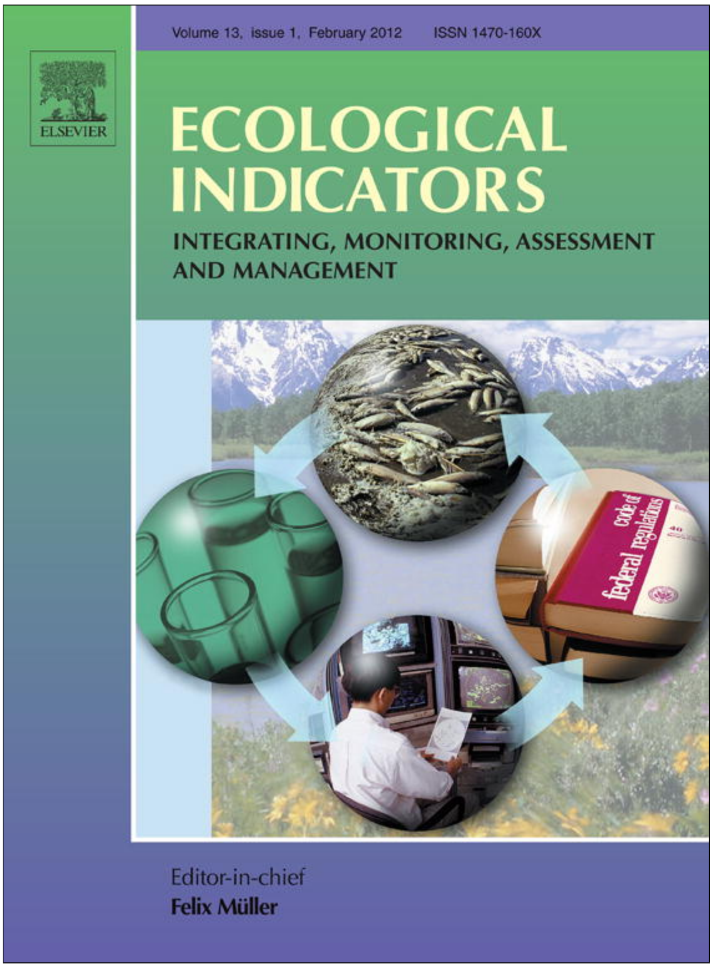


(This is a sample cover image for this issue. The actual cover is not yet available at this time.)

Ecological Indicators 20 (2012) 324–331

Contents lists available at SciVerse ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

A method for assessing the ecological quality of riparian forests in subtropical Andean streams: QBRy index

Martín G. Sirombra[a], Leticia M. Mesa[b,*]

[a] Cátedra Ecología General, Instituto de Limnología del Noroeste Argentino (ILINOA), Facultad de Ciencias Naturales e Instituto Miguel Lillo, Universidad Nacional de Tucumán, Miguel Lillo 205, 4000 San Miguel de Tucumán, Tucumán, Argentina

[b] Instituto Nacional de Limnología, Ciudad Universitaria, Pje. El Pozo, 3000 Santa Fe, Argentina

ARTICLE INFO

Article history:
Received 8 August 2011
Received in revised form 15 February 2012
Accepted 20 February 2012

Keywords:
Anthropogenic impacts
QBRy index
Riparian quality
Yungas forest

ABSTRACT

A modified QBR index adapted to examine the riparian quality of streams included in the Yungas biome is presented. The index, named QBRy, included modifications of the original index in three of the four sections in order to be useful for the studied region. The assessment of QBRy included trials in three subtropical sub-basins of Tucumán province (Argentina). Thirty-seven sampling sites were assessed. The composition of riparian forest varied in relation to a geographical pattern, and this was related with the climatic differences existing within the same ecoregion. The quality of riparian vegetation was poor near population centers and in sites impacted by livestock, while good quality conditions were related with areas adjacent to a protected region and in physiographical inaccessible zones. The introduction of exotic species represents a real problem to the integrity of Yungas riparian vegetation. The protection of the few well preserved zones and the necessity of restoration of highly altered ones becomes an essential priority for biodiversity conservation.

1. Introduction

Riparian vegetation structure, composition and dynamics have received growing attention in the past decade (Jungwith et al., 2002; Richardson et al., 2007; Yang et al., 2011). The riparian zone is defined as the transitional area between a river or stream and the adjacent terrestrial upland ecosystem, including both the stream channel itself and the surrounding land that is influenced by fluctuating water levels (Malanson, 1993). It can support a high biodiversity; protects the main channel from temporal changes, buffers large disturbances, regulates the temperature of streams, filters and retains nutrients and provides habitat, refuge and food for wildlife (Naiman et al., 1993; Stanford and Ward, 1993; Naiman and Décamps, 1997). Although all services provided by these ecosystems are critical for ecological functions, the riparian forests are among the most threatened ecosystems in the world (Tockner and Stanford, 2002).

Yungas is an Andean biome that extends in Venezuela, Colombia, Bolivia and the northwestern region of Argentina. In Argentina, Yungas ranges from the frontier of Bolivia (23°) to the north of Catamarca (29°), with an area of 52,000 km^2. Minimum and maximum altitudes varies between 400 and 3000 m.a.s.l., respectively. This biome, which includes the headwaters of the most important basins, plays an important role in the regulation of the hydraulic of streams that goes through the American continent, and enhances a high biodiversity of species with a high number of endemism (Brown, 1986; Brown et al., 2002).

Yungas riparian forests have been subjected to intensive land-use scenarios. Agricultural transformations, road construction, gravel extractions, deforestation, overgrazing and the introduction of exotic species are some impacts that affect biotic communities and individual species (Grau and Aragón, 2000; Brown et al., 2006; Balducci et al., 2009).

Being under increasing threats and in order to conserve and manage the remaining riparian forests, it is useful to describe the riparian zone in a systematic and, if possible, low time-consuming way.

The QBR index ("qualitat del bosc de ribera") is a simple method to evaluate riparian habitat quality. It was developed to be used in Mediterranean streams of Spain (Munné et al., 1998; Prat et al., 1999; Suárez et al., 2002; Munné et al., 2003) and applied in several regions of the world with satisfactory results (Ocampo-Duque et al., 2007; Palma et al., 2009; Kazoglou et al., 2010). Some changes have been introduced by several authors in order to adapt it to other geographical areas (Colwell, 2007; Acosta et al., 2009; Kutschker et al., 2009), although the basic structure and the assessment procedure have not significantly changed.

* Corresponding author. Tel.: +54 342 4511645/48x106; fax: +54 342 4511645x111.
E-mail addresses: sirombra@gmail.com (M.G. Sirombra), letimesa@hotmail.com (L.M. Mesa).

