Finally, two-thirds of the sampled riversides (63%) showed other types of local impacts as well. The most common was the presence of roads in the proximity of the stream (51% of that subtotal), followed by the presence of channels (12%).

The CA showed different associations between the land uses occurring on adjacent floodplains and anthropogenic impacts (Fig. 3). In this regard, urban land use was related to riparian soils including debris or garbage or that had been replaced by concrete blocks, as well as riverbanks replaced by rigid structures, presence of storm water discharges, roads or bridges, and signs of channelization, rectification or access by people. Rural land use was associated with signs of livestock access, as well as absence of access by people, riversides without any sign of channelization or rectification, natural riparian soil, absence of roads or bridges, but presence of wire fencing. Peri-urban land use was related to the presence of channels and mounds, signs of erosion by runoff or vegetation clearance, and riversides showing evidence of instability. Finally, forest cover was not associated with any of the recorded impacts.

Degradation gradient and types of riversides

The PCA shows the sampled sites ordered according to their level of degradation (Table 1, Fig. 4). The first principal component (PC 1), which accounts for 19.1% of overall variability, is capturing the degradation gradient associated with the urban–rural gradient.

Table 1 Eigenvectors of the PCA performed for quantitative variables surveyed on sites in the Matanza-Riachuelo watershed: variables describing geomorphology, vegetation and cover of garbage

Variables	PC 1	PC 2
Connectivity	− 0.18	0.04
Riparian width	0.33	− 0.15
Riparian slope	0.15	0.29
Point bars	0.02	0.35
Channel width	0.35	0.12
Channel sinuosity	− 0.07	0.26
Trees	0.28	− 0.28
Shrubs	− 0.07	− 0.20
Herbs	− 0.07	− 0.24
Grasses	− 0.25	0.04
Riparian aquatic plants	0.13	0.47
Channel aquatic plants	− 0.39	− 0.10
Leaf litter	0.26	− 0.43
Bare soil	0.23	0.30
Riparian garbage	0.28	0.04
Channel garbage	0.43	− 0.08

Sites located in rural surroundings were positioned to the left of the PC 1, associated with a higher cover of grasses and aquatic plants in the channel and higher degree of connectivity. These sites represented the lowest level of degradation occurring in the CMR. Sites located in urban surroundings, as well as those invaded by exotic woody species, were positioned to the right of PC 1, associated with wider riversides and

Fig. 3 CA performed for qualitative variables surveyed on riparian sites in the Matanza-Riachuelo watershed: local land use, factors affecting bank stability, channel modifications and other anthropogenic impacts

