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REPORT

Riparian rehabilitation planning in an urban–rural gradient: Integrating social needs and ecological conditions

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Abstract In the present context of global change and search for sustainability, we detected a gap between restoration and society: local communities are usually only considered as threats or disturbances when planning for restoration. To bridge this gap, we propose a landscape design framework for planning riparian rehabilitation in an urban–rural gradient. A spatial multi-criteria analysis was used to assess the priority of riversides by considering two rehabilitation objectives simultaneously—socio-environmental and ecological—and two sets of criteria were designed according to these objectives. The assessment made it possible to identify 17 priority sites for riparian rehabilitation that were associated with different conditions along the gradient. The double goal setting enabled a dual consideration of citizens, both as beneficiaries and potential impacts to rehabilitation, and the criteria selected incorporated the multi-dimensional nature of the environment. This approach can potentially be adapted and implemented in any other anthropic–natural interface throughout the world.

Keywords Argentina · GIS · Matanza-Riachuelo watershed · Priority sites · Restoration beneficiaries · Spatial multi-criteria analysis

INTRODUCTION

Systematic planning has been recognized as an important step in any ecological restoration project and whenever resources are not sufficient for recovering all sites simultaneously, it is essential to identify priorities. Moreover, the selection of sites with the highest potential of success assures the attainment of goals and the maximization of benefits (Russell et al. 1997; Orsi and Geneletti 2010). Considering that the impact of any management action is determined by its location in the landscape, numerous studies have implemented multi-criteria analysis (MCA) coupled with geographical information systems (GIS) (Bryan and Crossman 2008; Jackson et al. 2013). The identification of restoration priorities at the landscape scale is a multi-objective planning problem in which other issues, such as social or economic aspects, should be involved. In this context, MCA proved to be effective in handling decision problems with different and conflicting objectives (Orsi and Geneletti 2010). It enables constraints to restoration to be translated into decision criteria: whereas ecological constraints define what is possible and economic constraints determine what is realistic, social constraints establish whether a project is acceptable (Miller and Hobbs 2007; Orsi and Geneletti 2010). Ecological constraints set limits on what is possible based on the biophysical characteristics of a particular site and its surroundings, whereas economic and social constraints, which are also inter-related, set limits on the scope of what can be done. Financial constraints define the degree of realism of a proposal in a particular socio-economic context and depend on public acceptance of a project. At the same time, the degree to which the public embraces a project may be influenced by the ratio between costs and perceived benefits (Miller and Hobbs 2007).

In order to assess the development of the spatial MCA approach in the field of restoration, we performed a systematic review of research articles available in Scopus. We used two sets of keywords: “restor* AND multi-criteria AND GIS” and “restor* AND priorit* AND GIS.” We retrieved 468 results, out of which only 63 actually corresponded to the identification and prioritization of sites for restoration. The papers did not usually specify or consider who or what would benefit from the restoration activities,

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with the exception of some articles that explicitly stated that their objective was to restore habitat for a particular species. Regarding the set of rules designed for the prioritization, two-thirds of the articles included criteria related to social aspects, such as the type of land use, distance to roads, or population density. However, in the majority of cases, social criteria constituted restrictive factors: either they implied the unsuitability of certain land uses for restoration (Russell et al. 1997; Gkaraveli et al. 2004), or they considered that local communities acted as threats or disturbances (Diefenderfer et al. 2009; Orsi and Geneletti 2010; Thom et al. 2011). Only three studies showed an opposite reasoning and explicitly prioritized sites with potential for ecotourism (Llewellyn et al. 1996) or recreational and educational benefit (Strager et al. 2011), or close to populated areas (Nogués and Arroyo 2016). Although it could be argued that this review is a biased sample, at least it certainly shows the trend in which restoration prioritization by spatial MCA has been addressed. We believe that, in the present context of global change and search for sustainability, a different approach for restoration planning is needed. We have to start considering the social goals for restoration and designing social planning criteria according to those goals. We consider that it is urgent to explicitly incorporate the social dimension and to start thinking about society's needs, in other words to reflect on for whom we are restoring, in order to bridge this gap between restoration and society.