1470-160X/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ecolind.2012.02.021

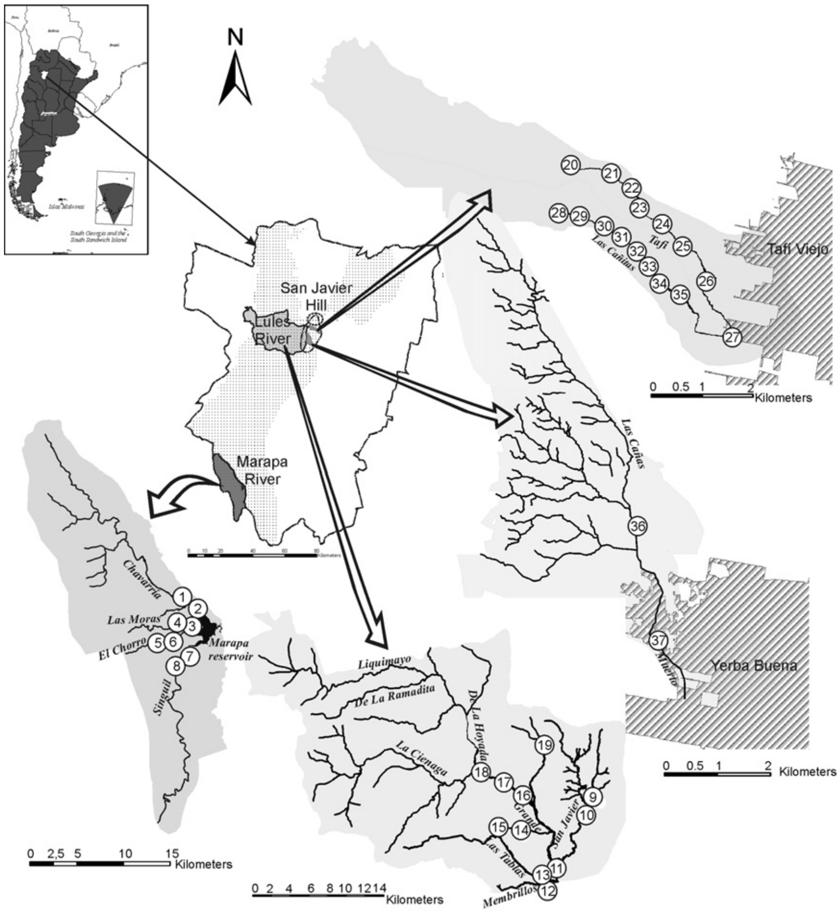


Fig. 1. Map of the three studied sub-basins showing the sampled sites, their localization in Tucumán province and the nearest urban centers. In shading within Tucumán is the localization of Yungas biome. The position of the protected area in the north side of San Javier Hill is also shown.

This paper describes the adaptation of the QBR index in order to assess the riparian quality of Yungas streams. The adapted index, named QBRy, was applied in three sub-basins of the northwestern Argentina. We also explored the spatial distribution of riparian species and its relationship with some variables.

We tested the hypothesis that: (1) riparian composition varies according to a geographical pattern of distribution, and (2) values of QBRy are higher in sites of higher altitude due the lower anthropogenic impacts in these regions.

2. Materials and methods

2.1. Study area

The adaptation of the QBR index included trials in subtropical streams of the northwestern Argentina including within Yungas biome. Thirty-seven sites in three sub-basins were studied: 8 in Marapa River, 11 in Lules River and 18 in the eastern side of the San Javier Hill. These sub-basins were selected in order to the distinct environmental conditions that include. Lules River sub-basin is located in the central-west of Tucumán province, with an area of 787 km^2. The maximum altitude is around 4488 m.a.s.l., decreasing toward the piedmont (408 m.a.s.l) (Fig. 1). San Javier Hill is situated in the eastern of this sub-basin, with altitudes between 600 and 1900 m.a.s.l. On the eastern of San Javier Hill, several low order streams infiltrate to reach the flat area. This sub-basin includes a protected area in the north, San Javier Hill Park (140 km^2), managed by the National University of Tucumán (Fig. 1). Marapa River sub-basin is located in the southwestern of Tucumán province, with several important streams such as Chavarría, Las Moras, El Chorro and Singuil draining into Escaba reservoir (Fig. 1).

The studied region is subject to the monsoon climate, with an average annual precipitation of 1000 mm. Within Yungas, climatic condition varies strongly in short distances (Brown et al., 2002; Bianchi, 2006). Altitude, the exposure of mountain ranges to humid southeastern winds and the presence of a particular geological feature (Conception bay) significantly influence the distribution and intensity of precipitation. The region of maximum precipitation ranges from Santa Ana Hill to Potrero de las Tablas, including Lules River and the eastern side of San Javier Hill sub-basins (2000 mm annually). Marapa River, located in the southern of Santa Ana Hill, presents a drier climate, with an annual precipitation between 800 and 1000 mm (Bianchi, 2006).

2.2. Riparian vegetation sampling

Each studied site was centered on the stream-bed and extended 50 m in length following the stream channel. The width was variable, extending through the riparian forest to the edge of the floodplain. Floodplain width was delimited taking into account several characteristics such as bank topography, position of terraces or dikes, presence of piles of debris left by previous flooding and indicator species. In areas with a narrow riparian corridor, forest edge was considered. Individual trees from 30 cm perimeter at breast height (PAP) were considered to limit the riparian area. Presence/absence data of trees, shrubs and woody climbers were recorded. We followed Zuloaga and Morrone (2011) for taxonomic identification of the riparian species.

2.3. QBRy index

Changes were made in three of the four sections of the QBR in order to be applied to Yungas streams. The first section of the original index, total riparian cover, had remained unchanged. In the second component of the QBR, cover structure, the community of helophytes was replaced by a more representative community of mountain streams such as woody climbers. The main difference between the QBRy and the original QBR was related with the third component. This was simplified in the QBRy: cover quality was estimated taking into account the percentage of native and exotic species independent of their number and the geomorphologic type of the studied site. Finally, in the forth component of the original index, channel alteration, the distinction of the impact on one or two terraces and margins was considered in order to facilitate the monitoring of the studied area. New sections related with common anthropogenic impacts in the Yungas biome were included as factors that decrease the score of this section.

2.4. Statistical analyses

A non-metric multidimensional scaling (NMS) with Sorensen's distance was used to explore the patterns in the presence–absence of riparian vegetation data (PC-ORD 4.27, McCune and Mefford, 1999). One hundred iterations were carried out from random starting co-ordinates with a step length of 0.2 (the default rate of movement toward minimum stress).

Spearman correlation analysis was used to examine the relation between the values of the QBRy and altitude of each site, and the relation between the axes of NMS and several selected variables (values of QBRy, altitude, mean bankfull height, richness and number of exotic and native species).

3. Results

3.1. QBRy index

A total of seventy-seven riparian species were found (Appendix A). Thirty-five were present in Marapa sub-basin, five of these were exotic; Lules sub-basin included forty-eight species (eight exotic), whereas sixty species were found in streams of the eastern side of San Javier Hill (twelve exotic).

The field sheet of QBRy index is shown in Appendix B.