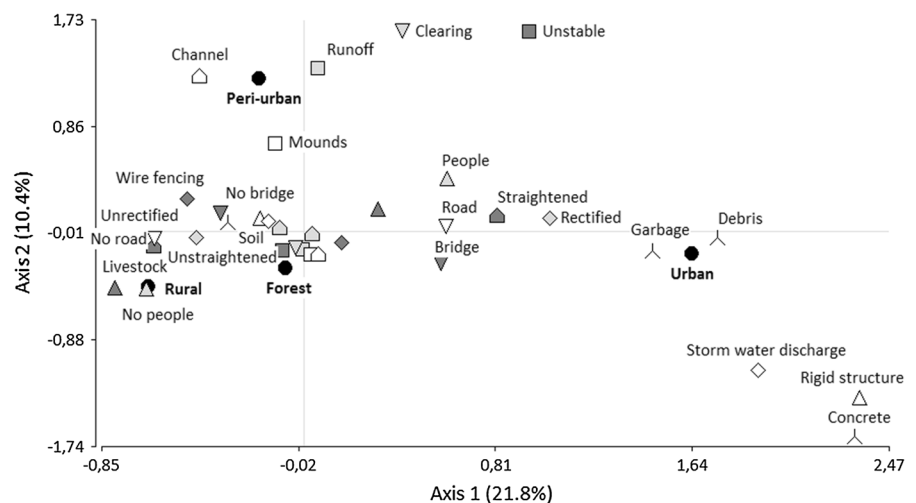
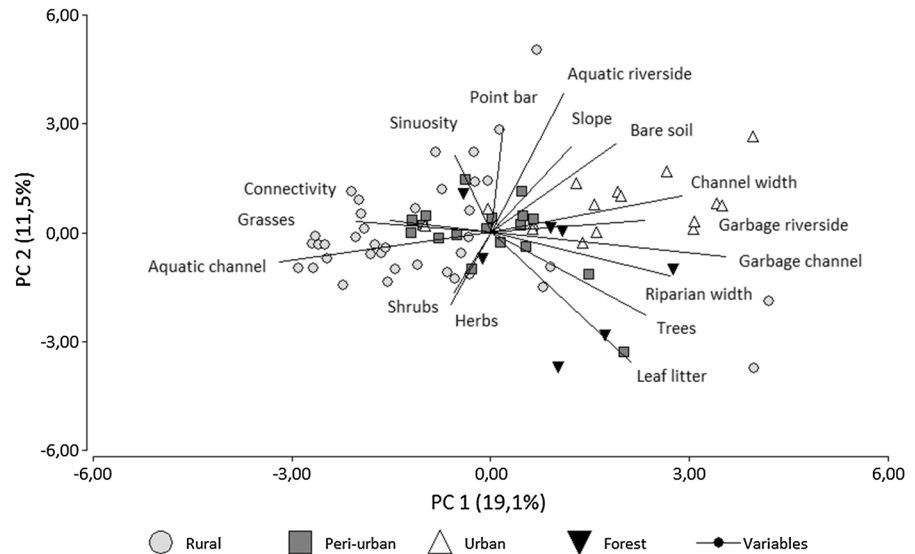


Fig. 4 PCA performed for quantitative variables surveyed on riparian sites in the Matanza-Riachuelo watershed: variables describing geomorphology, vegetation and cover of garbage



channels, higher cover of garbage on the riverside and in the channel and higher cover of trees, leaf litter and bare soil. Finally, peri-urban sites were positioned at the center of the PC 1, constituting intermediate disturbance conditions.

Considering the ordination of sampled sites in the PCA, we defined four groups of riversides: slightly, moderately, severely and extremely degraded (Fig. 5). Associating these results and the results obtained in the CA, we also identified the main degradation drivers for each type of riverside. Slightly degraded riparian sites were located in rural surroundings and associated with a higher cover of grasses and aquatic plants in the channel, higher connectivity, sinuosity and proportion of point bars. Moderately degraded riversides were associated with a higher cover of herbs and shrubs, and they were also located in rural surroundings. In both cases, the main degradation driver was livestock grazing. The major difference between these two types of sites is related to the composition of the riparian vegetation, as exotic weed species were detected in moderately degraded sites, such as *Cirsium vulgare* or *Dipsacus fullonum*. Severely degraded riparian sites were associated with a higher cover of bare soil, wider channels and a higher proportion of garbage on the riverside and in the channel. Most of them were located in urban or peri-urban surroundings and their main degradation driver was urbanization. Finally, extremely degraded sites were related to a higher cover of trees and leaf litter, as

well as wider riversides. This last type of site was invaded by woody species, such as *Acer negundo* or *Gleditsia triacanthos*. They were also found in rural or peri-urban surroundings. In this case, the main degradation driver was the invasion of these species, which was related to the geomorphologic and/or hydrologic conditions of each site rather than to the land use occurring on the adjacent floodplain.