Streams associated with human settlements have been extensively affected over the last 5000 years, imposing a long history of degradation on these environments (Groffman et al. 2003; Gregory 2006). As a result, they are among the most seriously threatened ecosystems (Sala et al. 2000), and thus, riparian restoration has received much attention, especially during the last 20 years (Palmer et al. 2007). Restoration has been defined as an activity that initiates or accelerates the recovery of an ecosystem that has been degraded as the result of anthropogenic impacts (SER 2004) and, sensu stricto, it intends to return that ecosystem to its pristine state (Aronson et al. 1993). However, the feasibility of restoration could be questioned in the case of ecosystems subjected to great environmental degradation, such as riversides located in urban environments. In these cases, the objective is to rehabilitate potential sites, which implies the return to a previous condition or status (Bradshaw 1996). Restoration sensu lato or rehabilitation intends to repair processes, functions, productivity and/or services, but does not try to return to the pristine state (Aronson et al. 1993; SER 2004). In this regard, riparian rehabilitation in urban environments represents an interesting opportunity to create green infrastructure (Bryant 2006), which improves climate and aesthetics, as well as meeting certain social and psychological needs of the urban population, offering opportunities for recreation, alternative transportation and environmental education (Bryant 2006; Ignatieva et al. 2011; Voigt et al. 2014). Therefore, riparian rehabilitation of urban streams has the potential to aid the achievement of sustainable goals in cities, enhancing the provision of ecosystems services for urban dwellers. Spatial MCA has been successfully applied in the identification of priority sites for riparian restoration (Russell et al. 1997; Pieterse et al. 2002; Meixler and Bain 2010).

In this paper, we present a landscape design framework for planning riparian rehabilitation in an urban–rural gradient in Buenos Aires (Argentina). This approach is characterized by its methodical simplicity, considering that complex models may be difficult for decision-makers to implement because of the extensive data and computation requirements (Peacock et al. 2012). First, we defined two riparian rehabilitation objectives, which helped to encompass different needs occurring along the urban–rural gradient: socio-environmental and ecological. The first objective was directly related to the necessities of citizens as it implied creating green infrastructure that could improve human welfare and be used by the local community for recreation, social participation and environmental education (Rohde et al. 2006; Purcell et al. 2007; Özgüner et al. 2012). The second objective was to recover ecological processes and functions, implementing rehabilitation measures, such as creation of buffer zones, reconnection between riparian habitats and their adjacent floodplains, reintroduction of native species, and control of exotic species (Rohde et al. 2005; Bay and Sher 2008; Miller et al. 2010). We consider that this simple approach may serve as a means to lead the way towards the design and implementation of rehabilitation planning strategies that include explicit considerations about their beneficiaries.

MATERIALS AND METHODS

Case study: Matanza-Riachuelo watershed

The Matanza-Riachuelo watershed (CMR, acronym in Spanish for *Cuenca Matanza-Riachuelo*) 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 the area of influence of the watershed. The CMR is an emblematic case study since it is the most polluted in Argentina and one of the most polluted in the world. Its main environmental problems are as follows: water, soil and air pollution; anthropogenic alteration of the drainage system; flooding of urbanizations and settlements which

