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RESEARCH ARTICLE

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The role of riparian vegetation in the evaluation of ecosystem health: The case of semiarid conditions in Northern Mexico

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Abstract

The Pesquería River (north-eastern Mexico) has long been subjected to considerable anthropogenic pressures. For this reason, it has been identified by the Mexican National Commission for the Knowledge and Usage of Biodiversity as a priority resource to be evaluated and restored. In order to establish the means required for the restoration of the river, the condition of its riparian ecosystem must be evaluated. To evaluate the quality of the riparian forest, we adapted the Qualitat del Bosc de Ribera index methodology for Mediterranean rivers for the semiarid rivers of north-eastern Mexico (QBR-RNMX). The QBR-RNMX index included modifications to the four sections that comprise the original index, and their values range between 0 and 100. Using the five levels of riparian quality defined in the index, in the area surrounding the Pesquería River, we found poor or very poor conditions at 66% of the sampling sites, average-good conditions at 27% of the sites, and only one sampling site with excellent conditions. These results show that the riparian forest has been impacted significantly by urbanization, agriculture, and the presence of many invasive species. We recommend the application of the QBR-RNMX annually in order to evaluate the riparian forest's quality and to assess its ecological status. This may be used for the establishment of restoration plans in high-impact zones and contingency plans to eliminate invasive species along the Pesquería River.

KEYWORDS

anthropogenic pressures, invasive species, QBR-RNMX, riparian forest, semiarid rivers

1 | INTRODUCTION

An increased interest in the ecological condition of rivers has been observed around the world, because rivers are ecosystems that are subject to anthropogenic pressures and have significant consequences for freshwater ecosystems (Allan, 2004; Master et al., 1998; Naiman & Turner, 2000). Anthropogenic impacts upon freshwater ecosystems alter their physical and biological characteristics, thus modifying their natural condition (Nilsson, Jansson, Malmgvist, & Naiman, 2007). The European Union Water Framework Directive (D.O.C.E., 2000) considers the ecological condition of freshwater bodies as a measure of ecosystem health. The river health can be evaluated using a series of biological, physicochemical, and hydromorphological indicators (Mendoza Cariño et al., 2014), including some specific methodologies for assessing riparian areas. Therefore, the characterization of the reference conditions is a key process in the successful evaluation of the ecological state of a river (Feio et al., 2014).

The riparian zone is one of the areas most disturbed by anthropogenic activities, and objectives for restoration plans should be clearly stated. The riparian zone is defined as the area of transition between the river channel and the adjacent land-based ecosystem and includes both the flowing channel and the surrounding land that is influenced by fluctuations in water level (Malanson, 1993). The heterogeneity and complexity of riparian ecosystems make studying, evaluating, and restoring them difficult and mean that managing them sustainably is a complex endeavour (Chovanec et al., 2000; Reed & Carpenter, 2002). Because they represent an interface between the land and the water, one of their functions is to regulate the river water quality by acting as a filter, preventing soil erosion, regulating temperature and light levels, and decreasing the number of contaminants that enter the stream. Riverside vegetation is an important indicator in the evaluation of the ecological status of rivers used in land planning and ecosystem management (Suárez et al., 2002).

The most important pressure factors associated with a global reduction in biodiversity and the degradation of the riparian zones are deeply linked to loss of habitat due to anthropogenic impacts, combined with the invasion of non-native flora and fauna (Millennium Ecosystem Assessment, 2005; Ruzycki, Beauchamp, & Yule, 2003). These pressures deeply affect the natural environmental heterogeneity of riverbank environments, causing considerable damage to both the levels of biodiversity and to ecological processes (Strayer et al., 2003; Townsend, Doledec, Norris, Peacock, & Arbuckle, 2003; Ward, 1998). This often has grave consequences for human health and for the local economy (Vitousek, D Antonio, Loope, & Westbrooks, 1996).

Various procedures for evaluating and measuring the quality of riparian vegetation have been developed (Boon, Wilkinson, & Martin, 1998; Raven, Holmes, Dawson, & Everard, 1998). The Qualitat del Bosc de Ribera (QBR) index was developed to assess the riparian forest quality of Mediterranean rivers in Spain (Munné, Prat, Solà, Bonada, & Rieradevall, 2003; Munné, Solà, & Prat, 1998; Munné, Solà, Prat, & Rieradevall, 1998). Numerous authors have adapted this methodology to different geographical regions because of its simplicity and efficiency (Acosta, Ríos, Rieradevall, & Prat, 2009; Carrasco et al., 2014; Colwell & Hix, 2008; Kutschker, Brand, & Miserendino, 2009; Sirombra & Mesa, 2012).

The QBR index considers key aspects of riparian vegetation, such as coverage and structure, and aspects of the morphology of the riparian zone, such as anthropogenic intervention in the landscape. It is worth noting that in the investigation carried out by Suárez and Vidal-Abarca (2000), they conclude that the index must be adapted in order to consider the local environment, placing considerable emphasis on ephemeral rivers.

In Mexico, the QBR index has been applied to the El Tunal and Sauceda Rivers in the state of Durango, and the results showed the current pressures on the riparian forest ecosystem. The ease of application, the low costs incurred, and the reliability of the information generated were noted as important factors in the decision to use this methodology (Rodríguez-Téllez, Domínguez-Calleros, Pompa-García, Quiroz-Arratia, & Pérez López, 2012; Rodríguez-Téllez et al., 2016). Previous work suggests that with the appropriate changes, the QBR index allows for the in situ evaluation of the conservation value of riverbank vegetation, including the assessment of anthropogenic impacts on any riparian ecosystem (Fernández, Rau, & Arriagada, 2009).