The geographic position, altitude, mean bankfull height and values of QBRy relative to each site and sub-basin are shown in Table 1. The values of QBRy ranged from 15 to 100 (Table 1). Most sites relative to Marapa and Lules sub-basins (>45%) had good quality (QBRy = 75–90). In addition, 30% of sites of Lules and San Javier Hill sub-basins had extreme degradation (QBRy < 25) (Fig. 2).

In Marapa sub-basin, sites 1 and 7 showed the highest and lowest values of QBRy, respectively (95 and 45); sites 9, 12 and 13 exhibited the lowest values of this index in the Lules basin (QBRy ≤ 25), whereas the riparian habitat of site 15 was in natural condition (Table 1). In the eastern side of San Javier Hill, the riparian zones of sites 26, 27, 34, 35 and 36 exhibited extreme degradation (QBRy ≤ 25), whereas in 1, 15, 28, 29 and 30 the riparian habitat were in natural condition (QBRy ≥ 95) (Table 1).

The values of the sections total riparian cover and alterations in the riparian zone were higher in Marapa sub-basin than in the other two sub-basins (Kruskal–Wallis test, $H = 7.24$, $P < 0.05$; $H = 11.9$, $P < 0.001$, respectively, Fig. 4) determining the better riparian conditions of this basin. Some sites of Lules sub-basin showed the lower values of total riparian cover, cover structure and cover quality, whereas in San Javier Hill, some sites exhibited the lower values of the section channel alteration (Fig. 4). Anthropogenic modifications in the stream channel and floodplain determined low values of the QBRy in most sites of San Javier Hill sub-catchment (Table 1, Figs. 3 and 4).

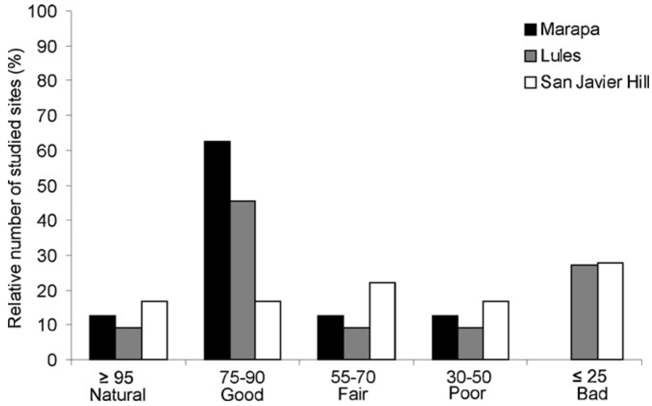


Fig. 2. Relative number of sites (in percentage) of each riparian quality class for each sub-basin.

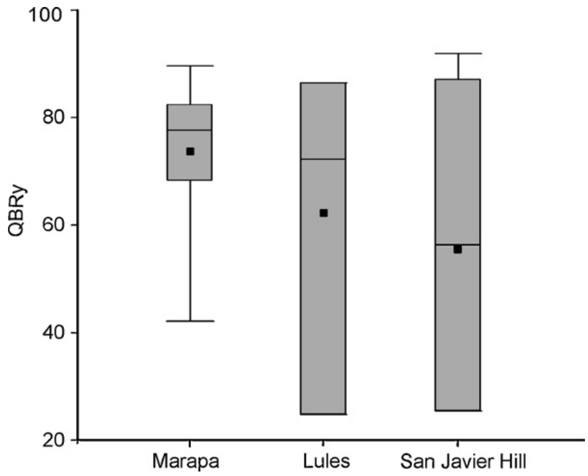


Fig. 3. Box-plot of values of the QBRy relative to each site for the three studied sub-basins (mean, median and standard deviation are also shown).

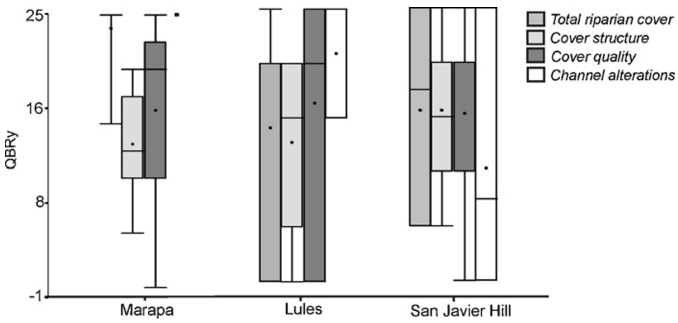


Fig. 4. Box-plot of values of each section of QBRy relative to each site for the three studied sub-basins (mean, median and standard deviation are also shown).

Correlation value between altitude and QBRy was positive and significant ($R = 0.40$, $P = 0.01$), indicating the higher quality of riparian vegetation of higher altitude sites (Fig. 5).

3.2. Multivariate analysis

The NMS ordination (stress = 22.8, $P = 0.01$) represented 68% of the variation in the dataset, with 35% on axis 1 and 33%

Table 1
Geographic position, altitude, mean bankfull height and values of the QBRy relative to each site and sub-basin.

Sub-basin	Site	Latitude/longitude	Altitude (m.a.s.l)	Mean bankfull height (m)	QBRy
Marapa	1	27°37′59″S; 65°47′34″W	651	0.8	95
	2	27°38′15″S; 65°47′26″W	653	1.3	85
	3	27°38′48″S; 65°47′13″W	633	2.2	75
	4	27°38′48″S; 65°47′72″W	633	4.0	85
	5	27°40′36″S; 65°49′42″W	754	3.0	80
	6	27°40′36″S; 65°49′41″W	779	1.5	90
	7	27° 41′18″S; 65°47′51″W	657	0.4	45
	8	27°41′20″S; 65°47′55″W	662	0.4	70
Lules	9	26°46′26″S; 65°23′23″W	860	2.8	15
	10	26°47′28″S; 65° 23′56″W	830	1.2	75
	11	26°51′18″S; 65°25′46″W	650	0.9	85
	12	26°51′23″S; 65°25′53″W	680	1.6	25
	13	26° 51′39″S; 65°25′88″W	692	1.7	25
	14	26°48′24″S; 65°27′55″W	1053	1.3	60
	15	26°48′16″S; 65°29′12″W	925	0.4	100
	16	26°46′05″S; 65°28′52″W	957	1.2	90
	17	26°45′30″S; 65°29′31″W	1070	1.2	90
	18	26°44′53″S; 65°30′46″W	1105	1.9	90
	19	26°43′24″S; 65°26′67″W	1127	2.0	50
San Javier Hill	20	26°43′2″S; 65°18′12″W	929	3.5	90
	21	26°43′5″S; 65°17′45″W	863	1.3	65
	22	26°43′15″S; 65°17′32″W	832	0.5	90
	23	26°43′27″S; 65°17′24″W	761	1.7	40
	24	26°43′34″S; 65°17′13″W	746	2.8	40
	25	26°43′43″S; 65°17′00″W	733	3.4	25
	26	26°44′82″S; 65°16′49″W	688	2.2	40
	27	26°44′34″S; 65°16′29″W	635	1.6	25
	28	26°43′27″S; 65°18′10″W	886	1.8	95
	29	26°43′29″S; 65°18′2″W	872	1.9	95
	30	26°43′30″S; 65°17′59″W	855	1.6	95
	31	26°43′36″S; 65°17′43″W	814	2.5	75
	32	26°43′48″S; 65°17′27″W	769	5.0	60
	33	26°43′52″S; 65°17′24″W	751	2.2	55
	34	26°44′0″S; 65°17′17″W	714	3.9	25
	35	26°44′11″S; 65°17′2″W	697	2.3	25
	36	26°48′32″S; 65°19′35″W	559	2.5	15
	37	26°47′22″S; 65°19′50″W	656	1.5	65