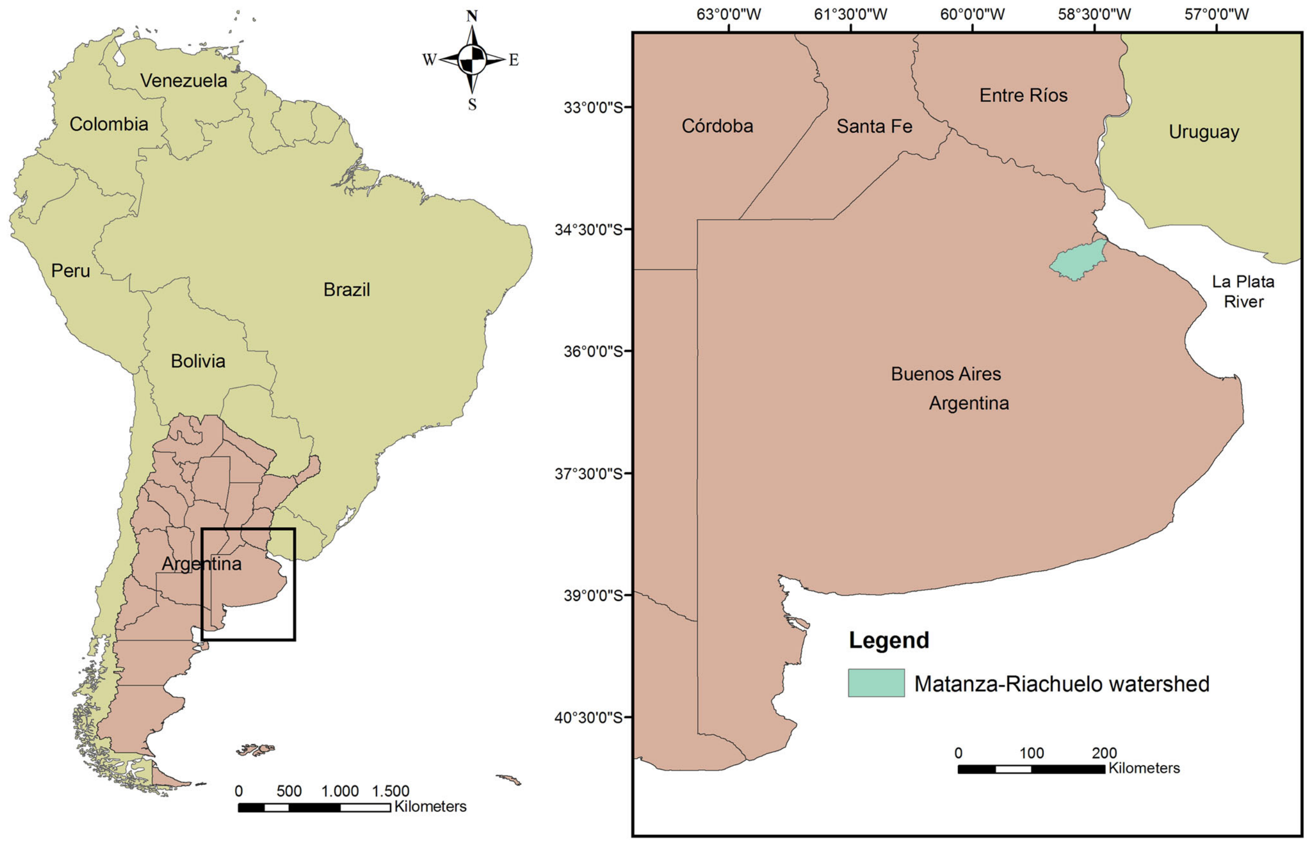

Fig. 1 Location of the study area in Argentina

occupy floodplains and low river terraces; open dumps which constitute a risk to human health; and the loss of biodiversity associated with the massive transformation and destruction of habitats, as well as the invasion of exotic species (Pereyra 2004; Nápoli 2009; Zuleta et al. 2012). Some of the socio-political factors that have contributed to the current degraded condition of the watershed are the unplanned residential and industrial development, lack of enforcement of the legislation by the authorities, and failure to comply with liabilities by most of the private sector (Nápoli 2009; ACUMAR 2010; Zuleta et al. 2012).

In 2004, 17 residents of the lower part of the basin filed a lawsuit against the national state, the province of Buenos Aires, the city of Buenos Aires, 14 municipalities, and several companies in order to be compensated for damages caused by the pollution of the watershed, as well as to stop the contamination. In 2006, the Argentina Supreme Court, in an unprecedented verdict, ruled that the national, provincial, and municipal authorities should improve the quality of life of CMR residents, restore the environment and prevent any further damage. The Authority of the watershed was then created and is responsible for the compliance of this ruling (Nápoli 2009). A comprehensive environmental decontamination plan has been enforced since 2009, and it is still ongoing. It includes measures, such as conversion of industries, expansion of the water supply and sewage system, monitoring of water and sediment quality, relocation of slums, cleaning of riverbanks and beds, and environmental education, among other objectives that are still not completely fulfilled (ACUMAR 2010). It should be noted that the plan does not include a riparian rehabilitation approach. Although many of its actions could be considered as preliminary stages of rehabilitation, no actual restoration measures are included. In fact, the development of this discipline is relatively recent in Argentina (Zuleta et al. 2015).