Given the lack of information and considerable pressures that Mexican rivers are subject to, the National Commission for the Understanding and Usage of Biodiversity implemented the Priority Hydrological Regions programme in 1998 (Aguilar et al., 2009). Currently, the programme considers the Pesquería River (Nuevo Léon, México) as a priority case for ecological evaluation. The aim of this investigation is to fully understand the current quality of the Pesquería River's riparian forest by typifying it and applying the QBR index, which has been adapted for specific local conditions.

2 | MATERIALS AND METHODS

2.1 | Study area and river characterization

The Pesquería River (within Hydrological Region 24, Bravo-Conchos) has a catchment area of 5,255.56 km^2, and its main course is 288.22 km in length (Figure 1). The river drains its waters from west to east with an annual average flow of 2.04 m^3/s through the states of Coahuila and Nuevo Léon. The climate where the subbasin is located is extremely variable but is predominately semiarid and has a mean elevation of 542 m above sea level with an average gradient of 0.4%. The average temperature in the subbasin is between 20°C and 24°C with a total annual rainfall of between 400 and 700 mm (Ferriño, 2016).

Prior to the study, land use in the basin was characterized using digital maps from the digital map database of the National Institute of Statistics and Geography of Mexico (2015). We established the area of the riparian zone as stipulated in section XLVII of the third article of the “Mexican National Water Law 1992” (L.A.N., 1992). The distance between sampling sites was chosen so that it did not exceed 10 km (Acosta et al., 2009), given that at larger distances the factors being evaluated may lose continuity and parts of the vegetation may remain unanalysed (Rodríguez-Téllez et al., 2012). The river characterization was conducted in February 2016. It consisted of an inventory of the composition and structure of the vegetation as well as an in situ physicochemical analysis of the water in order to determine the nature of the water present in the study area and the possible anthropogenic effects on the river. This study was conducted over 108 km of the hydrological subbasin of the Pesquería River where 15 sampling sites were selected (Figure 2) using digital maps from the National Institute of Statistics and Geography of Mexico (2015), which were obtained from the geographic information system GAIA.

A transect of a maximum of 150 m was estimated for each sampling site, taking into consideration the riparian zone and the width of the channel. For each sampling site, the QBR-RNMX was applied using the field sheet (Appendix A), containing the adapted version of the index. Aerial photographs obtained via drone were used to evaluate the level of riparian coverage (vegetation coverage and connectivity between the adjacent forest ecosystem and the riparian forest), the structure of the coverage (tree coverage and concentration of halophytes), and any modifications to the waterway. Images were taken at two heights in order to show waters above and below the source and to create an orthomosaic map with various images of the stretch studied (Figure 3).

In order to evaluate the third category, the most abundant species of vegetation and the geomorphological type corresponding to each sampling site were determined in situ. For this study, halophytes and shrubs that grow between the riparian zone and the channel were recorded. They increase the value of the index as they offer a habitat for many species.

Statistical analyses were conducted using the open-source software R (R Core Team, 2016) with R Studio 1.0.153 Data (Racine, 2011). The Pearson correlation was used to analyse the relationship between the QBR-RNMX and the physicochemical parameters.