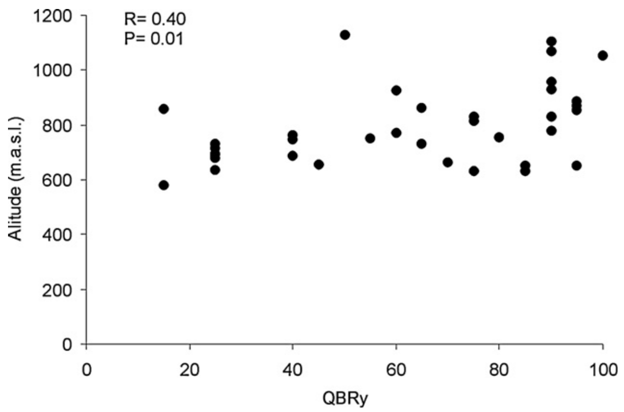


Fig. 5. Relationship between altitude and values of QBRy. Result of correlation analysis and significance value were also showed.

on axis 2 (Fig. 6). Ordination diagram separated sites according with the sub-basin. *Myrcianthes cisplatensis*, *Phyllostylon rhamnoides*, *Schinus bumelioides* and *Ruprechtia laxiflora* characterized Marapa sub-basin, *Zanthoxilum naranjillo* and *Duranta serratifolia* were associated with Lules, whereas twelve species (*Sambucus peruvianum*, *Rubus imperiales*, *Urera baccifera*, *Persea americana*, *Lantana camara*, *Psychotria carthagenensis*, *Heliocarpus popayanensis*, *Guadua angustifolia*, *Eucalyptus* sp., *Tabebuia avellanedae*, *Arundo donax* and *Eriobotrya japonica*) characterized streams of the eastern side of San Javier Hill.

The number of exotic species was positively and significantly associated with axis 1, whereas the values of QBRy and altitude were negatively associated with this axis (Table 2). Axis 2 exhibited a negative relationship with altitude, richness and number of native species (Table 2).

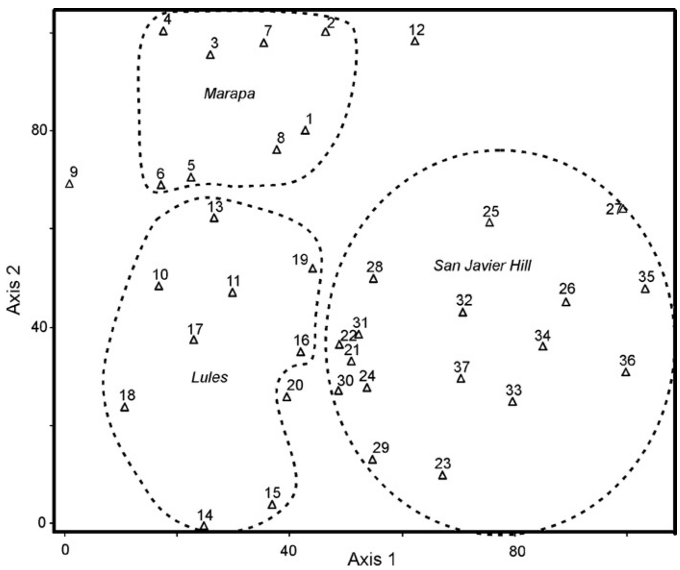


Fig. 6. Sites ordination of non-metric multidimensional scaling plot based on presence–absence data of riparian species. Dotted line encloses sites relative to each sub-basin.

Table 2
Results of correlation analysis between variables and axes 1 and 2 of non-metric multidimensional scaling ordination.

Variables	1	2
QBRy	−0.52**	−0.12
Altitude (m.a.s.l.)	−0.38**	−0.56**
Mean bankfull height (m)	0.27	−0.04
Richness	0.04	−0.40**
Number of exotic species	0.49**	0.03
Number of native species	−0.08	−0.46**

*$P < 0.05$.
** $P < 0.01$

4. Discussion

4.1. Yungas riparian vegetation

Yungas riparian species were the same than those occurring in adjacent areas such as terraces (Sirombra and Mesa, 2010). A humid climate characterizes this biome, determining that water be not restrictive to the establishment of species. This characteristic differed from several studies related with arid regions (Suárez et al., 2002; Richardson et al., 2007) delimiting a restricted area of riparian species different in structure and function from the adjacent terrestrial zone.

Disturbance, climate change and spatial heterogeneity are important influential factors of the structure and functioning of plant communities, which often are not in compositional equilibrium (Pickett and White, 1985; Chesson and Huntly, 1997). The riparian species of the studied area have to deal with the hydrological disturbance related with the monsoonal climate. Most species do not depend on a period of flooded soil, although some vital functions may be related with the aquatic environment (Neiff, 2004). In addition, hydraulic impacts enabled the development of morphological adaptations in some species in order to withstanding flooding. During high water period, spates produce abrasion and erosion of the banks, displacing and killing most part of the riparian vegetation. Longs and whole trees are displacing downstream, leading open areas to be colonized during low water period. The rapid dispersion of seeds of alien plants by floods and cattle added to the high edge:area ratio would determine that exotic vegetation be the pioneer colonizer of riparian area (Ede and Hunt, 2008).

In accordance with the first hypothesis, ordination analysis detected a geographical pattern of distribution of riparian species, and this was related with the climatic differences existing within the same biome. The southern area of Yungas is drier than those at lower latitude (Bianchi, 2006). Marapa River sub-basin is situated in this southern dry zone, determining some singularities in the composition of riparian species. For example, *M. cisplatensis* was restricted to this sub-basin. This specie is characteristic of the northwestern area of the Chaco dry biome, situated between Tucumán and Catamarca provinces, near to Marapa sub-basin (Demaio et al., 2002). The climatic similarity of the northwestern dry Chaco forest with the southern area of Yungas would determinate that *M. cisplatensis* be exclusive in Marapa sub-basin. In addition, this zone could represent a transitional area between these two ecoregions.

The negative significant relationship between the first axis of the NMS and the total values of QBRy showed the higher anthropic pressure on riparian vegetation of San Javier Hill sub-basin, reflected in a higher number of exotic species. In addition, this relationship showed the sensitive of the modified index to changes in the structure and composition of species at regional scale.