The CMR presents two main types of land use, urban and rural, which are spatially arranged as a gradient (Laflitto et al. 2011). The lower part of the watershed is occupied by the city of Buenos Aires, while peri-urban land use predominates in the middle sector. Rural land use, which includes agriculture and cattle ranching, is located mainly in the upper part of the basin and, to a lesser extent, in the middle sector. The economic development of this region was related to the nature of the soils that have outstanding characteristics due to their fertility, which combined with weather conditions and a flat relief have great potential for agricultural activities (Pereyra 2004). Consequently, climax vegetation communities of the original grasslands, known as the *Pampas*, have been totally altered or destroyed by the rural production activities that have taken place for over almost a century (Viglizzo et al. 2001). Moreover, although trees were not originally found in the *Pampas* except in certain edaphic environments, many woody species have been introduced, intentionally or unintentionally, from other ecoregions or from other parts of the world. Among the latter, *Gleditsia triacanthos* (honey locust) from eastern North America has been a highly successful invader, and together with species such as *Morus alba* (white mulberry) or *Melia azedarach* (white cedar), they have invaded several riparian corridors (Ghersa et al. 2002).

Spatial multi-criteria decision model

Spatial MCA was carried out on riversides located within a 100 m buffer area from all watercourses identified in the CMR (Fig. 2). Buffer width was defined based on the riparian width reported for other watercourses in the region (Rosso and Fernández Cirelli 2013; Cochero et al. 2016) and the spatial resolution of the available GIS data. Riversides were prioritized by using two sets of criteria, simultaneously and at the reach scale, which were selected according to the established premises (Orsi et al. 2011). In this regard, the premise for the socio-environmental objective was to prioritize riparian areas that implied the greatest benefits for the local community; while the premise for the ecological objective was to prioritize riversides associated with the greatest probability of success of the measures to be implemented. The criteria selection process was driven by a literature review, expert knowledge of the study area and its main environmental problems, as well as the availability of geo-referenced data.

Priority for socio-environmental rehabilitation was evaluated using three criteria: recreational opportunity, environmental degradation, and population density. The recreational opportunity criterion included the local community's need for green spaces (Reyes Päcke and Figueroa Aldunce 2010), prioritizing riversides that were further away from existing squares or parks. The environmental degradation criterion used impervious surface as an indicator given its effects on hydrology and water quality (Brabec et al. 2002), prioritizing riversides located in regions with a higher degree of imperviousness. Finally, the population density criterion, a frequently used variable to characterize urban–rural gradients (Hahs and McDonnell 2006), was included to maximize the number of potential beneficiaries from rehabilitation measures. Consequently, this criterion prioritized riversides located in the most densely populated areas.

Priority for ecological rehabilitation was based on another three criteria: exotic resistance, hydrological constraint, and urban pressure. The exotic resistance criterion incorporated the probability of success of controlling alien woody species, e.g., *G. triacanthos*, which requires great effort and entails elevated costs while the prospect of removal is scarce (Leggieri 2010). Accordingly, this criterion prioritized riversides further away from exotic riparian forests. The hydrological constraint criterion included the degradation imposed by road crossings, since bridges have been associated with altered hydrodynamics, disturbed sedimentation, and deposition processes, as well as declined stream health (Trombulak and Frissell 2000), prioritizing riversides further from bridges. Finally, the urban pressure criterion incorporated the threat imposed by direct anthropogenic impacts, considering that most users