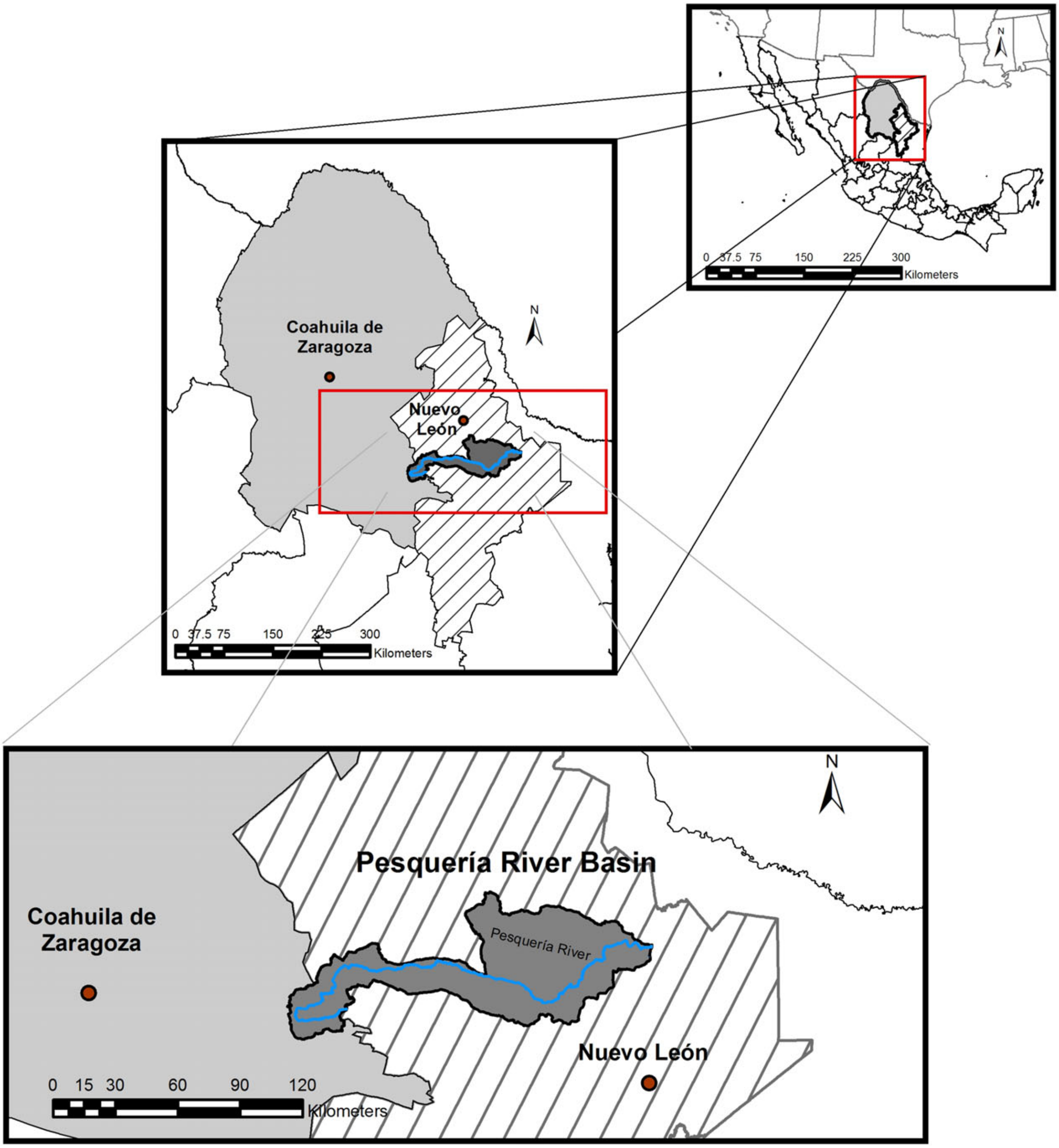

FIGURE 1 Study area: Pesquería River subbasin (located between coordinates 25°48′15.67″N, 100°39′15.80″W and 25°39′21.94″N, 99°41′11.87″W) [Colour figure can be viewed at wileyonlinelibrary.com]

2.2 | QBR-RNMX index

When riverbank forests are evaluated using the QBR index proposed by Munné and colleagues (Munné et al., 2003; Munné, Solà, & Prat, 1998), there should be a focus on the essential aspects of riverbank vegetation according to four different categories (Jáimez-Cuéllar et al., 2002). The adaptation of the QBR index for use along the Pesquería River, for which we propose the name QBR-RNMX (QBR Ríos del Norte de México [northern rivers of Mexico]), included the modification of several categories based on previous adaptations of the QBR to other rivers (Acosta et al., 2009; Munné et al., 2003; Munné, Solá, & Pagés, 2006).

For the first category, the percentages for evaluating riverbank vegetation coverage were modified (Table 1). This does not affect the evaluation, because the aridity gradient in this climate reduces the natural density of the arboreal layer and prevents species from colonizing (Tabacchi, Planty-Tabacchi, Salinas, & Décamps, 1996). Furthermore, the salinity of the systems found here usually limits the survival of many potential species (Suárez & Vidal-Abarca, 2000).

For the second section of the criteria, the expression regarding "tree coverage less than 50% and other shrub coverage between 10 and 25%" was adapted as follows: "tree coverage less than 25% and other shrub coverage between 10 and 25%," considering the

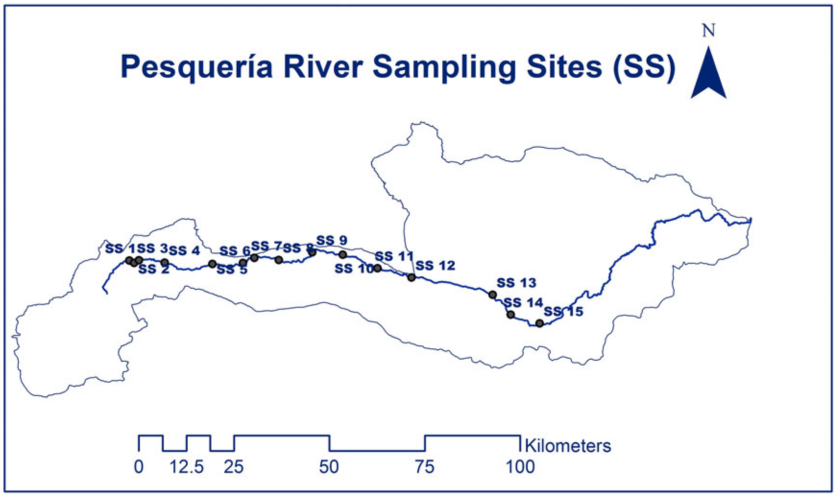

FIGURE 2 Pesquería River sampling sites [Colour figure can be viewed at wileyonlinelibrary.com]