Rehabilitation techniques in the literature

The systematic review of the literature resulted in 358 hits. Most of these were eliminated on the basis of the abstracts as they were in fact base line or modeling studies, or they dealt with restoration planning or prioritization. We also decided to exclude reviews of past projects since some information important for our study, such as specific measures or detected constraints, was missing due to the approach of those articles. A final criterion for elimination was idiomatic limitation, since we decided to exclude another two articles that were written in Chinese and German, respectively. This process led to us finding 52 articles about the implementation of rehabilitation measures in urban or rural rivers worldwide (the complete list of articles is in the Supplementary material). Some articles presented the same case study, resulting in 46 cases of fluvial rehabilitation; whereas some articles assessed more than one stream or reach, resulting in 107 restored streams or reaches. The

Fig. 5 Riversides representative of each degradation condition identified in the Matanza-Riachuelo watershed.
a Slightly degraded: riparian site located in the upper part of the watershed, associated with rural land use and resembling natural characteristics with predominance of grasses;
b moderately degraded: riparian site also located in rural surroundings, showing greater presence of exotic weed species;
c severely degraded: riparian site located in the lower part of the watershed, associated with urban land use;
d extremely degraded: riparian site invaded by woody species located in the middle part of the watershed



majority of the case studies were located in Europe (34.8%), followed by North America (32.6%) and Asia (19.6%); and the vast majority of cases were urban streams (82.0%).

We identified every fluvial rehabilitation technique implemented and we grouped them into the following types of measures: passive restoration, active abiotic techniques, active biotic techniques and active social techniques. Passive restoration was found in only one case in which livestock was excluded from a rural stream. Active abiotic techniques included: water quality improvement; stormwater control; flow recovery or improvement (i.e. dam removal, flood control system, surface water connection or lowering floodplains); removal of artificial constructions (i.e. concrete banks or embankments, bridges or constructions); bank stabilization; waste cleaning; daylighting; natural channel design or meandering; and habitat creation or improvement (i.e. in the stream, bank or floodplain). Biotic techniques referred to either revegetation or removal of exotic vegetation. Social techniques included: waterscape aesthetics improvement, public participation, environmental education, communication, and recreation (i.e. creation of green urban areas). Considering that more than one technique was implemented in some cases, we found 117 measures reported. Most common techniques were abiotic (62.4% of the reported measures), and among them, the most frequently implemented were: habitat creation or improvement (20.5%), natural channel design or meandering (16.4%), water quality improvement (13.7%), stormwater control (12.3%), and bank stabilization (12.3%). Next, we found biotic techniques (21.4% of total reported measures), most of which involved revegetation (88.0%). Finally, social techniques represented 15.4% of the implemented measures; in particular, they were implemented in only nine cases (19.6% of total case studies). Among this type of technique, the most frequently implemented were: recreation (33.3%), waterscape aesthetics improvement (27.8%), and public participation (16.7%). Most studies found significant effects for the implemented rehabilitation measures on at least one of the indicators assessed. However, none of the studies had previously set an explicit indicator value for success.

Regarding the reported limitations encountered during the planning, implementation or monitoring of the rehabilitation measures, more than half (52.2%) of the studies reported different kinds of constraints.

Among them, most were ecological constraints (62.5%) and the majority were associated with the fact that impacts or stressors were still present, natural dynamics could not be reestablished, sites were subjected to high levels of degradation or the assemblies of species had been altered. Social constraints (37.5%) included low acceptance or support, conflicts with other land uses and lack of communication between stakeholders. Economic constraints (16.7%) involved too high costs or citizens' low willingness to pay, whereas political constraints (16.7%) included lack of planning or management and limited technical capability of municipal authorities.

Riparian rehabilitation opportunities in the CMR

In order to identify rehabilitation opportunities in the CMR, we integrated the data found in the field regarding the environmental quality of the riversides and the rehabilitation measures implemented in the assessed study cases, and we determined which technique could be applied to counter each degradation driver (Table 2). We also considered the reported constraints encountered in the study cases found in the literature. Identified degradation drivers were: (1) livestock grazing, which was acting on slightly and moderately degraded riparian sites; (2) urbanization, associated with severely degraded riparian sites; and (3) woody species invasion, which was causing the degradation of extremely degraded sites.

Slightly and moderately degraded sites were associated with the most natural geomorphologic attributes and vegetation structure. As already stated, the difference between them would be the presence of exotic weed species in the latter. Therefore, these riversides are candidates for the implementation of a passive restoration approach and, at least initially, no active abiotic technique would be necessary. Considering the presence of exotic species, this approach could be complemented with both identified biotic techniques. Since the implementation of a buffer zone to exclude livestock would represent a grazing land loss to farmers, in order to anticipate social constraints (Muller et al. 2016) passive restoration must be also accompanied by social measures, such as public participation and communication.