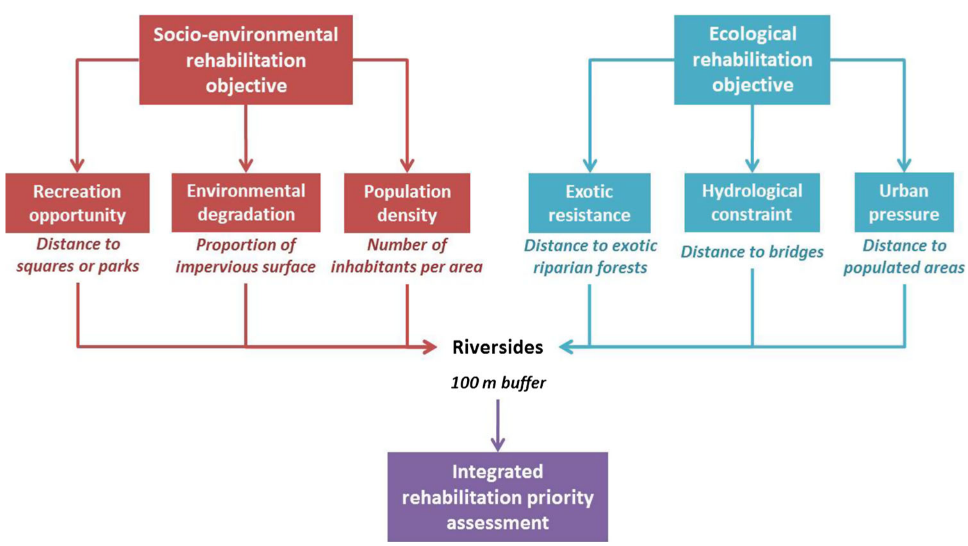

Fig. 2 Criteria selected to prioritize riparian areas in the spatial multi-criteria analysis according to both rehabilitation objectives: socio-environmental (*dark gray*) and ecological rehabilitation (*light gray*)

of public open spaces live within close proximity (Giles-Corti and Donovan 2002). Consequently, it prioritized riversides further away from populated areas.

GIS data analysis

In order to evaluate the first socio-environmental criterion, a map of green urban areas was produced by visual interpretation of Google Earth images, which was then transformed into a map of Euclidean distances from squares or parks. For the second criterion, a map of impervious surface was generated using a Tasseled Cap transformation from the Landsat scene (Lafflitto et al. 2011). To incorporate the third criterion, population density data provided by INDEC (2010) were combined with the limits of the national census units, made available online by the city (Dirección General de Estadística y Censos 2014) and the province of Buenos Aires (Dirección Provincial de Estadística 2014). In order to evaluate ecological rehabilitation criteria, Euclidean distance maps were produced for each criterion. The location of exotic riparian forests and populated areas was identified in a CMR land use/land cover map generated by visual interpretation of a Landsat 5 TM image acquired in 2010 (Lafflitto et al. 2011). The location of bridges was derived from data made available online by the National Geographic Institute (IGN 2014).

Spatial MCA was implemented in ArcGIS 10.3. All maps were transformed into a 0–1 linear scale, assigning a value of 1 to the greatest priority in the study area according to the corresponding criterion. Correlation coefficients (r) for all six criteria were calculated in order to evaluate their interdependency. Selected criteria were not highly correlated as $|r| < 0.6$ for all possible pairs (the most highly correlated criteria were recreational opportunity and environmental degradation with $r = -0.53$, as well as environmental degradation and population density with $r = 0.52$). Therefore, selected variables were considered as independent criteria. Priority values for all six criteria were then added by means of a fuzzy overlay. Comparative studies of MCA showed that top alternatives obtained by different methods are usually in close agreement and there is no clear methodological advantage to any single technique (Hajkowicz and Collins 2007; Huang et al. 2011). In this study, we selected a fuzzy sum because it would prioritize riversides that rank higher in a larger number of criteria. We believe that any stakeholder, despite their technical background, can easily understand this prioritization logic, which represents an additional advantage to the simplicity of this approach. The resulting map was intersected with riparian buffers and priorities values were divided into five categories by means of the Jenks natural breaks classification method, distinguishing between: very high, high, medium, low, and very low level of priority. Priority sites for riparian rehabilitation in the CMR were identified as riversides that had resulted in a very high level of priority for the spatial MCA.