4.2. QBRy

Modifications of the original QBR were accurate and necessary in order to evaluate the conservation status of the riparian zone of Yungas streams. Changes associated with the third paragraph of the original QBR were similar to those included in the QBR-And (Acosta et al., 2009). The high richness of riparian trees reported in Andean streams (Acosta et al., 2009; Sirombra and Mesa, 2010) added to the lack of definition of geomorphologic types in Yungas streams determinated the necessity of a modification in this section in order to be applied in the studied area.

According to Fernández et al. (2009) and Kazoglou et al. (2010), sites of QBRy ≥ 95 such as 1, 15, 28, 29 and 30 could be considered as references due to their natural riparian conditions. The higher stream quality of the sites 28, 29 and 30 would be related with their closeness with the protected area 'San Javier Hill Park'. This zone constitutes an important reservoir of native riparian vegetation, acting as a buffer in front of increasing anthropogenic threats.

In accordance with the second hypothesis, altitude showed a significant positive relationship with the values of QBRy. This result was in accordance with other studies (Ibero et al., 1996; Carrascosa Gómez and Munné, 2000; Suárez et al., 2002) exposing the increase of riparian quality in higher altitude sites as a consequence of the higher distance to urban areas and the inaccessibility of these places. In addition, this relation was not strong as we expected, and this was related with the higher value of QBRy in lower sites of Marapa sub-basin. The distance of these sites to urban areas would determinate the higher quality of riparian condition in this sub-basin.

4.3. Human disturbances in riparian zones

In recent decades, human factors have played an important role, even higher than natural primary succession, in determining changes in riparian landscapes (Décamps et al., 1988). The elimination and substitution of native riparian complexes by non-native ones determinate the simplification of the structural heterogeneity (e.g. Croonquist and Brooks, 1993; Montalvo and Herrera, 1993; Keller et al., 1993). Exotic vegetation reduces the abundance and diversity of native species, impacting in long-term on the structure and function of ecosystems (Lowe et al., 2000).

In Yungas riparian forests, cattle has played a definitive role in the introduction of exotic species (Sirombra and Mesa, 2010). Livestock, by trampling and browsing, has produced soil compaction and the elimination of native plant regrowth (Sirombra and Mesa, 2010). Added to this impact, agriculture expansion, urbanization and recreation are the main determinants of the proliferation of alien plants (Grau and Aragón, 2000; Grau et al., 2008; Sirombra and Mesa, 2010).

In areas previously impacted by livestock, species characterized by an endocarp or seed resistant to digestion were abundant. This includes species typical of the Yungas such as *Juglans australis* and *Enterolobium contortisilicuum*, species characteristic of Chaco biome (e.g. *Acacia*), and exotic species such as *Gleditsia triacanthos* and *Psidium guajaba* (Chalukian, 1992; De Viana and Colombo-Speroni, 2000; Grau and Aragón, 2000). *Morus alba* and *Ligustrum lucidum* are natives from China. Birds feed their fruits, dispersing their seeds at distant locations where they may germinate and become established (Tolaba, 1996). *L. lucidum* is extremely invasive and forms dense monospecific layers inside forests (Batcher, 2000). *G. triacanthos* is a deciduous tree of the southeastern of North America (Burton and Bazzaz, 1995). Within Yungas forest, cattle graze their fruits, dispersing their seeds wherever they move (Quiroga et al., unpublished results). This specie has expanded in San Javier Hill, displacing native vegetation (Grau and Aragón, 2000). *Acacia macracantha*, *Acacia caven* and *Schinus bumellioides* are typical of Chaco biome (Zuloaga and Morrone, 2011). The presence of these species in Yungas streams was restricted to areas disturbed by cattle (Saravia Toledo, 1996; Quiroga et al., unpublished results). *L. camara* and *A. donax* have been nominated as one of the top 100 worst invaders of the world by the invasive species specialist group of the World Conservation Union (Lowe et al., 2000). The facility of *A. donax* to invade river banks added to its high water requirement (Boose and Holt, 1999) would determinate the importance of this specie as threat to the integrity of the riparian zone. The success of *L. camara* in the riparian ecosystems may be attributed to the large number of fruits per plant (Kohli et al., 2004; Parveen, 2010), the ability to grow under a wide range of climatic conditions (Day et al., 2003), and the release of allelochemicals by roots (Ambika et al., 2003). The explicit invasion of *L. camara* in riparian zones has been recently reported in India (Parveen et al., 2011).

In some riparian areas of the piedmont and hillside of Yungas, native vegetation had been replaced by species of *Pinus* and *Eucalyptus*. Monospecific forestry practices have been considered as an alternative to restore degraded lands with the potential to become diverse in the long-term (Lugo, 1997; Parrota et al., 1997). Preliminary observations in San Javier Hill suggested that *Pinus* and *Eucaliptus* would promote the recovery of native forest and would provide habitat for birds (Vides-Almonacid, 1992).

The negative consequences of the introduction of exotic species are evident in some sectors of Lules River sub-basin, resulting in significant changes in the physiognomy of the landscape, seemly to a forest with xerophytic characteristics than one corresponding to the Yungas biome (Quiroga et al., unpublished results).

The historic use of Lules vegetation as feeding area for livestock determinates the name of Potrero de las Tablas (site 13) constituting with sites 12 and 19, a path for cattle movement. In addition, the natural condition of riparian vegetation of some sites such as 15 was related to their inaccessible physiographical characteristics that make difficult the introduction of people and cattle.

Agricultural expansion, construction of roads, intense arid extraction, dump of solid and industrial waste, modification of fluvial terraces constraining the river channel, introduction of rigid structures in the channel and along the margins, were some of the impacts that deteriorated the cover, structure and quality of the streams and riparian vegetation of the eastern side of the San Javier Hill. Abandoned fields of citrus plantations are common in this sub-basin. After some years of abandonment, the secondary vegetation has a structure that results attractive for birds allowing the arrival of pioneers native species such as *Cinamommum porphyrium*, *Solanum riparium*, *Urera caracasana* and the exotic *Morus* spp. (Grau, 2004).

This study is the first in the northwestern of Argentina to adapt an index to evaluate the quality of riparian vegetation. The QBRy index represents a useful tool to identify sites where stream and riparian vegetation are severely impaired or pristine, and those where conservation effort should be directed. The introduction of exotic species represents a real problem that threatens the integrity of the Yungas forest. In addition, this study highlights the importance of a protected area for conservation of the quality of riparian vegetation. Within Yungas where riparian corridors acts as refuge to a great variety of plants and animals, the protection of the few existing well-preserved riparian sites and the necessity of restoration of highly altered riparian ones becomes an essential priority for biodiversity sustainability.

Finally, this work represents the first approximation of a protocol that can be applied in other Yungas basins. We suggest to evaluate the status of riparian vegetation in conjunction with other biological indicators in order to obtain a holistic view of the health of these lotic systems.

