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Riparian Quality Index (RQI): A methodology for characterising and assessing the environmental conditions of riparian zones

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ABSTRACT

Riparian Quality Index (RQI): A methodology for characterising and assessing the environmental conditions of riparian zones

This paper presents a new version of the Riparian Quality Index (RQI). This index serves to assess the ecological status of riparian systems. The paper provides recommended field forms for the collection of the data used to characterise riparian systems prior to their assessment. The RQI considers the main sources of riparian ecological functions and environmental services. It represents a useful tool for monitoring and evaluating the structure of riparian zones, an element of the river morphological conditions considered by the Water Framework Directive. The Index was applied to the Guadiana Basin and other Spanish rivers providing helpful criteria for not only evaluating the present status of riparian systems but also formulating diagnosis and rehabilitation options. It represents a checklist of riparian natural characteristics and possible human-impacted riparian features, and it has valuable potential applications for post-project appraisals.

Key words: Riparian systems, environmental assessment, RQI, physical habitat evaluation, Water Framework Directive, river restoration.

RESUMEN

Índice de Calidad Riparia (RQI): Una mateodología para caracterizar y valorar las condiciones ambientales de las zonas riparias

En este trabajo se presenta una nueva versión del índice RQI, conjuntamente con una propuesta de estadillos de campo para la toma de datos y la caracterización de las riberas, que debe ser previa a la interpretación y valoración de su estado. Esta nueva versión del RQI considera los principales componentes de las riberas de los ríos que desarrollan las funciones ecológicas y los servicios ambientales de los corredores fluviales, y representa una herramienta útil para el control y seguimiento de la estructura riparia, la cual forma parte de las condiciones morfológicas de los ríos consideradas por la Directiva Marco del Agua. El índice ha sido aplicado en la Cuenca del Guadiana y en otras regiones españolas, suministrando criterios útiles no solo para la evaluación del estado ecológico de las riberas, sino también para la formulación de diagnosis y opciones de rehabilitación o restauración, representando una lista de características naturales y posibles impactos derivados de actividades humanas de las zonas riparias, con un uso potencial para la evaluación post-proyecto.

Palabras clave: *Riberas fluviales, valoración ambiental, RQI, evaluación del hábitat físico, Directiva Marco del Agua, restauración de ríos.*

INTRODUCTION

The study of riparian systems is of great scientific interest. The riparian habitat supports the surrounding fluvial ecosystem throughout its entire length and integrates many interactions between the aquatic and terrestrial components of the landscape. It is therefore crucial to the preservation of river biodiversity (Ward, 1989; Ward *et al*., 2002; Naiman *et al*., 2005; Corenblit *et al*., 2007).

Riparian systems also represent a vital component of river management because their state affects many river-related environmental services. Because of their spatial position and connectivity with flowing water channels, riparian systems are flooded periodically and play an important role in water infiltration and aquifer recharge. Moreover, they provide flood attenuation and serve to decrease hydrological risks (Horn & Richards, 2006). As an important landform agent and flow resistance factor, riparian vegetation is responsible for the majority of energy losses in fluvial systems. Roots increase substrate cohesion, and stems and leaves modify bed roughness, thereby controlling sediment erosion, transport and deposition, both in the channel and in the floodplain (Gurnell & Petts, 2002; 2006; Corenblit *et al*. 2008; 2009). Several processes for the exchange of matter and energy with the river channel occur in the riparian zone. This habitat serves to protect in-stream water quality by acting as a sink and filter of sediment and nutrients (Tabachi *et al*. 2000; Naiman *et al*., 2005; Burt *et al*., 2006). Moreover, riparian forests represent important natural corridors in the landscape (Schnitzler-Lenoble, 2007) and constitute areas of high biodiversity. These forested corridors have great value as the site of recreation and cultural events.

The importance of riparian zones in the ecological functioning of river systems has been widely recognised in recent European policies. Thus, the Water Frame Work Directive (OJEC, 2000) includes the structure of the riparian zone in the morphological conditions that, together with the hydrological regime and river continuity, represent the main hydromorphological elements supporting the biological communities. The Directive recommends that the structure of riparian zones should be analysed systematically and that their restoration and conservation should be included within the programmes of measures that form part of the Integrated Basin Management Plans. Moreover, two additional recent European Directives highlight the existing interest in monitoring and restoring riparian and flood-prone areas. The Floods Directive (OJEU, 2007) seeks to prevent damage and hydrological risk, and the Pesticides Directive (OJEU, 2009) aims to minimise the risk of off-site pollution.