RESULTS

The total extension of riversides assessed by the spatial MCA was 1058 km in length. Most riversides showed a medium (27%) or low (26%) level of priority for rehabilitation according to the established criteria (Table 1), whereas high or very high-priority riparian areas in the CMR watershed accounted for 28% of the total drainage system. Among the latter, only 9% corresponded to a very high level of priority and they were selected as the 17 riparian rehabilitation priority sites identified for the study area (Fig. 3). Therefore, the analysis performed enabled the detection of few but specific locations where riparian rehabilitation would simultaneously represent a maximization of the potential beneficiaries and a higher probability of success.

The integration of all criteria related to both rehabilitation objectives (socio-environmental and ecological) resulted in the selection of riparian areas distributed among different types of land use along the gradient present in the watershed: rural (42% of very high-priority riparian areas), urban (32%), and peri-urban (26%, Table 2). Very high-priority riparian areas surrounded by rural land use were located in the upper part of the watershed. These priority sites (numbered 1, 2, 3, 5, and 6 in Fig. 3) would be associated with high-priority values for the ecological rehabilitation criteria. The rest of the riparian areas (58%) were either surrounded by urban or peri-urban land. Riparian areas associated with very high priority for rehabilitation and located in peri-urban areas were distributed evenly among the upper part of the watershed (12% of the areas, corresponding to site 4) and the middle part (14% of the areas, corresponding to sites 7, 8, 10, and 11). These sites would be associated with a balance between high-priority values for the ecological rehabilitation criteria and high-priority values for the socio-environmental

Table 1 Priority of riversides assessed by the spatial multi-criteria analysis for integrated rehabilitation objectives: socio-environmental and ecological (expressed as percentage of the total drainage system)

Priority for rehabilitation	Relative riparian area (%)
Very high	9
High	19
Medium	27
Low	26
Very low	19
Total	100