Acknowledgments

Special thanks to Ramón Luis Imbert for his assistance in map diagram. We greatly appreciate to Dr. Mercedes Marchese and Dr. Carolyne Stephens for their constructive suggestions. We are also grateful to the two anonymous reviewers for their comments that significantly improved the manuscript. This study was supported by ILINOA, Research Program No. 26/G446-1, Ministerio de Ciencia y Tecnología, Universidad Nacional de Tucumán and Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET).

Appendix A.

List of riparian species relative to the three studied sub-basins. Origin and habit are also shown.

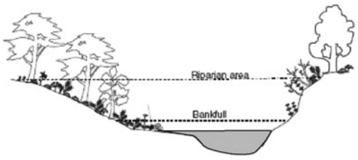
Taxa	Origin	Habit
Acacia caven (Molina) Molina var. caven	Exotic	Tree
Acacia macracantha Humb. & Bonpl. ex Willd.	Exotic	Tree
Acacia praecox Griseb.	Native	Tree
Allophylus edulis (St. Hill.) Radlkofer	Native	Tree
Aloysia gratissima (Gill. ex Hook. et Arn.) Hicken	Native	Shrub
Anadenanthera colubrina (vell.) Bernan Ver (grises) atschul	Native	Tree
Arundo donax L.	Exotic	Reed
Baccharis salicifolia (Ruiz et Pav.) Persoon	Native	Shrub
Blepharocalyx salicifolius (H.B.K.) O.Berg.	Native	Tree
Boehmeria caudata Sw.	Native	Shrub
Carica quercifolia (St.Hil.) Solms-Laub.	Native	Tree
Cassia carnaval Speg.	Native	Tree
Cedrela lilloi C. DC.	Native	Tree
Celtis iguanaea (Jacq.) Sarg.	Native	Climber
Cestrum parqui L'Hér.	Native	Shrub
Cestrum strigillatum Ruiz & Pav.	Native	Shrub
Chamissoa altísima (Jacq.) H.B.K.	Native	Climber
Cinnamomum porphyrium (Griseb.) Kosterm.	Native	Tree
Cupania vernalis Cambess.	Native	Tree
Duranta serratifolia (Griseb.) Kuntze	Native	Tree
Enterolobium contortisiliquum (Vell. Conc.) morong	Native	Tree
Eriobotrya japonica (Thunb.) Lindl.	Exotic	Tree
Eucalyptus sp.	Exotic	Tree
Eugenia uniflora L.	Native	Tree
Eupatorium lasiophtalmun Griseb.	Native	Shrub
Gleditsia triacanthos L.	Exotic	Tree
Grevillea robusta A. Cunn.	Exotic	Tree
Guadua angustifolia Kunth	Exotic	Reed
Heliocarpus popayanensis H.B.K.	Native	Tree
Jacaranda mimosifolia D.Don	Native	Tree
Juglans australis Griseb	Native	Tree
Lantana camara L.	Exotic	Shrub
Ligustrum lucidum W.T. Aiton	Exotic	Tree
Lycium cestroides Schldl.	Native	Tree
Manihot grahamii Hook.	Exotic	Tree
Morus alba L.	Exotic	Tree
Myrcianthes cisplatensis (Cambess.) O. Berg	Native	Tree
Myrcianthes mato (Griseb.) McVaugh	Native	Tree
Myrcianthes pungens (Ver) Legrand	Native	Tree
Myrsine laetevirens (Mez) rechav.	Native	Tree
Parapiptadenia excelsa (Griseb.) Burkart	Native	Tree
Persea americana Mill.	Exotic	Tree
Phenax laevigatus Wedd.	Native	Shrub
Phyllostylon rhamnoides (J. Poiss.) Taub.	Native	Tree
Pinus sp	Exotic	Tree
Piper hieronymi C DC.	Native	Tree
Piper tucumanum C. DC.	Native	Tree
Pisonia ambigua Heimerl	Native	Tree
Pisoniella arborescens var. glabrata Heimerl	Native	Climber
Prunus tucumanensis Lillo	Native	Tree
Psidium guajava L.	Exotic	Tree
Psychotria carthagenensis Jacq.	Native	Shrub
Pyracantha angustifolia (Franch.) C.K. Schneid.	Exotic	Shrub
Ricinus communis L.	Exotic	Shrub
Rubus imperialis Cham. & Schltdl	Native	Climber
Ruprechtia laxiflora Meisn.	Native	Tree
Salix humboldtiana Willd.	Native	Tree
Sambucus peruvianum H.B.K.	Native	Tree
Schinus bumelioides Johnst.	Exotic	Tree
Senecio peregrinus Griseb.	Native	Shrub
Solanum riparium Pers. Syn.	Native	Tree
Tabebuia avellanedae Lorentz ex Griseb.	Native	Tree
Tecoma stans (L.) Juss. ex H. B. K.	Native	Tree
Terminalia triflora (Griseb.) Lillo	Native	Tree
Tessaria integrifolia Ruiz et Pavon	Native	Tree
Tipuana tipu (Benth.) O. Kuntze	Native	Tree
Trema micrantha (L.) Blume	Native	Tree
Urera baccifera (L.) Gaud	Native	Tree
Urera caracasana (Jacq.) Gaudich ex Griseb	Native	Tree
Verbesina suncho (Griseb.) S.F. Blake	Native	Shrub
Vernonia fulta Griseb.	Native	Climber
Vernonia squamulosa Hook. et. Arn.	Native	Shrub
Xylosma pubescens Griseb.	Native	Tree
Zanthoxilum fagara (L.) Sarg.	Native	Tree
Zanthoxilum naranjillo Griseb.	Native	Tree

Appendix B.

QBRy INDEX

Riparian habitat quality

Field sheet



Score of each part cannot be negative or exceed 25

Station	
Date	

SECTION 1: Total riparian cover Section 1 score

Score	
25	>80% of riparian cover (excluding annual plants)
10	50-80% of riparian cover
5	10-50% of riparian cover
0	<10% of riparian cover
+ 10 + 5	If connectivity between the riparian forest and the woodland is total If the connectivity is higher than 50%
- 5 -10	Connectivity between 25 and 50% Connectivity lower than 25%

SECTION 2: Cover structure Section 2 score

Score	
25	>75% of tree cover
10	50-75% of tree cover or 25-50% tree cover but 25% covered by shrubs
5	Tree cover lower than 50% but shrub cover at least between 10 and 25%
0	< 10% of either tree or shrub cover
+ 10 + 5 + 5	At least 50% of the channel has shrubs or climber plants If 25-50% of the channel has shrubs or climber plants If trees and shrubs are in the same patches
- 5 - 5 - 10	If trees are regularly distributed and shrubland is >50% If trees and shrubs are distributed in separate patches, without continuity Trees distributed regularly, and shrubland <50%