The CA and the PCA showed that riversides located in urban and peri-urban land use were related to a great number of impacts on floodplains and banks.

Table 2 Rehabilitation opportunities identified for each degradation driver recognized in the Matanza-Riachuelo watershed

		Degradation driver		
		Livestock grazing	Urbanization	Woody species invasion
Local land use/land cover		Rural	Urban and peri-urban	Forest, rural and peri-urban
<i>Fluvial rehabilitation measures</i>				
Passive restoration		x		
Active abiotic techniques	Water quality improvement		x	
	Stormwater control		x	
	Flow recovery or improvement		x	
	Removal of artificial structures		x	
	Bank stabilization		x	
	Waste cleaning		x	
	Daylighting		x	
	Natural channel design or meandering		x	
	Habitat creation or improvement		x	
Active biotic techniques	Revegetation	x	x	x
	Removal of exotic vegetation	x	x	x
Active social techniques	Waterscape aesthetics improvement		x	
	Public participation	x	x	x
	Environmental education		x	
	Communication	x	x	x
	Recreation		x	

Therefore, all active abiotic techniques identified are applicable and which one would depend on specific site conditions. Although during the field sampling no culverted stream was located, we know from another study that some watercourses have been piped underground in this watershed (Pereyra 2004). Therefore, the daylighting technique is also appropriate to address this degradation driver. Active biotic techniques could complement the recovery of geomorphological attributes and, in this case, every social measure would be of great importance in order to avoid social conflicts in urban environments (Yamashita et al. 2013; Cockerill and Anderson 2014; Yocom 2014; Hartig and Wallace 2015; Lee and Jung 2016; Zingraff-Hamed et al. 2018).

Finally, extremely degraded sites were not associated with any anthropogenic impact in particular, but rather with the invasion of riparian vegetation by woody species. Therefore, active biotic techniques must be tested in order to assess their capability to reverse this degradation driver. In the case of sites located in rural or peri-urban surroundings, social

techniques such as public participation and communication should accompany rehabilitation efforts in order to avoid social constraints.

Discussion

Pristine riparian habitats are almost completely extirpated in the CMR, one of the most urbanized watersheds in Latin America. In fact, most of the streams sampled showed signs of bank instability, modified channels, as well as other types of anthropogenic impacts. Moreover, the local impacts recorded in the watercourses and on their banks were associated with the land use that occurred on the adjacent floodplains, as has already been reported for other streams in urban and rural areas (Kauffman and Krueger 1984; Sliva and Williams 2001; Groffman et al. 2003; Allan 2004; Walsh et al. 2005; Meek et al. 2010). The high proportion of bridges, roads and signs of access of people found in the urban land use correlates with the high population density of this

watershed, whereas the signs of erosion by runoff associated with vegetation clearance in the peri-urban land is probably related to the mowing of riparian vegetation that is performed regularly by municipal authorities as part of their margin cleaning activities (ACUMAR 2009). The assessment led to the identification of a degradation gradient in the riverside areas in relation to their environmental quality, which correlated with the urban–rural gradient occurring in the CMR. The association of an urban–rural gradient with a degradation gradient has also been reported for other streams (Moffatt and McLachlan 2004; Tavzes et al. 2006; Hepp and Santos 2009). In this case, peri-urban land use represented an intermediate disturbance condition regarding riparian health. The assessment also enabled the definition of four types of riversides according to their level of degradation, which to a certain extent was also related to the local land use. Riparian vegetation structure and geomorphological attributes in slightly degraded sites resembled that of the original ecosystem, whereas geomorphologic attributes in severely or extremely degraded sites correspond to the natural traits of the Riachuelo (i.e. highest order river located in the lower part of the watershed) and of those rivers that are able to sustain exotic forests due to their higher flows, respectively. The megacity of Buenos Aires in the lower sector of the basin is associated with a higher proportion of garbage due to the access of people to the streams and the deficient garbage collection service. Leaf litter is related to tree cover since these invasive species are successful competitors with respect to species in the undergrowth; whereas bare soil is associated with urban sites as in many cases the riparian soils included debris or garbage or had been replaced by concrete blocks.