Mainly as a consequence of the requirements of the European Directives cited above, there is great interest in practical environmental assessment methods that address the structure and functionality of riparian zones. With the aid of these methods, the needed assessment and monitoring tasks may be easily performed. These methods should support the periodic surveillance and diagnosis of riparian status, and they should help to formulate restoration activities that include fluvial processes serving to mitigate alterations resulting from human activities. These methods should also be useful for post-project appraisals intended to detect ecological trajectories of recovery or degradation following interventions or management changes.

Several methods have been proposed to evaluate the riparian conditions of rivers. Some of these methods give special emphasis to vegetation structure (Munné *et al*., 1998; Munné *et al*., 2003; Winward, 2000), whereas others are based more on riparian dimensions, habitat quality and land use (Petersen, 1992; Bjorkland *et al*., 2001; Ward *et al.,* 2003; Jansen *et al*., 2004; González del Tánago *et al*., 2006). Other river assessment methods also use some riparian characteristics to assess the status of the physical habitat according to different objectives. Several of these methods deserve particular mention: the protocols of Raven *et al*. (1997) and Pardo *et al*. (2002) to characterise and classify rivers; the methods proposed by Barbour *et al.* (2002), Ladson & White (1999), and Simpson & Norris (2000) to link physical features with biota and to determine the ability of the aquatic habitat to support optimal biological conditions; the approach of Brierley *et al*. (2002) to describe river behaviour and to predict river character and responses to disturbance; the proposal of Davies *et al*. (2000) to estimate the ecological condition of the instream habitat and predict the probability of occurrence of each habitat feature at certain sites; and the methodology of Ollero *et al*. (2008) to assess the hydromorphological status of rivers. A revised version of the Ollero *et al*. (2008) methodology is included in this volume (Ollero *et al*. 2011).

In this paper, a more up-to-date version of the RQI methodology proposed by González del Tánago *et al*. (2006) is presented, together with additional new data-collection forms.

The RQI represents a quick and standardised survey method that is relatively easy to apply in the field to gather quantitative information on the structure of riparian zones for assessing their ecological status. The method has potential applications to monitoring and diagnosis, to rehabilitation or restoration design, to setting conservation priorities and to post-project evaluation.

The initial version of RQI methodology only described the scoring system used to assess riparian conditions but did not include protocols for previous riparian characterisation. This new version of RQI recognises that it is of great interest to store the quantitative information that has been collected in the field and that will subsequently be encapsulated by scoring systems. Accordingly, the new version of RQI includes field forms that serve to standardise the collection and storage of riparian data and thereby to facilitate the creation of databases for future analysis. The variables proposed for riparian characterisation can be used for riparian monitoring and riparian recovery or degradation evaluation. They can therefore be used as needed to achieve different purposes. With this new approach, riparian systems are first characterised according to their hydromorphological and ecological conditions. They are then assessed and scored by comparing their actual status with an appropriate potential or reference status based on valley and river types.

The previous application of the first version of RQI to several different rivers produced some misleading statements and interpretations. Longitudinal continuity and the assessment of bank conditions proved to be of particular concern. In this new version of RQI, important refinements have been added to address these two ri-

Table 1. RQI Scores for assessing width dimension status of riparian zones. *Puntuaciones del RQI para evaluar el estado de la anchura de la zona riparia.*

1. DIMENSIONS OF LAND WITH RIPARIAN VEGETATION (AVERAGE WIDTH OF RIPARIAN CORRIDOR)														
Assess each margin separately. Identify the band containing riparian species (any species which presence is related to the river) and estimate its average width along the study reach. Look for restrictions to riparian corridor width due to human influence. If they do not exist, any width would be considered very good status. Take into account that riparian dimensions can be naturally reduced in confined valleys due soil constraints or the adjacent slopes.														
Very good			**Good**			**Moderate**			**Poor**			**Bad**		
No restrictions to riparian vegetation development and extension across the valley due to human influence. Riparian vegetation is connecting with upland species, and covers all land between channel and adjacent slopes.			*Average width of Riparian corridor slightly restricted by human action.* In unconfined valleys, average width more than 3 active channel widths, or exceeding 60 m. In morphologically confined valleys, reductions in riparian width affect less than 30 % of riparian length.			*Average width of Riparian corridor moderately restricted by human action.* In unconfined valleys, average width between 3 and 1 active channel widths, or exceeding 30 m. In confined valleys, reduction in riparian width affect between 30 and 60 % of riparian length.			*Average width of Riparian corridor significantly reduced by human action.* In unconfined valleys, average width less than 1 active channel width. In confined valleys, reduction in riparian width affects more than 60 % or riparian length.			*Average width of Riparian corridor severely reduced, or non-existent due to human actions.* Channel banks connected to agricultural fields, urbanized areas or roads. Consider 0 score when the channel is laterally limited and connects with paved areas where riparian vegetation cannot grow.		
15	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**