SECTION 3: Cover quality Section 3 score

Score	
25	All native trees in the riparian zone
10	75% of native tree cover and <25% of isolated non-native trees
5	25-50% of native tree cover and 50-75% of isolated non-native trees
0	>50% of isolated non-native trees cover
+10 +5	>75% of native shrubs cover 50-75% of native shrub cover and 25-50% of non-native shrub cover
-5 -10 - 10	25-50% of native shrubs cover and 50-75% of non-native shrub cover. <25% of native shrubs cover Exotic species forming monoespecific communities (trees or shrubs)

SECTION 4: Channel alteration Section 4 score

Score	
25	Unmodified river channel
15	Modifications in one fluvial terrace adjacent to the river bed, constraining the river channel
10	Modifications in both fluvial terraces adjacent to the river bed, constraining the river channel
10	Channel modified by rigid structures along one margin
5	Channel modified by rigid structures along both margins
0	Channelized river
- 10 - 10 -10 -10 -5	River bed with rigid structures (e.g wells) Transverse structures into the channel (e.g weirs) If there are discharge of urban solid waste and/or industrial effluents Intense gravel or sand extraction Some gravel or sand extraction

Final score (sum of four section scores)	

References

Acosta, R., Ríos, B., Rieradevall, M., Prat, N., 2009. Propuesta de un protocolo de evaluación de la calidad ecológica de ríos andinos (CERA) y su aplicación a dos cuencas en Ecuador y Perú. Limnetica 28, 35–64.

Ambika, S.R., Poornima, S., Palaniraj, R., Sati, S.C., Narwal, S.S., 2003. Allelopathic plants: *Lantana camara* L. Allelopathy 12, 147–162.

Balducci, E.D., Arturi, M.F., Goya, J.F., Brown, A.D., 2009. Potencial de plantaciones forestales en el pedemonte de las Yungas. Fundación ProYungas. Ediciones del Subtrópico, Tucumán, Argentina.

Batcher, M.S., 2000. Element Stewardship Abstract for *Ligustrum* spp. The Nature Conservancy, Arlington, VA.

Bianchi, A., 2006. Mapa de las isohietas anuales del Noroeste argentino (NOA). Secretaría de Agricultura, Ganadería, Pesca y Alimentación. Instituto Nacional de Tecnología Agropecuaria (INTA). Centro regional Salta, Jujuy. Estación Experimental Agropecuaria Salta, Recursos Naturales.

Boose, A.B., Holt, J.S., 1999. Environmental effects on asexual reproduction in *Arundo donax*. Weed Res. 39, 117–127.

Burton, P.J., Bazzaz, F.A., 1995. Ecophysiological responses of tree seedlings invading different patches of old-field vegetation. J. Ecol. 83, 99–112.

Brown, A.D., 1986. Autoecología de Bromeliáceas epífitas y su relación con Cebus apella, Primates en el noroeste argentino. Tesis doctoral. Universidad Nacional de La Plata, Argentina.

Brown, A.D., Grau, A., Lomáscolo, T., Gasparri, N.I., 2002. Una estrategia de conservación para las selvas subtropicales de montaña (Yungas) de Argentina. Ecotropicos 15, 147–159.

Brown, A.D., Malizia, L., Lomáscolo, T., 2006. Reserva de la Biosfera de las Yungas: armando el rompecabezas entre todos. Secretaria Programa sobre El Hombre y la Biosfera Artículo para el Libro sobre Reservas de la Biosfera de países que integran la Red Iberomab.

Carrascosa Gómez, V., Munné, A., 2000. Qualificació dels boscos de ribera andorrans. Adaptació delĩindex QBR als rius dĩalta muntanya. Habitats 1, 4–13.

Chalukian, S., 1992. Regeneración, sucesión y plantas invasoras en un bosque de Yungas, Salta, Argentina. Tesis de Magister. Programa de Maestría en Vida Silvestre. Universidad Nacional. Heredia, Costa Rica.

Chesson, P., Huntly, N., 1997. The role of harsh and fluctuating conditions in the dynamics of ecological communities. Am. Nat. 150, 519–553.

Colwell, S., 2007. The application of the QBR Index to the riparian forests of central Ohio streams. Ph.D. Thesis. The Ohio State University. School of Environment and Natural Resources.

Croonquist, M.J., Brooks, R.P., 1993. Effects of habitat disturbance on bird communities in riparian corridors. J. Soil Water Conserv. 48, 65–70.

Day, M.D., Wiley, C.J., Playford, J., Zalucki, M.P., 2003. Lantana: current management status and future prospects. Australian Centre for International Agricultural Research Canberra. ACIAR Monogr. 102, 1–128.

Décamps, H., Fortuné, M., Gazelle, F., Pautou, G., 1988. Historical influence of man on the riparian dynamics of a fluvial landscape. Landsc. Ecol. 1, 163–173.

Demaio, P., Karlin, U.O., Medina, M., 2002. Árboles Nativos del Centro de Argentina. L.O.L.A. Editorial, Buenos Aires.

De Viana, M., Colombo-Speroni, F., 2000. Invasion de *Gleditsia triacanthos* L. (Fabaceae) en el bosque de San Lorenzo, Salta, Argentina. In: Grau, H.R., Aragón, R. (Eds.), Ecologia de árboles exóticos en las Yungas argentinas. Laboratorio de Investigaciones Ecológicas de las Yungas, Tucumán, pp. 71–84.

Ede, F.J., Hunt, T.D., 2008. Habitat Management Guide. Riparian: Weed Management in Riparian Areas: South-eastern Australia. CRC for Australian Weed Management, Adelaide.

Fernández, L., Rau, J., Arriagada, A., 2009. Calidad de la vegetación ribereña del río Maullín (41°28′S; 72°59′O) utilizando el índice QBR. Gayana Bot. 66, 269–278.

Grau, H.R., Aragón, R., 2000. Árboles invasores de la Sierra de San Javier Tucumán, Argentina. In: Grau, H.R., Aragón, R. (Eds.), Ecología de árboles exóticos en las Yungas Argentinas. Laboratorio de Investigaciones Ecológicas de las Yungas, Universidad Nacional de Tucumán, Tucumán, Argentina, pp. 5–20.

Grau, H.R., Hernández, M.E., Gutierrez, J., Gasparri, N.I., Casavecchia, M.C., Flores, E.E., Paolini, L., 2008. A peri-urban neotropical forest transition and its consequences for environmental services. Ecol. Soc. 13, 35.

Grau, R.H., 2004. Dinámica de bosques en el gradiente altitudinal de las Yungas Argentinas. In: Arturi, M.F., Frangi, J.L., Goya, J.F. (Eds.), Ecología y manejo de los bosques de Argentina, Argentina.

Ibero, C.C., Álvarez, J.C., Blanco, J.C., Criada, J., Sánchez, A., Viada, C., 1996. Ríos de vida. El estado de conservación de las riberas fluviales en España. Sociedad Española de Ornitología, SEO/Birdlife.

Jungwith, M., Muhar, S., Schmutz, S., 2002. Re-establishing and assessing ecological integrity in riverine landscapes. Freshw. Biol. 47, 867–887.