The variables recorded to assess the environmental quality of riversides were expected to be thorough. However, the first two principal components only explained a limited proportion of the overall variability between sites, indicating a great degree of heterogeneity among the streams in the CMR. The multiple impacts recorded on the watercourses and their possible interactions could explain the great heterogeneity found in the riparian conditions. Therefore, it is highly recommended that an additional assessment is performed in the event of planning the implementation of riparian rehabilitation techniques at a particular site, so as to identify its specific degradation

condition. Some exceptions were detected regarding the land use associated with each degradation condition, possibly due to isolated events of invasion of riparian vegetation. Adding this evidence to the aforementioned high level of heterogeneity detected among the riversides, the recommendation of an additional assessment is reinforced in order to select appropriate techniques for each site from the pool of potential rehabilitation measures identified.

Regarding the systematic review of the literature, in the context of the EU Water Framework Directive, most articles reported case studies in Europe. Moreover, it must be noted that most restoration efforts in the last 10 years were implemented in urban regions. However, social measures were implemented in less than 20% of the study cases. Although streams are being restored where people live, which could address the question of for who are we restoring (Guida-Johnson and Zuleta 2017), it appears that the social dimension it is not fully incorporated. In fact, some studies encountered social and economic constraints to restoration. Whether it is due to low acceptance or support (Weigelhofer et al. 2011; Lee and Jung 2016), conflicts with other land uses (Yocom 2014; Hartig and Wallace 2015; Zingraff-Hamed et al. 2018), lack of communication between stakeholders (Cockerill and Anderson 2014) or citizens' low willingness to pay (Lee and Jung 2016), these types of limitations must be addressed. One way to approach this issue is through the study of the environmental perception of key stakeholders. In a previous study, residents of the CMR were questioned about their perception related to the condition of streams (Guida Johnson et al. 2015). They were asked about how they valued the watercourses considering several dimensions (water quality, biodiversity, aesthetics and recreational value) and if they perceived the need for riparian rehabilitation. Most interviewees were negative about the health condition of the watercourses given the profound level of degradation to which streams are currently subjected. Moreover, they did not value the rivers for their wildlife, potential natural beauty or potential for recreation. However, a vast majority of respondents did express their desire to have them rehabilitated and to participate in such activities. In highly degraded urban settings where restoration outcomes are limited by the possibility to address stressors at the watershed scale, the benefits from social techniques may be more appropriate targets

(Smith and Chadwick 2014). In fact, most ecological constraints reported in the literature were related to irreversible levels of degradation and the presence of watershed stressors (Selvakumar et al. 2010; Stranko et al. 2012; Rios-Touma et al. 2015), which could possibly be the case for the CMR too.

This approach is applicable to any watershed worldwide that is arranged in an urban–rural gradient. This type of assessment is recommended for characterizing major degradation drivers of any riparian site subjected to multiple threats in order to identify the pool of appropriate rehabilitation techniques. Potential constraints, regarding all possible dimensions, must be recognized during the planning stage of rehabilitation and must be properly addressed before and during the implementation of measures to guarantee the success of interventions. The complexity of urbanized watersheds demands this type of holistic approach.

Acknowledgements This research was funded by the National Agency for Science and Technology of Argentina (PICT-2009-0125 and PME funds granted to GZ and PFDT doctoral scholarship granted to BGJ at the National University of Lomas de Zamora). We would also like to thank the Maimónides University for financial and logistic support and Adriana Pérez for her assistance in the sampling design and the statistical analysis. We gratefully thank Mariano Arias, Matías Ciancio, Gerardo Elsesser, Francisco Ferrer, Andrés Said and Diego Schell for their collaboration during the field surveys. We would also like to thank Mark Briggs and two anonymous reviewers for their valuable comments and suggestions, which helped to improve the manuscript.