parian attributes. Moreover, some simplifications in the assessment of vegetation structure have been made to facilitate field analysis, and the assessment of the presence of large woody debris on banks and floodplains has been added as an indicator of river naturalness and lateral connectivity.

Table 2. RQI Scores for assessing longitudinal continuity, coverage and distribution pattern of riparian corridors. *Puntuaciones del RQI para evaluar la continuidad longitudinal, la cobertura y el patrón de distribución del corredor ripario.*

2. LONGITUDINAL CONTINUITY, COVERAGE AND DISTRIBUTION PATTERN OF RIPARIAN CORRIDOR (WOODY VEGETATION)

Assess each margin separately, referred to the riparian vegetated area. Estimate longitudinal continuity and coverage based on distribution pattern of woody vegetation associations. Estimate intensity of fragmentation based on size and frequency of open areas created by human action, and land-use within these areas compromising corridor functions.

In natural conditions, different succession stages of riparian vegetation linked to floods variability and fluvial forms can be observed, resulting in a high heterogeneity of vegetation forms and floodplain geomorphic units, with open gravel and sand areas corresponding to "very good" status (Corenblit *et al*. 2009). Score the intensity of human intervention determining: a gradually lost of this heterogeneity linked to the continuous interaction between floods, sediments and vegetation; a decrease of natural continuity and coverage promoting fragmentation; or, by the contrary, an increase of mature forest continuity and coverage with homogeneous distribution pattern due to flow regulation and flood control.

Very good	Good	Moderate	Poor	Bad
Continuity and Coverage of riparian corridor in natural condition. Usually, different vegetation strata cover the full length of the segment, showing a heterogeneous pattern linked to natural fluvial forms and flood dynamics, without alterations related to human actions.	*Riparian corridor slightly cleared or fragmented by human intervention, or slightly induced by flow regulation.* Riparian vegetation covers the full length of the segment but with slightly reduced coverage, being higher than 60 % of natural coverage, and includes several strata; or it forms a dense but partly fragmented corridor, with open spaces less than 50 m long, free of land uses which may compromise corridor or filtering functions. // Or continuity and coverage of riparian corridor slightly promoted by flow regulation, with an increasing of tree dominance.	*Riparian corridor moderately fragmented or cleared by human intervention, or moderately induced by flow regulation.* Riparian vegetation covers the full length of the segment but with moderately reduced coverage (between 30 % and 60 % of the natural coverage), including several strata, or with a higher coverage but only of tree canopy layer. Or it appears in patches, leaving open spaces more than 50 m long, with agro-forest land uses that moderately compromise corridor and filtering functions. Or continuity and coverage of riparian corridor moderately promoted by flow regulation, showing a continuous and dense tree canopy layer containing shrubs.	*Riparian corridor significantly fragmented or cleared by human intervention, or significantly induced by flow regulation.* Riparian vegetation appears in small patches covering less than 30 % of the length of the segment, or refers to isolated tree or shrub individuals, with scattered rushes or bushes. Or more than 60 % of the riparian area has no vegetation and contains urban or agricultural occupations. // Or riparian corridor strongly promoted by flow regulation, containing only tree species.	*Riparian corridor intensively altered by human intervention.* Riparian vegetation is reduced to isolated trees or shrubs, leaving large open areas with buildings or land-uses that severely compromise corridor and filtering functions. Or there is no riparian woody species and only herbaceous communities exist due to human actions. Use the score 0 in areas where no woody riparian species exist (i.e. paved reaches) where natural riparian corridor functions are completely prevented.
15 14 13	**12 11 10**	**9 8 7**	**6 5 4**	**3 2 1**