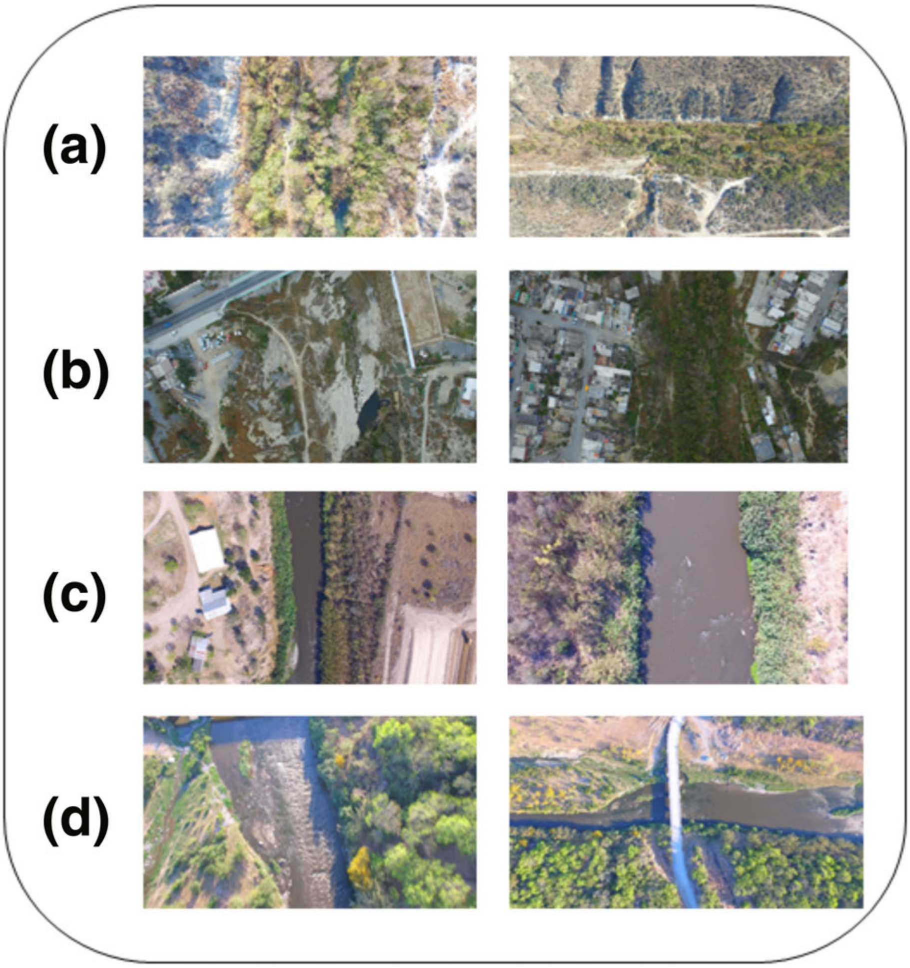

FIGURE 3 Drone aerial pictures. (a) Reference condition zone (Sampling Site 1). (b) Industrial and urban zone (Sampling Site 4). (c) Agricultural impacted zone (Sampling Site 12). Nonimpacted agricultural zone (Sampling Site 15) [Colour figure can be viewed at wileyonlinelibrary.com]

vegetation characteristics of the river and grading them in the same manner (Vidal-Abarca, Gómez, & Suárez, 2004).

The section that required the most modifications was section three, which was adapted to consider the geomorphology and number of autochthonous and allochthonous species present. In this section, the possible definitions for the geomorphological type of the riparian zone were reduced from three to two, offering only the following typologies: headwaters and middle stretches. As a tributary of the San Juan River, the Pesquería River does not fit the characteristics of the third type, which as defined by Munné et al. (2003) represents

TABLE 1 Differences in the evaluation criteria between Qualitat del Bosc de Ribera (QBR) index and QBR index for ephemeral rivers to assess the total riparian cover

Score	QBR index (Munné et al., 2003)	QBR index ephemeral rivers (Munné et al., 2006)
25	>80% of riparian cover	>50% of riparian cover
10	50–80% of riparian cover	30–50% de of riparian cover
5	10–50% of riparian cover	10–30% of riparian cover
0	<10% of riparian cover	<10% of riparian cover

the final stretch of a river. The number of autochthonous and allochthonous species was evaluated during the characterization in order to set boundaries between quality classes in this category. Within this section, an extra option was removed, which reads as follows: "if there exists any continuity in the community throughout the river (between 75% and 50% of the riparian zone)." This was because during the investigation, no area was found to demonstrate this characteristic, and further, it is considered to be within the extra positive aspects gradable for each section. Finally, for the fourth section, one of the "extra" negative values was imported from the third section, which evaluates the presence of waste in the stretch of river studied; an extra negative marking point was added for the presence of permanent waste in the river that is difficult to remove (Acosta et al., 2009).

3 | RESULTS

3.1 | River characterization

The characterization of the Pesquería River showed morphological characteristics consistent with loamy basins and an elevated concentration of salt in the water, as well as vegetation and fauna typical of semiarid zones. The distribution of the land use and vegetation obtained for the subbasin was scrubland (61%), mesquite–huizachal (16%), woodland (2.3%), thicket (0.65%), agricultural, livestock and forestry use (18.7%), major towns (1.34%), and areas without vegetation (0.04%).

3.1.1 | Riparian zone vegetation

A total of 14 species of riparian trees and shrubs were recorded for all transects, covering every sampling site. Six of the species were present at the majority of the sites, whereas two of the 14 were recorded at a single site. The vegetation inventory revealed seven native species. Four are considered representative of the region whereas three are widely distributed across Mexico. The rest were identified as invasive species (Appendix B). Some of the common species are not specific to the riparian area and are widely distributed in the basin, whereas the species associated exclusively with the riparian areas (e.g., *Salix nigra*) were not the most abundant in many cases.

3.1.2 | River water characteristics and the QBR-RNMX

The physicochemical characterization is an indicator of the potential anthropogenic pressures. It also shows the high natural salt content of the river water (see the total of dissolved solids and the conductivity at Site 1, which is close to reference conditions). The physiochemical parameters used in the characterization are presented in Table 2. The physicochemical results show a close relationship with those obtained using the QBR-RNMX index. The results of the Pearson correlation are presented in Table 3; this table indicates the correlation between each evaluation category of the QBR-RNMX with the physicochemical parameters obtained during the characterization of the Pesquería River. The results indicate that Categories 1, 2, and 4 display a negative correlation with most physicochemical parameters. Only Category III (largely influenced by the presence of invasive species) displayed no significant correlations.