Kazoglou, Y., Fotiadis, G., Koutseri, I., Vrahnakis, M., 2010. Assessment of structural components of riparian forest vegetation of the Prespa Basin with the means of the QBR index. BALWOIS, Ohrid, Republic of Macedonia.

Keller, C.M.E., Robbins, C.S., Hatfield, J.S., 1993. Avian communities in riparian forests of different widths in Maryland and Delaware. Wetlands 13, 137–144.

Kohli, R.K., Dogra, K.S., Batish, D.R., Singh, H.P., 2004. Impact of invasive plants on the structure and composition of natural vegetation of north western Indian Himalayas. Weed Technol. 18, 1296–1300.

Kutschker, A., Brand, C., Miserendino, M.L., 2009. Evaluación de la calidad de los bosques de ribera en ríos del N.O. del Chubut sometidos a distintos usos de la tierra. Ecología Austral 19, 19–34.

Lowe, S., Browne, M., Boudjelas, S., De Poorter, M., 2000. 100 of the World's Worst Invasive Alien Species A selection from the Global Invasive Species Database. The Invasive Species Specialist Group (ISSG), Auckland, N.Z, http://www.issg.org/database.

Lugo, A.E., 1997. The apparent paradox of reestablishing species richness on degraded lands with tree monocultures. Forest Ecol. Manag. 99, 9–19.

Malanson, G.P., 1993. Riparian Landscapes. Cambridge University Press, Cambridge.

McCune, B., Mefford, M.J., 1999. PC-ORD: Multivariate Analysis of Ecological Data, Version 4. 27. MjM Software, Gleneden Beach, Oregon, U.S.A.

Montalvo, J., Herrera, P., 1993. Diversidad de especies de los Humedales: Criterios de Conservación. Ecología 7, 215–231.

Munné, A., Solá, C., Prat, N., 1998. QBR: Un índice rápido para la evaluación de la calidad de los ecosistemas de ribera. Tecnología del Agua 175, 20–37.

Munné, A., Prat, N., Solá, C., Bonada, N., Rieradevall, M., 2003. A simple field method for assessing the ecological quality of riparian habitat in rivers and streams: QBR index. Aquat. Conserv.: Mar. Freshw. Ecosyst. 13, 147–163.

Naiman, R.J., Décamps, H., Pollock, M., 1993. The role of riparian corridors in maintaining biodiversity. Ecol. Appl. 2, 209–212.

Naiman, R.J., Décamps, H., 1997. The ecology of the interfaces; riparian zones. Ann. Rev. Ecol. Syst. 28, 621–658.

Neiff, J.J., 2004. Bosques fluviales de la cuenca del Paraná, in: Arturi M.F., Frangi J.L., Goya J.F. (Eds.). Ecología y manejo de los bosques de Argentina, Argentina, pp. 1–26.

Ocampo-Duque, W., Schuhmacher, M., Domingo, J.L., 2007. A neural-fuzzy approach to classify the ecological status in surface waters. Environ. Pollut. 148, 634–641.

Palma, A., Figueroa, R., Ruiz, V.H., 2009. Evaluación de ribera y hábitat fluvial a través de los índices QBR e IHF. Gayana 73, 57–63.

Parrota, J.A., Turnbull, J.W., Jones, J., 1997. Catalyzing native forest regeneration on degraded tropical lands. Forest Ecol. Manag. 99, 1–7.

Parveen K.D., 2010. Ecological audit of invasive weed *Lantana camara* L. along an altitudinal gradient in Pauri Garhwal (Uttranchal). Ph.D. Thesis. Faculty of Sciences, Panjab University Chandigarh, India.

Parveen, K.D., Ravinder, K.K., Batish, D.R., 2011. Impact of *Lantana camara* L. invasion on riparian vegetation of Nayar region in Garhwal Himalayas (Uttarakhand India). J. Ecol. Nat. Environ. 3, 11–22.

Pickett, S.T., White, P.S., 1985. The Ecology of Natural Disturbance and Patch Dynamics. Academic Press, Orlando, FL, U.S.A.

Prat, N., Munné, A., Solá, C., Rieradevall, M., Bonada, N., Chacón, G., 1999. La qualitat ecològica del Llobregat, el Besòs i el Foix. Estudis de la Qualitat Ecològica dels Rius, Diputació de Barcelona, Área de Medi Ambient, Spain.

Richardson, D.M., Holmes, P.M., Esler, K.J., Galatowitsch, S.M., Stromberg, J.C., Kirkman, S.P., Pysek, P., Hobbs, R.J., 2007. Riparian vegetation: degradation, alien plant invasions, and restoration prospects. Divers. Distrib. 13, 126–139.

Saravia Toledo, C.J., 1996. Impacto de la ganadería en las cuencas hidrográficas del Noroeste Argentino. Anales de la Academia Nacional de Agronomía y Veterinaria 50, 13–32.

Sirombra, M.G., Mesa, L.M., 2010. Composición florística y distribución de los bosques ribereños subtropicales andinos del Río Lules, Tucumán, Argentina. Rev. Biol. Trop. 58, 499–510.

Stanford, J.A., Ward, J.V., 1993. An ecosystem perspective of alluvial rivers: connectivity and the hyporheic corridor. J. N. Am. Benthol. Soc. 12, 48–60.

Suárez, M.L., Vidal-Abarca, M.R., Sánchez-Montoya, M.M., Alba-Tercedor, J., Álvarez, M., Avilés, J., Bonada, N., Casas, J., Jáimez-Cuéllar, P., Munné, A., Pardo, I., Prat, N., Rieradevall, M., Salinas, M.J., Toro, M., Vivas, S., 2002. Las riberas de los ríos mediterráneos y su calidad: el uso del índice QBR. Limnetica 21, 135–148.

Tockner, K., Stanford, J.A., 2002. Riverine flood plains: present state and future trends. Environ. Conserv. 29, 308–330.

Tolaba, J.A., 1996. Flora del valle de Lerma, Moraceae L. Aportes botánicos de Salta-Ser. Flora. Herbario MCNS. Facultad de Ciencias Naturales Universidad Nacional de Salta.

Yang, J., Dilts, T.E., Condon, L.A., Turner, P.L., Weisberg, P.J., 2011. Longitudinal and transverse-scale environmental influences on riparian vegetation across multiple levels of ecological organization. Landsc. Ecol. 26, 381–395.

Vides-Almonacid, R., 1992. Estudio comparativo de la taxocenosis de aves de los bosques montanos de la sierra de San Javier, Tucumán. Bases para su manejo y conservación. Tesis doctoral, Facultad de Ciencias Naturales, Universidad Nacional de Tucumán, Tucumán, Argentina.

Zuloaga, F.O., Morrone, O., 2011. Catálogo de Plantas Vasculares de la República Argentina. II. Instituto de Botánica Darwinion http://www.darwin.edu.ar/publicaciones/catalogovascII/atalogovascII.asp.