DESCRIPTION OF THE RQI METHODOLOGY

Rationale and spatial scale

According to current scientific literature (e.g., Malanson, 1993; Hughes *et al*., 2003; Ward *et al*., 2002; Brierley & Fryirs, 2005; Naiman *et al*., 2005; Hupp & Rinaldi, 2007; Corenblit *et al*., 2009), the "natural conditions" of riparian systems should be defined in general terms by using the following characteristics:

- Extensive and continuous riparian corridors, occupying the banks and the total active floodplain area and including a more or less continuous vegetation corridor, of variable dimensions and coverage depending on valley type and natural constraints. The vegetation corridor connects with adjacent upland or terrestrial vegetation.
- Species composition typical of the biogeographical area and hydrogeomorphological conditions, with only native species and including natural regeneration.
- Dynamic banks with natural mobility resulting from erosion and deposition and the presence of geomorphological units characteristic of the flow regime and the calibre of transported materials.
- Lateral and vertical connectivity maintaining an exchange of organisms, matter and energy at different spatial and temporal scales.

To a great extent, these characteristics determine how riparian systems function and provide the environmental services.

The main ecological functions of the riparian zone are to provide a habitat and refuge for aquatic and terrestrial species, to facilitate biological connections in the landscape, to maintain plant diversity, to supply organic matter to aquatic food chains and to control stream water temperature. These functions are all related to the dimensions, the longitudinal continuity and the vegetation structure of riparian corridors (Malanson, 1993; Forman, 1999). Other hydrological and geomorphological riparian functions that are also essential for fluvial ecosystems, such as the retention of plant propagules, the reduction of bank erosion, the filtering of nutrients, sediment trapping, natural water purification, flood timing and energy dissipation, and infiltration and groundwater recharge are also very closely related to the structure of riparian vegetation, the dimensions of riparian corridors and lateral and vertical connectivity (FISRWG, 1998; Poole, 2002; Jansen *et al*., 2004; Naiman *et al*., 2005). Finally, apart from the functions already mentioned, riparian systems offer other environmental services of vital interest for human well-being, such as the provision of beauty, cultural inspiration and emotional values (Balmford *et al.,* 2002). These characteristics also depend on the dimensions, continuity, sinuosity and naturalness of the riparian corridor.

The human impacts resulting from flow regulation, channelisation and floodplain occupancy gradually alter riparian conditions by reducing the width and continuity of riparian corridors, by promoting non-native species, by reducing natural regeneration, and by constraining lateral and vertical connectivity (Bendix & Hupp, 2000; Nilsson & Berggren. 2000; Tockner & Stanford, 2002, Hughes & Rood, 2003).

Based on the ecological principles of river behaviour, it is possible to assess the deviation of current riparian conditions from those corresponding to the "natural" or reference status and to establish a scoring system to evaluate the existing differences. In this sense, the RQI methodology attempts to take into account the main riparian components that perform the abovementioned functions and environmental services (González del Tánago & García de Jalón, 2006) and to assess their gradual degradation or deviation from the theoretical reference conditions.

Consequently, riparian systems are assessed within the RQI using three physical attributes of their structure (land dimensions, longitudinal continuity and vegetation structure) and four other attributes related to their functioning (natural regeneration, bank condition, lateral connectivity and riparian substratum). The present conditions are compared with theoretical "natural or reference" conditions, defined as the absence of human impacts and based on river typology. Tables 1 to 7 show the scoring systems proposed for these seven attributes. This approach aims not only to estimate the present status of riparian zones but also to identify the main features and causes of the existing constraints, thereby facilitating prioritisation and planning of restoration measures.

The RQI method is designed to be applied at the reach scale, where a relatively homogeneous riparian structure can be observed in terms of landscape (geology, vegetation and land use), valley and river type, flow conditions and floodplain characteristics. In general, these homogeneous conditions can be expected in the river segments between tributary confluences (Benda *et al.* 2004). However, other natural factors or man-made impacts, such as reservoirs, channelisation works, urbanisation, etc., can create riparian discontinuities and force consideration of separate reaches within the same river segment. For detailed surveys, a length of 500-1000 m for each study reach is recommended, with a predicted approximate time of at least thirty minutes for field-data collection at each site.

Table 3. RQI Scores for assessing composition and structure of riparian vegetation status. *Puntuaciones del RQI para evaluar el estado de la composición y estructura de la vegetación riparia.*

<table>
<tr><th colspan="15">3. COMPOSITION AND STRUCTURE OF RIPARIAN VEGETATION</th></tr>
<tr><td colspan="15">Assess each margin separately. Identify natural composition and strata structure of riparian vegetation and natural succession stages for the study reach.