TABLE 2 Physicochemical parameters in the Pesquería River

Sampling sites	pH	Conductivity (μS/cm)	Salinity (ppt)	TSS (ppt)	TDS (ppm)	Cl^- (mg/L)	SO^{-2}_4 (mg/L)	DO (mg/L)	BOD (mg/L)
SS 1	6.21	1,907	0.92	1	894.33	547.30	500.00	8.90	8.40
SS 2	6.97	1,683	0.81	4	792.33	323.27	386.00	8.84	13.30
SS 3	7.02	1,707	0.92	2	886.67	180.83	450.00	8.60	9.25
SS 4	7.38	1,663	0.91	123	880.33	430.88	775.00	8.70	45.64
SS 5	8.5	10,170	3.85	259	3,473.00	779.57	838.33	5.92	19.00
SS 6	6.16	4,100	3.57	19	3,230.00	1,251.53	220.00	7.13	9.50
SS 7	6.59	3,720	2.54	12	2,337.00	809.71	1,527.00	7.19	9.90
SS 8	7.09	3,810	2.41	13	2,200.00	583.70	1,800.00	7.82	13.30
SS 9	6.45	2,269	2.36	8	3,220.00	564.69	200.00	6.67	15.50
SS 10	6.77	2,122	1.06	4	1,000.00	226.49	250.00	5.61	9.10
SS 11	6.2	2,160	1.09	5	1,000.00	221.83	600.00	6.81	17.30
SS 12	6.7	1,897	0.86	20	828.67	253.55	558.00	6.20	15.60
SS 13	6.13	2,123	1.01	94	966.00	177.36	320.00	6.78	22.50
SS 14	6.96	2,283	1.08	41	1,010.00	314.90	380.00	6.28	19.50
SS 15	7.08	2,637	1.13	46	1,120.00	657.30	1,074.00	5.58	18.70

Note. BOD: biochemical oxygen demand; Cl^-: chlorides; DO: dissolved oxygen; SO^{-2}_4: sulfates; TDS: total dissolved solids; TSS: total suspended solids.

TABLE 3 Pearson correlation coefficients and significance between QBR-RNMX categories and physicochemical parameters in the Pesquería River

QBR-RNMX	pH	Conductivity	Salinity	TSS	TDS	SO^{-2}_{4}	Na^{+}	Cl^{-}	DO	BOD
Block 1	−0.28	**−0.67****	**−0.69****	−0.31	**−0.69****	−0.11	**−0.70****	−0.48	−0.02	−0.07
Block 2	−0.33	**−0.54***	**−0.57***	−0.5	−0.60*	0.05	**−0.59***	**−0.56***	0.28	−0.27
Block 3	−0.14	−0.1	−0.12	−0.21	−0.15	0.39	−0.14	−0.05	0.23	−0.14
Block 4	−0.2	−0.47	**−0.51***	−0.31	**−0.55***	0.18	**−0.54***	−0.49	0.09	−0.21

Note. Significant correlations are in bold. BOD: biochemical oxygen demand; DO: dissolved oxygen; TDS: total dissolved solids; TSS: total suspended solids. *$p < 0.05$. **$p < 0.01$. ***$p < 0.001$.

3.2 | Assessing riparian vegetation quality using the QBR-RNMX

A total of 15 sampling sites were evaluated where the average value of the QBR-RNMX index for the Pesquería River was 59, which indicates the presence of major disturbances throughout the basin. Only 6% of the sites sampled were of excellent quality and without disturbances (Sampling Site 1, QBR-RNMX = 100), whereas 27% were of good quality but showed some disturbances (Sampling Sites 2, 13, 14, and 15, QBR-RNMX = 90, 85, 80, and 85, respectively); 34% were of intermediate quality with significant disturbances (Sampling Sites 3, 7, 8, 11, and 12, QBR-RNMX = 65, 65, 70, 65, and 70, respectively). Of the stations, 13% showed significant disturbances and were of poor quality (Sampling Sites 9 and 10, QBR-RNMX = 30 and 40, respectively). Finally, 20% (Sampling Sites 4, 5, and 6, QBR-RNMX = 15, 15, and 5, respectively) of the sites evaluated showed evidence of extreme disturbances and had very-poor-quality riparian vegetation (Figures 4 and 5).

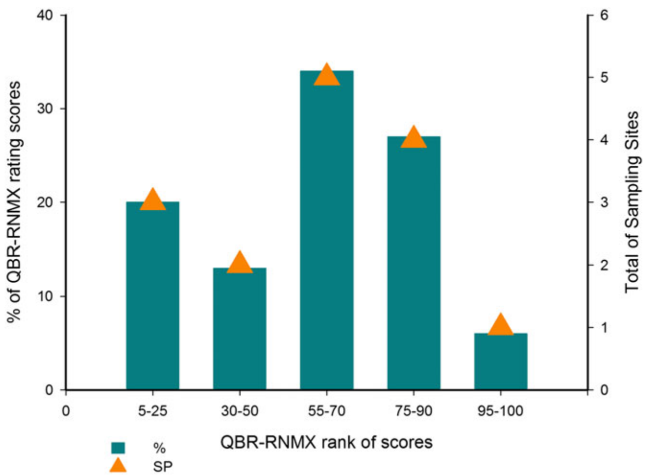

FIGURE 4 Percentage and number of sampling sites over the total number sampled in each quality class according to the QBR-RNMX index [Colour figure can be viewed at wileyonlinelibrary.com]

4 | DISCUSSION

4.1 | Quality of riparian vegetation along the Pesquería River as measured using the QBR-RNMX

The use of the QBR methodology to establish the environmental health of the riparian areas of the Pesquería has been demonstrated to be useful. Different levels of degradation have been detected. Previous adaptations of the QBR index explain that scores >95 could be considered as reference condition sites (Kazoglou, Fotiadis, Koutseri, & Vrahnakis, 2010). The only site in our study with these conditions is located at the Pesquería River's headwaters. Nevertheless, the increase of human activities is related to the lower index scores (Vannote, Minshall, Cummins, Sedell, & Cushing, 1980). More than 80 km of the main reach of the Pesquería River crosses the city