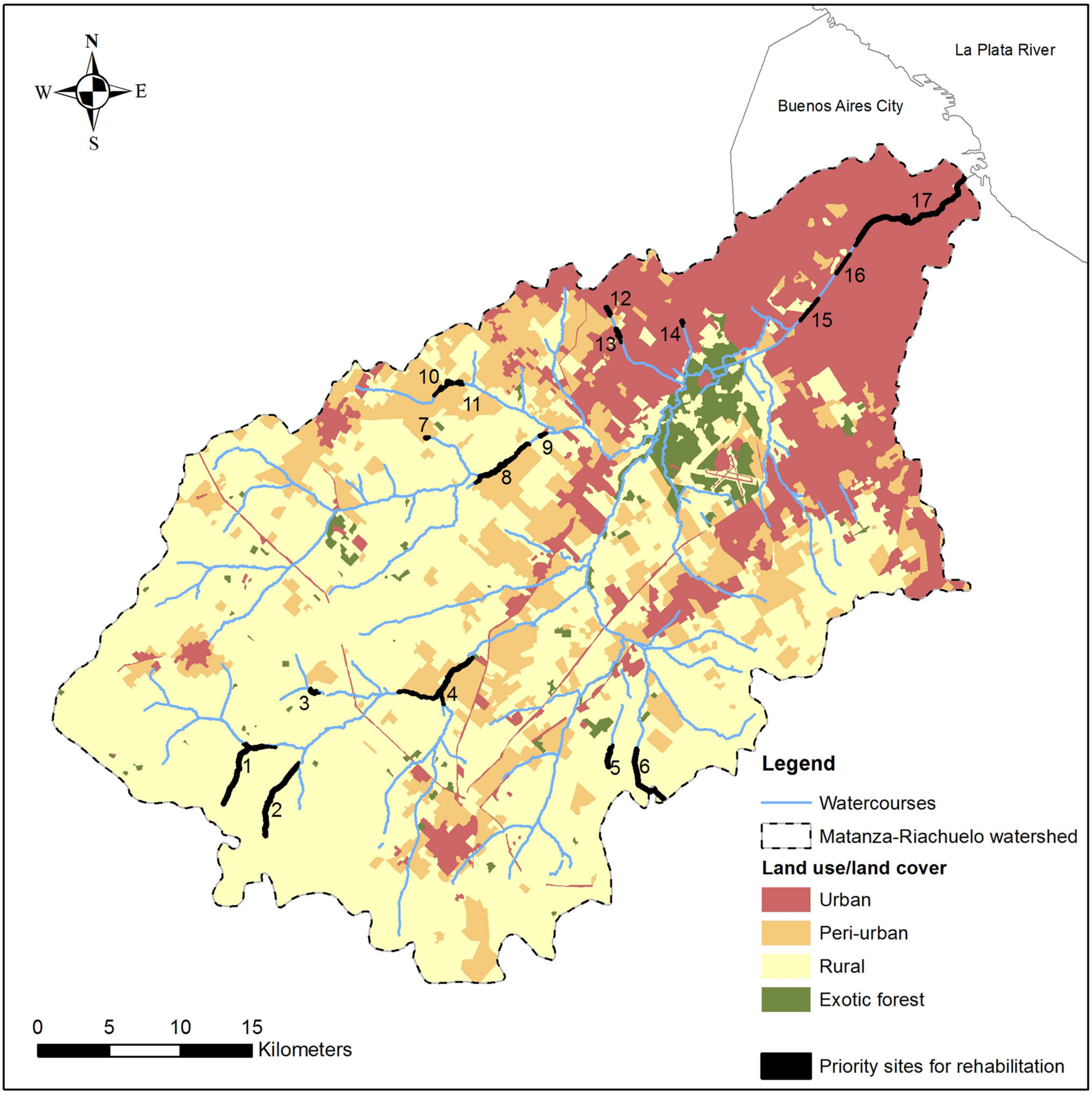

Fig. 3 Priority sites for riparian rehabilitation identified in the CMR

criteria. Finally, urban riparian areas associated with very high priority were concentrated in the lower part of the watershed (28% of the areas, corresponding to sites 15, 16, and 17), which would be related to high-priority values for the socio-environmental criteria. Very high-priority riparian urban areas in the middle part of the watershed (4% of the areas, corresponding to sites 9, 12, 13, and 14), would also be associated with a balance between high-priority values for the ecological rehabilitation criteria and high-priority values for the socio-environmental criteria.

DISCUSSION

The landscape design framework proposed for planning riparian rehabilitation at the watershed scale enabled the integration of the different needs occurring in the urban–rural gradient. The definition of two alternative rehabilitation objectives constitutes a novelty, since previous studies only determined a single goal for each study area (Russell et al. 1997; Pieterse et al. 2002; Rohde et al. 2006; Meixler and Bain 2010). It is precisely this double goal setting which enabled the dual consideration of citizens, both as beneficiaries of socio-environmental measures and as potential impacts to ecological rehabilitation. In this paper, we defined one of these rehabilitation objectives considering society's needs and thus, the rehabilitation of riparian sites was interpreted as an opportunity to provide ecosystem services for local urban communities. Only few studies included social variables and followed the same reasoning when selecting restoration priorities (Llewellyn et al. 1996; Strager et al. 2011). Other examples simply excluded urban areas during the implementation of the spatial MCA to plan riparian restoration (Russell et al. 1997; White and Fennessy 2005; Rohde et al. 2006). In our case study, it was imperative to consider for whom we were restoring when planning rehabilitation, considering the high population density and the low environmental quality associated with the CMR. Therefore, the proposed framework enabled the identification of priority sites for rehabilitation that maximize benefits for the local community while being associated with the highest probability of success of ecological rehabilitation measures. In this first approximation, we considered that the local community was an homogenous subject, with the same needs and the same perception of potential benefits. This aspect could be deepened by a profound characterization of the rehabilitation beneficiaries, which could be translated into additional decision criteria to be incorporated in this framework if more detailed spatially explicit socio-economic data were available for the study area. Such improvement could refine the definition of priority sites, which in turn would enhance the probability to provide ecosystems services for urban dwellers and, therefore, it would promote the attainment of sustainable goals in this city.