Look for differences between this potential vegetation and actual vegetation forms, number and coverage of exotic species and abundance of mats, reeds, nitrophilous or ruderal species.</td></tr>
<tr><th colspan="3">Very good</th><th colspan="3">Good</th><th colspan="3">Moderate</th><th colspan="3">Poor</th><th colspan="3">Bad</th></tr>
<tr><td colspan="3">Riparian vegetation in natural condition.
Riparian corridor including a mix of species corresponding to the native vegetation associations of the river segment, with different strata (canopy, understory, ground) often including shade and climbing plants. No exotic species.</td><td colspan="3">Riparian vegetation slightly altered by human action.
Riparian corridor containing most of the species belonging to native vegetation associations of the river segment. 1 or 2 exotic species with less than 10 % coverage. //
Scattered presence of Rubus, mats or reeds due to low-significant riparian land-use.</td><td colspan="3">Riparian vegetation moderately altered by human action.
Riparian corridor containing only certain species of potential vegetation associations, with scarcity of understorey strata; or including exotic species with 10-30 % coverage //
Moderate presence of Rubus, mats, reeds, thorny, ruderal or invasive herbaceous species (coverage less than 30 %) due to moderate intensity of riparian land-use.</td><td colspan="3">Riparian vegetation significantly altered by human action.
Riparian corridor containing only a small representation of potential vegetation forms, or including exotic species with 30-60 % coverage. //
Abundance of Rubus mats, reeds, thorny ruderal or invasive herbaceous species (30-60 % cover) due to intensive riparian land-use.</td><td colspan="3">Riparian vegetation badly altered by human influence.
Riparian corridor with more than 60 % coverage of exotic species. Or dominance of Arundo donax formations, Rubus mats, ruderal or invasive species (coverage larger than 60 %), or overgrowth of dense herbaceous communities along the bank indicating artificial maintenance of water level, or nitrogenous enrichment. //
Riparian vegetation only with grass due to human influence. //
Consider score 0 when soil bank is sealed or paved and riparian vegetation is non-existent.</td></tr>
<tr><th>15</th><th>14</th><th>13</th><th>12</th><th>11</th><th>10</th><th>9</th><th>8</th><th>7</th><th>6</th><th>5</th><th>4</th><th>3</th><th>2</th><th>1</th></tr>
</table>

The lateral dimensions of riparian areas, the longitudinal continuity and vegetation structure of these areas, and the vegetation associations to be identified may be analysed using aerial and satellite photographs in the office or laboratory by using landscape metrics and tools for digital image analysis. The results found for these characteristics may define a general riparian condition at a broad or reach scale. Information about species composition, natural regeneration, bank conditions, lateral connectivity and the riparian substratum must be collected through more detailed and field-based reconnaissance work. This information provides statements about more finely defined riparian conditions at a smaller scale.

General information and assessment procedure

Theoretically, the RQI methodology could be used in many different river types. Initially, it was based on typologies of Iberian rivers, which have catchment areas up to 100 000 km^2.

An analysis of recent aerial and satellite photographs of the river is recommended before the actual field work begins. This analysis is useful for gaining an improved visualisation of the homogeneity of the riparian conditions and the continuity of the river corridor. It also permits a proper selection of representative field study sites. These sites will then better reflect the status of the entire study area. Prior knowledge of the following characteristics is also necessary:

Table 4. RQI Scores for assessing age diversity and natural regeneration status of woody riparian vegetation. *Puntuaciones del RQI para evaluar la diversidad de edades y el estado de regeneración natural de la vegetación riparia.*