References

- ACUMAR (2009) Plan integral de saneamiento ambiental de la cuenca Matanza-Riachuelo. ACUMAR, Buenos Aires
- Allan JD (2004) Landscapes and riverscapes: the influence of land use on stream ecosystems. *Annu Rev Ecol Evol Syst* 35:257–284
- Bilenca D, Codesido M, González Fischer C, Pérez Carusi L (2009) Impactos de la actividad agropecuaria sobre biodiversidad en la ecorregión pampeana. Ediciones INTA, Buenos Aires
- Bradshaw AD (1996) Underlying principles of restoration. *Can J Fish Aquat Sci* 53:3–9. <https://doi.org/10.1139/f95-265>
- Brailovsky AE, Foguelman D (2009) Memoria verde. Historia ecológica de la Argentina, 8va edn. Debolsillo, Buenos Aires
- Cabrera ÁL (1971) Fitogeografía de la República Argentina. *Bol Soc Argent Bot* XIV:1–42
- Cockerill K, Anderson WP (2014) Creating false images: stream restoration in an urban setting. *J Am Water Resour Assoc* 50:468–482. <https://doi.org/10.1111/jawr.12131>
- Feijó CS, Lombardo RJ (2007) Baseline water quality and macrophyte assemblages in Pampean streams: a regional approach. *Water Res* 41:1399–1410. <https://doi.org/10.1016/j.watres.2006.08.026>
- Ghersa CM, de la Fuente E, Suárez S, León RJC (2002) Woody species invasion in the Rolling Pampa grasslands, Argentina. *Agric Ecosyst Environ* 88:271–278. [https://doi.org/10.1016/S0167-8809\(01\)00209-2](https://doi.org/10.1016/S0167-8809(01)00209-2)
- Giorgi A, Feijó C, Tell G (2005) Primary producers in a Pampean stream: temporal variation and structuring role. *Biodivers Conserv* 14:1699–1718. <https://doi.org/10.1007/s10531-004-0694-z>
- González del Tánago M, García De Jalón D (2006) Attributes for assessing the environmental quality of riparian zones. *Limnetica* 25:389–402. <https://doi.org/10.1016/B978-0-12-374794-5.00003-1>
- Gregory KJ (2006) The human role in changing river channels. *Geomorphology* 79:172–191. <https://doi.org/10.1016/j.geomorph.2006.06.018>
- Groffman PM, Bain DJ, Band LE et al (2003) Down by the riverside: urban riparian ecology. *Front Ecol Environ* 1:315–321. [https://doi.org/10.1890/1540-9295\(2003\)001%5b0315:DBTRUR%5d2.0.CO;2](https://doi.org/10.1890/1540-9295(2003)001%5b0315:DBTRUR%5d2.0.CO;2)
- Guida Johnson B, Faggi A, Voigt A et al (2015) Environmental perception among residents of a polluted watershed in Buenos Aires. *J Urban Plan Dev* 141:A5014002. [https://doi.org/10.1061/\(ASCE\)UP.1943-5444.0000250](https://doi.org/10.1061/(ASCE)UP.1943-5444.0000250)
- Guida-Johnson B, Zuleta GA (2017) Riparian rehabilitation planning in an urban–rural gradient: integrating social needs and ecological conditions. *Ambio* 46:578–587. <https://doi.org/10.1007/s13280-016-0857-7>
- Harris RR (1999) Defining reference conditions for restoration of riparian plant communities: examples from California, USA. *Environ Manag* 24:55–63. <https://doi.org/10.1007/s002679900214>
- Hartig JH, Wallace MC (2015) Creating world-class gathering places for people and wildlife along the Detroit Riverfront, Michigan, USA. *Sustain* 7:15073–15098. <https://doi.org/10.3390/su71115073>
- Hepp LU, Santos S (2009) Benthic communities of streams related to different land uses in a hydrographic basin in southern Brazil. *Environ Monit Assess* 157:305–318. <https://doi.org/10.1007/s10661-008-0536-7>
- INDEC (2010) Censo Nacional de Población, Hogares y Viviendas. <http://www.censo2010.indec.gov.ar/>. Accessed 12 Jan 2015
- Jacobson CR (2011) Identification and quantification of the hydrological impacts of imperviousness in urban catchments: a review. *J Environ Manag* 92:1438–1448. <https://doi.org/10.1016/j.jenvman.2011.01.018>
- Kauffman JB, Krueger WC (1984) Livestock impacts on riparian ecosystems and streamside management implications. A review. *J Range Manag* 37:430–438. <https://doi.org/10.2307/3899631>
- 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. [https://doi.org/10.1577/1548-8446\(1997\)022%3c0012:AEPORA%3e2.0.CO;2](https://doi.org/10.1577/1548-8446(1997)022%3c0012:AEPORA%3e2.0.CO;2)
- Laffitto CM, Zuleta GA, Schell D, Guida Johnson B (2011) Land use at the watershed scale: restrictive factors or