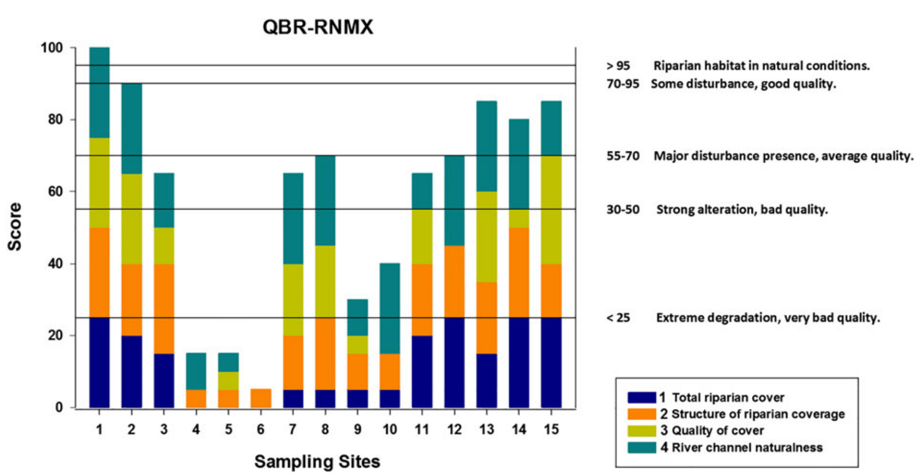

FIGURE 5 The final score obtained for each sampling site and the value for each of the four categories in which the index is divided. The limits between quality classes are shown in the figure [Colour figure can be viewed at wileyonlinelibrary.com]

of Monterrey (Mexico), and the city's edifices and the urban area are located close to the river. Another factor that negatively impacted the QBR-RNMX values is the use of the river as a disposal site for waste by local people.

The agricultural practices on the city's outskirts produce lower pressures on the riparian ecosystem than the urban areas, and the majority of sites sampled in this area gave values of moderate quality. The agricultural areas did show reduced quality values mostly in Block 1; this is due to the reduced level of connectivity between the riparian zone and the naturally occurring adjacent vegetation (Rodríguez-Téllez et al., 2016). In our study, the majority of the sampling sites in the agricultural area had farmland only in one bank of the river, whereas the other side usually still had vegetation. In each case, the agricultural area was normally found to be at some distance from the river itself, far enough to produce any relevant impact upon the QBR-RNMX scores. Therefore, the major reductions in the final scores in the index are due to both the lack of vegetation coverage and the connectivity to other ecosystems.

Transverse structures such as roads and bridges also contribute to the modification of the natural river channel and to soil erosion. They also act as routes of invasion for exotic species and as barriers that alter the dispersion patterns of native species (Smith & Armesto, 2002). In this study, we have tried to ensure that the role of such structures was minimal. Because they were used to access most sampling sites, the stretch evaluated was usually located 50 m either side of these structures, although the presence of several invasive species cannot be discounted. As invasive species are one of the most important problems in Mexican riparian forests, we chose to examine this aspect in detail.

4.2 | Role of invasive species

In recent decades, human activities have played an important role in transforming landscapes by reducing and changing the natural vegetation cover (Décamps, Fortuné, Gazelle, & Pautou, 1988). The replacement and eradication of native riparian communities by non-native ones lead to the simplification of the structural heterogeneity (Rodríguez & Herrera, 1993). Alien species reduce the diversity and abundance of native species, changing the structure and function of ecosystems (Lowe, Browne, Boudjelas, & Poorter, 2000). Nearly 50% of the tree and shrub taxa found were invasive (six of 14), and this is one of the more important features that prevent the riparian area from having very good or good conditions. The most predominant invasive species found throughout the investigation were *Arundo donax* (giant cane), *Ricinus communis* (castor bean), and *Tamarix aphylla* (salt cedar).

In Mexico, giant cane has proven to be one of the most difficult plants to eradicate. This species represents a substantial threat to ecosystems because it can drain rivers and streams (Boose & Holt, 1999). It may transform habitats by displacing native species, thus diminishing the levels of diversity and modifying the structure and composition of species and increasing the risk of bushfires (Contreras-Arquieta, 2012). The castor bean is often present in zones where there has been a previous anthropogenic or natural disturbance such as at the edge of roads, human settlements, and degraded riparian zones (Scarpa & Guerci, 1982). The salt cedar invades natural vegetation and is also capable of making soil more saline as it concentrates salt in its roots (Whaley et al., 2010). Its abundance near the Pesquería is in part due to the naturally high salt content of the basin. These three invasive species have historically caused most damage to Mexican water resources. This is due to the large quantities of water that they consume, which, in turn, increases the salinity of the water by concentration and increases hydrological stress in semiarid regions (I.M.T.A., 2007).

Interestingly, the presence of invasive species does not correlate with the QBR index. This is because at some sites where the QBR score is low (Sites 3, 4, 5, and 7), there are few invasive species, whereas some sites with higher QBR scores host numerous invasive species. Again, the poor vegetation cover appears to be the most important reason for a low QBR-RNMX score, and not the displacement of native species by invaders.