<table>
<tr><td colspan="15">4. AGE DIVERSITY AND NATURAL REGENERATION OF WOODY SPECIES
Assess both margins jointly. Look for age diversity of main woody species. Try to locate where regeneration takes place and search for the main causes limiting regeneration when they exist.</td></tr>
<tr><td colspan="3">Very good</td><td colspan="3">Good</td><td colspan="3">Moderate</td><td colspan="3">Poor</td><td colspan="3">Bad</td></tr>
<tr><td colspan="3">Age diversity and regeneration of woody species in natural conditions.
All age classes (seedlings, young, adult and mature individuals) of all woody species are observed in the riparian zone. //
Or without human activities affecting natural riparian species regeneration.</td><td colspan="3">Age diversity and regeneration of woody species slightly altered by human action.
All age classes (seedlings, young, adult and mature individuals) of main woody species are observed at least in some locations within the entire riparian zone, but missing the youngest age classes of the most sensitive species.
Human interventions with little effect on natural regeneration.</td><td colspan="3">Age diversity and regeneration of woody species moderately altered by human action.
Regeneration is confined to the pioneer species and only takes place in the proximal riparian zone. In the distal zone only adults and mature individuals are observed, with scarce representation of the youngest age classes.
Human interventions with moderate effect on natural regeneration due to low-intense regulation of flows, soil ploughing, periodical fire, cattle grazing, etc.</td><td colspan="3">Age diversity and regeneration of woody species significantly altered by human action.
Regeneration restricted to 1-2 species, and to the banks. In the rest of the riparian area only adults or mature individuals are observed.
Human interventions with significant effect on natural regeneration due to herbicides, channelization, water contamination, intense flow regulation, etc.</td><td colspan="3">Age diversity and regeneration of woody species badly altered by human action.
No or very little regeneration is observed, with very scarce youngest age classes and only in the sand or gravel bank-attached forms emerging in the active channel. In the rest of the riparian area only mature specimens exist, together with frequent dead individuals.
Severe restrictions due to human action, preventing vegetation establishment. Use score 0 when riparian zone is completely sealed or paved, with no regeneration potential.</td></tr>
<tr><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
</table>

- Flow regime data, presence of dams along the surveyed river and dam management information
- Human activities that may not be visible during field visits or that were conducted in the past (gravel mining, landfill, agricultural practices, controlled fire, grazing, periodic clearcuts, selective vegetation removal, etc.)
- Potential up-slope or terrestrial vegetation along adjacent margins
- Natural riparian vegetation associations for the study area. Morphological characteristics and habitat requirements of native and non-native species used for their identification and for determining their ecological indicator value (i.e., nemoral, ruderal, nitrophilous, etc.)

In the field, before data collection, the following characteristics must be analysed:

- Valley and channel type, in order to estimate the potential extension of riparian and floodplain areas (González del Tánago *et al.*, 2006). Basically, the following typologies should be taken into account (Brierley & Fryirs, 2005): (1) confined valleys, symmetrical, with the slopes connected directly with the channel. In this case, riparian zones

Table 5. RQI Scores for assessing active channel bank conditions. *Puntuaciones del RQI para evaluar el estado de las orillas del cauce activo.*

5. BANK CONDITIONS														
Assess both margins jointly, referred to river banks at bank-full discharge. Look for indicators of naturalness (mobility, bank-attached land forms, presence of woody debris and vegetation detritus, heterogeneity of water shore, etc.). Search for human influence determining bank instability, homogeneity of water shore, vegetation overgrowth in banks, incision or fine sediment deposition, revetments or direct alterations of bank-form, bank-height and bank-slope.														
Very good			**Good**			**Moderate**			**Poor**			**Bad**		
Banks in natural condition. Banks normally with heterogeneous water shoreline associated to natural bank-attached forms. Abundance of dead wood and vegetation detritus at lateral sides of channel. Fully developed riparian plant community firmly binding bank sediments along the total reach. Local erosion and sedimentation processes associated with channel bends could be observed, for example cliffs in the outer banks of meander, not related to human actions. // Channel morphology without human alterations.			*Banks slightly modified by human action.* Banks forms and processes are altered in less than 10 % of total length. Presence of dead wood and vegetation detritus at lateral sides of channel. Natural fully developed riparian plant community binding the bank sediments in more than 60 % of total length and local erosion and sedimentation processes associated with low impact of human interventions affect less than 10 % of total length. // Channel cross-section slightly altered by human action, but without stabilization measures.			*Banks moderately modified by human action.* Banks shape and processes moderately altered, devoid of vegetation and showing undercutting or mass failure due to human influence in 10-30 % of total length; or partially fixed with rip-rap or bioengineering techniques in less than 30 % of total length // Emerging incision or bank accretion due to fine sediments deposition In less than 30 % of reach length. // Channel cross-section moderately altered by human action, with increased banktop height at both margins forming side-slopes with average slope smaller than 1V:4 H.			*Banks significantly modified by human action.* Banks shape and processes significantly altered, devoid of vegetation and showing undercutting or mass failure due to human influence in 30-60 % of total length; or fixed with rip-rap or bioengineering techniques along 30-60 % of total length. // Moderate incision processes or significant accumulation of fine sediments in 30-60 % of total length. // Channel cross-section significantly altered by human intervention, over-deepened or with increased banktop height, forming mean side-slopes between 1V:4 H and 1V:2 H.			*Banks badly altered by human action.* Banks fixed with bio-engineering or rip-rap revetments covering more than 60 % of the total length. / / Significant incision or bank accretion due to massive fine sediment deposition along more than 60 % of the segment length. // Channel cross-section significantly altered by human intervention, over-deepened or with lateral embankments at both margins, forming uniform side-slopes steeper than 1V:2H. Consider score 0 when the banks are all paved and covered by concrete and any growth of vegetation is prevented.		
15	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**