- opportunities for environmental rehabilitation? Case study in Buenos Aires, Argentina. In: 4th World Conference on Ecological Restoration. Mérida, México
- Lee M, Jung I (2016) Assessment of an urban stream restoration project by cost-benefit analysis: the case of Cheong-gyecheon stream in Seoul, South Korea. *KSCE J Civ Eng* 20:152–162. <https://doi.org/10.1007/s12205-015-0633-4>
- McKergow LA, Weaver DM, Prosser IP et al (2003) Before and after riparian management: sediment and nutrient exports from a small agricultural catchment, Western Australia. *J Hydrol* 270:253–272
- Meek CS, Richardson DM, Mucina L (2010) A river runs through it: land-use and the composition of vegetation along a riparian corridor in the Cape Floristic Region, South Africa. *Biol Conserv* 143:156–164. <https://doi.org/10.1016/j.biocon.2009.09.021>
- Miller JR, Hobbs RJ (2007) Habitat restoration—do we know what we're doing? *Restor Ecol* 15:382–390. <https://doi.org/10.1111/j.1526-100X.2007.00234.x>
- Moffatt SF, McLachlan SM (2003) Effects of land use disturbance on seed banks of riparian forests in southern Manitoba. *Ecoscience* 10:361–369
- Moffatt SF, McLachlan SM (2004) Understorey indicators of disturbance for riparian forests along an urban-rural gradient in Manitoba. *Ecol Indic* 4:1–16. <https://doi.org/10.1016/j.ecolind.2003.08.002>
- Muller I, Delisle M, Ollitrault M, Bernez I (2016) Responses of riparian plant communities and water quality after 8 years of passive ecological restoration using a BACI design. *Hydrobiologia* 781:67–79. <https://doi.org/10.1007/s10750-015-2349-3>
- Nápoli AM (2009) Una política de estado para el Riachuelo. In: Di Paola ME, Sangalli F, Caorsi S (eds) Informe ambiental anual 2009. Fundación Ambiente y Recursos Naturales, Buenos Aires, pp 175–233
- Nienhuis PH, Leuven RSEW (2001) River restoration and flood protection: controversy or synergism? *Hydrobiologia* 444:85–99. <https://doi.org/10.1023/A:1017509410951>
- Palmer M, Allan JD, Meyer J, Bernhardt ES (2007) River restoration in the twenty-first century: data and experiential knowledge to inform future efforts. *Restor Ecol* 15:472–481. <https://doi.org/10.1111/j.1526-100X.2007.00243.x>
- Pereyra FX (2004) Geología urbana del área metropolitana bonaerense y su influencia en la problemática ambiental. *Rev la Asoc Geol Argent* 59:394–410
- Ratto S, Marceca E, Moscatelli G et al (2004) Evaluación de la contaminación orgánica e inorgánica en un suelo aluvial de la costa del Riachuelo, Buenos Aires, Argentina. *Ecol Austral* 14:179–190
- Rios-Touma B, Prescott C, Axtell S, Kondolf GM (2015) Habitat restoration in the context of watershed prioritization: the ecological performance of urban stream restoration projects in Portland, Oregon. *River Res Appl* 31:755–766
- Roni P, Hanson K, Beechie T (2008) Global review of the physical and biological effectiveness of stream habitat rehabilitation techniques. *North Am J Fish Manag* 28:856–890. <https://doi.org/10.1577/M06-169.1>
- Sala OE, Chapin FS III, Armesto JJ et al (2000) Global biodiversity scenarios for the year 2100. *Science* (80-) 287:1770–1774. <https://doi.org/10.1126/science.287.5459.1770>