The criteria selected incorporated the multi-dimensional nature of the environment, which must be considered in order to address existing constraints to rehabilitation (Miller and Hobbs 2007; Orsi and Geneletti 2010). Prioritization criteria for socio-environmental rehabilitation addressed the social dimension since they determined what conditions would be more acceptable for riparian rehabilitation in the CMR. It has been established that the acceptance of the local community is a key aspect to guarantee the long-term implementation and success of rehabilitation measures (Woolsey et al. 2007). In a previous study, residents of the CMR were asked about their environmental perception related to the condition of streams and their rehabilitation needs. Given the profound level of degradation to which streams are subjected in this polluted watershed, most interviewees did not value 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 (Guida Johnson et al. 2015), which is evidence of the potential social acceptance among interviewees regarding the rehabilitation measures that could be attained. With respect to the prioritization for ecological rehabilitation, the selected criteria addressed both social and ecological dimensions. On one hand, two criteria referred to conditions that would be more favorable for the success of ecological rehabilitation measures, considering the key anthropogenic disturbances occurring in the CMR (e.g., exotic species invasions and alterations to hydrological processes). On the other hand, one criteria approached potential social conflicts (e.g., vandalism) derived from the low value that the inhabitants of the watershed may be assigning to riparian habitats (Guida Johnson et al. 2015). It must be noted that this last restriction could be avoided by means of implementing environmental education programs that address the re-valorization of this type of environments and the organization of social participation activities that promote symbolic local ownership of the rehabilitated sites.

Table 2 Priority sites for riparian rehabilitation identified in the CMR, according to surrounding land use and location in the watershed (expressed as percentage of high-priority riparian sites)

	Upper part	Middle part	Lower part	Total
Urban		4	28	32
Peri-urban	12	14		26
Rural	42			42
Total	54	18	28	100

Considering the spatial distribution of priority sites, the proposed framework enabled the identification of riparian areas distributed among different types of land use along the urban–rural gradient present in the watershed. Since the socio-environmental objective was related to the provision of urban services, built-up areas became appropriate surroundings for recovering riversides for this purpose. Riversides in rural environments were well suited for the ecological rehabilitation goal, since they would be associated with a higher probability of success and a higher feasibility of these types of measures. Finally, peri-urban areas appeared as especially relevant in this study, as they were found to be an opportunity to integrate both rehabilitation objectives. They would be likely to represent a certain degree of restorability but still providing considerable social benefits. Regarding different locations along the watershed, the upper part was associated with a third of the opportunities for rehabilitation. This aspect has additional interest, since most headwaters are concentrated in the upper sector of the watershed. Headwaters have been linked to a fundamental role in the maintenance of water quality, biodiversity, and ecological processes (Lowe and Likens 2005). Therefore, the rehabilitation of these riparian areas could also have tremendous implications on the extent of the beneficial effects of management measures.

The principal limitation of this type of framework is the availability of geo-referenced quality information. As previously stated, criteria selection was driven not only by a literature review and by expert knowledge about the study area and its main environmental problems, but also by the availability of geo-referenced data. For some criteria, we were able to use information that was made available online by different official organisms, but for other criteria data had to be generated specially for this study. Although one of the advantages of the systematic landscape planning approach is to increase clarity and transparency when dealing with multi-objective problems (Rohde et al. 2006; Bryan and Crossman 2008), this benefit could be jeopardized if researchers or managers cannot access reliable geographical information. In this context, we strongly recommend that government initiatives are demanded and supported to assure the free access of geographic information to the general public, as well as to promote collaboration and information sharing among research groups and different institutions.

CONCLUSIONS

Considering the current global context, one of the main challenges is to identify management measures for reversing degradation trends that affect many types of environments, especially freshwater ecosystems, such as the rehabilitation of degraded sites. Although environmental degradation could possibly jeopardize the provision of ecosystem services, the beneficiaries of these actions are not usually taken into consideration when planning for restoration. This simple approach constitutes an invitation to start thinking about restoration planning in these terms, in other words, to start integrating social needs and ecological conditions. This approach has the potential to be adapted and implemented in other anthropic–natural interfaces throughout the world.

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