4.3 | Importance of substrate composition and river water salinity in the QBR values

The characteristics of the banks of Pesquería River are typical of a loamy basin. The granulometric composition of the riverbed ranged from pebbles found at its edges to sand and clay found in the centre of the river channel, but in the banks, the loamy natural substrate predominates, which is rich in gypsum (calcium sulphate) and halite (sodium chloride). The composition of the sediments and the level of salinity are two of the main factors influencing the riparian vegetation and the river aquatic ecosystems (Moreno, Suárez, & Vidal-Abarca, 1996; Suárez & Vidal-Abarca, 2000; Vidal-Abarca et al., 2004). Moreover, it explains why the number of species of trees and shrubs is so low (only eight natural and six invaders; see Appendix B) compared with other basins where the vegetation might include more typical riparian trees such as alders. In fact, of the eight native riparian plants, many of them are trees (such as mesquite) that are present across the entire basin. Trees are abundant because of their adaptation to the aridity of the climate and the high salt content of the soil. Showing a significant negative relationship, the Pearson correlation between Evaluation Categories 1, 2, and 4 and the physicochemical parameters (conductivity, salinity, total dissolved solids, Cl^-, and Na^+) reinforces the importance of salt in the composition and structure of the riparian vegetation. Even though the Pesquería River has naturally high levels of salinity, the increase in salinity levels in areas of the river located close to the city demonstrates the anthropogenic impact of urbanization. This is mainly due to the discharge of clandestine waste from industry and from water treatment plants.

It is interesting to note that salinity increases at Site 4 not only due to the influx of salt from industrial waste but also due to the low river level (in the dry period) caused in part by the withdrawal of water from the river to supply Monterrey. As can be seen in Table 1, the salt value declines form Site 10 downstream due to the inputs from sewage plants that have lower concentrations of salt than sites upstream. The high conductivity of the water explains the relatively poor biodiversity of the riparian plants on the banks. Simultaneously, it provides an example of the utility of the QBR as a quality index that can describe the degradation of riparian areas even in these unfavourable conditions for plants.

4.4 | Use of drones as an ecological tool

Drones have great potential for monitoring ecosystem dynamics as they provide a low-cost and low-impact solution for environmental managers working in a variety of settings (Ivosevic, Han, Cho, & Kwon, 2015; Zhang et al., 2016). The use of a drone in this investigation proved to be extremely practical for the evaluation of anthropogenic impacts on the riparian zone and allowed us to clearly establish the composition, connectivity, distribution, and amount (%) of vegetation coverage in both the agricultural and urban areas. It is worth adding that the use of the drone was key in determining the geomorphological type of the Pesquería River, which is necessary in the evaluation of the third category of the QBR-RNMX (quality of the cover; Appendix A).

5 | CONCLUSIONS AND CHALLENGES

This is the first study to adapt the QBR index for the evaluation of riparian vegetation quality in north-eastern Mexico and the first attempt to evaluate the riparian vegetation of the Pesquería River. The assessment of riparian forest quality using the QBR-RNMX alongside other biological indicators and physicochemical parameters provides an overall picture of the general health of the Pesquería River. We recommend the application of the QBR-RNMX index for the management and development of ecological policies in Mexico.

As anthropogenic pressures and invasive species have the biggest impact on the Pesquería River's riparian vegetation, we encourage an annual quality measurement using the QBR-RNMX index. A vegetation inventory must also be completed during the restoration process, and a plan to eradicate invasive species needs to be put in place. Conservation plans that allow for the preservation and reestablishment of the riparian forests must be drawn up urgently. We also suggest that the river management strategy be multidisciplinary so that managers from different fields can collaborate in the restoration of the river and its habitats. Further, this work is a clear example of the use of the QBR-RNMX index as a cost–benefit tool to determine the quality of a riparian forest. The index could be straightforwardly applied elsewhere in Mexico and in other countries with similar morphological, ecological, and hydrological characteristics.

We have demonstrated that the main anthropogenic impacts are related to the sparse vegetation cover in the riparian area. When considerable vegetation cover is present, invasive species are dominant. The rehabilitation measures should therefore prevent further degradation of the riparian forests and enhance restoration efforts. The challenge that remains is how to use this information to preserve and/or restore the banks of the Pesquería River. Yet these measures will not be effective if the local population is not well informed about how the riparian forest supports the ecosystem, and consequently, their lives. The government should therefore provide social and economic programmes that engage local people in restoration activities. This will prevent further degradation and ensure that the rehabilitation measures are sustainable. Finally, we also encourage the use of drones for conducting more accurate surveys of the characteristics of riparian areas.

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APPENDIX A

QBR-RNMX INDEX
Field data sheet
Riparian Forest Quality in the rivers of Northern Mexico

Station
Observant
Date

The score for each section cannot be negative or exceed 25

TOTAL RIPARIAN COVER			**Section 1 score**
Score			
1A	**25**	**> 50 % riparian cover**	
1B	**10**	**30-50 % riparian cover**	
1C	**5**	**10-30 % riparian cover**	
1D	**0**	**< 10 % riparian cover**	
+10		if the riparian forest and woodland are fully connected	
+5		if less than 50% of the riparian forest and woodland is connected	
-5		if between 25 and 50% is connected	
-10		if less than 25% is connected	

COVER STRUCTURE						**Section 2 score**
Score						
	1A	**1B**	**1C**	**1D**		
2A	25	10	5	0	**75 % tree cover**	
2B	10	5	0	0	**50-75 % tree cover or 25-50 % tree cover with 25 % covered by shrubs**	
2C	5	0	0	0	**tree cover lower than 25% but shrub cover between 10 and 25 %**	
2D	0	0	0	0	**absence of trees***	
+ 10					if at least 50 % of the channel has helophytes or shrubs	
+ 5					if 25-50 % of the channel has helophytes or shrubs	
+ 5					if trees and shrubs are located in the same patches	
- 5					if trees are regularly distributed but there is less than 50 % shrubland	
- 5					if trees and shrubs are unevenly distributed in separate patches	
- 10					if trees are distributed regularly, and there is more than 50% shrubland	