- Selvakumar A, O'Connor TP, Struck SD (2010) Role of stream restoration on improving benthic macroinvertebrates and in-stream water quality in an urban watershed: case study. *J Environ Eng* 136:127–139. [https://doi.org/10.1061/\(ASCE\)EE.1943-7870.0000116](https://doi.org/10.1061/(ASCE)EE.1943-7870.0000116)
- Sliva L, Williams DD (2001) Buffer zone versus whole catchment approaches to studying land use impact on river water quality. *Water Res* 35:3462–3472. [https://doi.org/10.1016/S0043-1354\(01\)00062-8](https://doi.org/10.1016/S0043-1354(01)00062-8)
- Smith B, Chadwick MA (2014) Litter decomposition in highly urbanized rivers: influence of restoration on ecosystem function. *Fundam Appl Limnol/Arch für Hydrobiol* 185:7–18. <https://doi.org/10.1127/fal/2014/0581>
- Stacey PB, Jones AL, Catlin JC, et al (2009) User's guide for the rapid assessment of the functional condition of stream-riparian ecosystems in the American Southwest. Wild Utah Project
- Stranko SA, Hilderbrand RH, Palmer MA (2012) Comparing the fish and benthic macroinvertebrate diversity of restored urban streams to reference streams. *Restor Ecol* 20:747–755. <https://doi.org/10.1111/j.1526-100X.2011.00824.x>
- Tavzes B, Urbanic G, Toman MJ (2006) Biological and hydromorphological integrity of the small urban stream. *Phys Chem Earth* 31:1062–1074
- Turak E, Waddell N, Johnstone G (2004) New South Wales Australian River Assessment System (AUSRIVAS) sampling and processing manual
- Vidon P, Campbell MA, Gray M (2008) Unrestricted cattle access to streams and water quality in till landscape of the Midwest. *Agric Water Manag* 95:322–330. <https://doi.org/10.1016/j.agwat.2007.10.017>
- Walsh CJ, Roy AH, Feminella JW et al (2005) The urban stream syndrome: current knowledge and the search for a cure. *J North Am Benthol Soc* 24:706–723. <https://doi.org/10.1899/04-028.1>
- Weigelhofer G, Hein T, Kucera-Hirzinger V et al (2011) Hydrological improvement of a former floodplain in an urban area: potential and limits. *Ecol Eng* 37:1507–1514. <https://doi.org/10.1016/j.ecoleng.2011.05.005>
- Yamashita S, Shimatani Y, Watanabe R et al (2013) Comprehensive flood control involving citizens in a Japanese watershed. *Water Sci Technol* 68:791–798. <https://doi.org/10.2166/wst.2013.293>
- Yocom K (2014) Building watershed narratives: an approach for broadening the scope of success in urban stream restoration. *Landsc Res* 39:698–714. <https://doi.org/10.1080/01426397.2014.947249>
- Zingraff-Hamed A, Noack M, Greulich S et al (2018) Model-based evaluation of urban river restoration: Conflicts between sensitive fish species and recreational users. *Sustain*. <https://doi.org/10.3390/su10061747>
- Zuleta GA, Guida Johnson B, Laffitto CM et al (2012) Rehabilitación de ambientes perdidos en megaciudades: el caso de la cuenca Matanza-Riachuelo. In: Athor J (ed) Buenos Aires, la historia de su paisaje natural. Fundación de Historia Natural Félix de Azara, Buenos Aires, pp 445–459

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