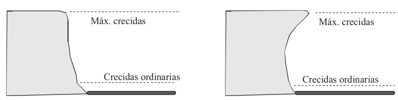
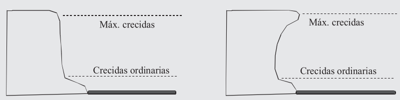
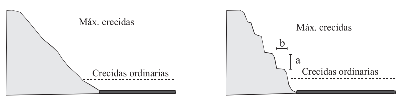
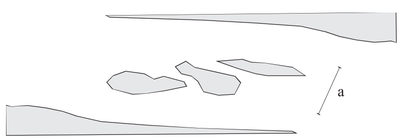
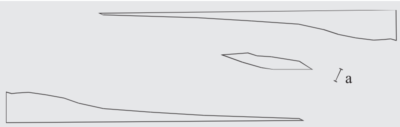
COVER QUALITY (THE GEOMORPHOLOGICAL TYPE SHOULD BE FIRST DETERMINED**)		**Section 3 score**	
Score		***Type1***	***Type2***
25	if the number of native tree species:	> 1	> 2
10	if the number of native tree species:	1	2
5	if the number of native tree species	-	1
0	if native trees are absent		

(Continues)

(Continued)

*COVER QUALITY (THE GEOMORPHOLOGICAL TYPE SHOULD BE FIRST DETERMINED**)*		**Section 3 score**	
+ 10	if the tree community is consistent along the river and covers		
+ 5	at least 75% of the riparian zone		
+ 5	if the tree community is fairly consistent and covers at least	> 2	> 3
	50% of the riparian area		
	if the number of shrub species is:		
- 5	if there are buildings in the riparian area		
- 5	if there are isolated species of non-native trees***		
- 10	if non-native tree communities are present		
- 10	if garbage is present		
NATURALNESS OF THE RIVER CHANNEL		**Section 4 score**	
Score			
25	**unmodified river channel**		
10	**fluvial terraces modified, river channel somewhat constrained**		
5	**channel modified by discontinuous rigid structures along the margins**		
0	**fully channelized river**		
- 10	if the river bed features rigid structures (e.g wells)		
- 10	if transverse structures have been added to the channel (e.g weirs)		
-5	if garbage is present		
-10	if there is a permanent landfill site in the section studied		
***Final score* (sum of level scores)**			

This score is obtained by adding the scores assigned to the left and right river margins based on their incline. This value can be modified if islands or hard substrata are present. The incline score should be added to the scores for the right- and left- hand sides of the bank, and further points added or subtracted in accordance with the first two sections.

		Score	
Incline and configuration of the riparian zone		**Left**	**Right**
Very steep, vertical or even concave (slope > 75°), margins are not expected to be exceeded by large floods.		**4**	**4**
Similar to the previous category, but with a bankfull which differentiates the ordinary flooding zone from the main channel.		**3**	**3**
Slope of the margins between 45 and 75 °, with or without steps. The Slope constitutes the angle subtended by the line between the top of the riparian area and the edge of the ordinary flow of the river. (a > b)		**2**	**2**
Slope between 20 and 45 °, with or without steps. (a < b)		**1**	**1**
Presence of one or several islands in the river			
Width of all the islands "a" > 5 m.		- 2	
Width of all islands "a" < 5 m.		- 1	
Percentage of hard substrata that inhibit the presence of plants with roots			
> 80 %		Not applicable	
60-80 %		+ 3	
30-60 %		+ 2	

(Continues)

(Continued)

Percentage of hard substrata that inhibit the presence of plants with roots		
20-30 %		+ 1
Total Score		
Geomorphological type according to the total score		
> 6	**Type 1**	**Closed riparian habitats. Riparian forest, if present, reduced to a small strip. Headwaters.**
3 to 5	**Type 2**	**Headwaters or midland riparian habitats. Forest may be large in size and may have previously been a gallery.**

*Bush-sized trees and tree-sized shrubs over 1.5m should still be counted as trees.

**This refers to riparian habitat type, which is to be determined in section 3, 'cover quality'.

***Allochthonous tree species in the study area**: *Acacia rigidula, Arundo donax, Chaptalia nutans, Cyperus alternifolius, Nicotina glauca, Ricinus communis, Tamarix aphylla, Typha ssp*.

APPENDIX B

VEGETATION INVENTORY RECORDED AND USED TO EVALUATE THE RIPARIAN VEGETATION QUALITY OF THE PESQUERÍA RIVER

Scientific name	Common name	PG[a]	Sampling points
Acacia farnesiana	Huizache	NRR	2, 4, 5, 6, 7, 8, 9, 11, 13, 15
Acacia rigidula	Chaparro prieto	NWDM	2
Arundo donax	Carrizo gigante	I	2, 8, 9, 10, 11, 12, 14, 15
Baccharis salicifolia	Azumiate o Jara	NWDM	1, 2, 3, 4, 5, 7, 13, 14, 15
Cercidium texanum	Palo Verde	NRR	5, 9, 11, 13
Chaptalia nutans	Agacha cabeza	I	6, 8, 9
Cyperus alternifolius	Paragüita	I	1, 2, 7, 10, 12
Nicotiana glauca	Tabachín	I	3
Pluchea carolinensis	Santa María	NWDM	1, 2, 3, 4, 5, 7, 13, 14, 15
Prosopis glandulosa	Mezquite	NRR	2, 3, 6, 7, 8, 9, 11, 13, 15
Ricinus communis	Higuerilla	I	5, 6, 7, 8, 9, 10, 11, 12, 15
Salix nigra	Sauce de río	NRR	1, 3, 4, 5, 8, 9, 11
Tamarix aphylla	Pinabete	I	3, 4, 5, 8, 9, 14
Typha latifolia	Junco, Tule	I	1, 2, 3, 6, 7

[a]PG: phytogeographic origin (I: invasive; N: native representative of the region; NWD: native widely distributed in Mexico).