are expected to be narrow, containing mixed forest with upland and riparian species, without a floodplain; (2) partly-confined valleys, asymmetrical, characteristics on one margin similar to those of confined valleys, characteristics on the other margin similar to wider riparian areas connected with discontinuous floodplain, and with riparian forest that may extend through the unconfined area; and (3) unconfined valleys, both margins having the channel and hill-slopes disconnected and buffered by a continuous floodplain, and with a riparian forest that may be wider.

- Transversal zonation according to channel morphology, with identification of the lower areas of banks and bank-attached geomorphic units. Under natural conditions, woody vegetation restricting natural channel mobility should not be dominant; in the bank-top and riparian proximal areas that are more exposed to shear stress during high flows, species that are better adapted to drag forces (more flexible stems and easy regeneration and short-lived species) should be found. The natural dynamic processes of erosion and sedimentation should be observed, at least on one margin. In the riparian distal areas in the active floodplain, less exposed to the force of the current, mature forests should remain.

Table 6. RQI Scores for assessing lateral connectivity status of riparian and floodplain areas. *Puntuaciones del RQI para evaluar el estado de la conectividad lateral de las riberas y llanuras de inundación*

6. FLOODS AND LATERAL CONNECTIVITY				
Assess both margins jointly. Look for intensity of flow regulation altering frequency and magnitude of floods and periodicity and area of flooding; and identify morphological changes or channelization works for preventing overflowing. In absence of flow data, look for inundation footprints on riparian and floodplain areas, such as woody debris and wastes hanging on vegetation after floods, open gravel and sand areas associated to secondary flood channels, vegetation detritus location, etc. Or assess lateral connectivity based on proximity of physical visible restrictions of flow accessibility to riparian zone.				
Very good	**Good**	**Moderate**	**Poor**	**Bad**
Natural flow regime and flood free access to riparian zones. Channel and floodplain topography in natural conditions, without any restrictions to over bank flooding. Abundance of dead wood and woody branches along the floodplain transported by large floods.	*Floods and lateral connectivity slightly controlled by human action.* Flow regulation with small reduction of bank-full discharge or natural ordinary floods frequency (return period between 2-10 years**); overflowing occurs at least two times every 10 years and inundates more than 50 % of riparian width. Presence of dead wood and woody branches along the banks transported by floods. // Or slight restrictions to flooding by small embankments located at a distance from the bank larger than 3 active channel widths.	*Floods and lateral connectivity moderately controlled by human action.* Flow regulation with moderate reduction of magnitude and frequency of natural ordinary floods. Overflowing occurs at least once every 10 years and inundates more than 30 % of riparian width. // Or moderate restrictions to flooding, due to embankments located at a distance from the bank between 1 and 3 active channel widths, or due to a moderate deepening of channel.	*Floods and lateral connectivity significantly controlled by human action.* Flow regulation with significant reduction of magnitude and frequency of natural floods; overflowing occurs only with large and low- frequent floods, around once every 25 years. // Or significant restrictions to flooding, due to river training and hydraulic engineering with embankments located at a distance from the bank less than one active channel width, or due to significant incision of channel.	*Floods and lateral connectivity badly reduced by human action.* Flow regulation with severe reduction of magnitude and frequency of natural floods; overflowing occurs rarely, only with very large floods, less than once every 25 years // Hard channelization works that severely reduce the flood-prone area. Consider score 0 in cases of very intense flow regulation or hard-engineered reaches where only very extraordinary flows can inundate river margins.
15 · 14 · 13	**12 · 11 · 10**	**9 · 8 · 7**	**6 · 5 · 4**	**3 · 2 · 1**

** Ordinary floods include the annual maximum flows around bank-full discharge, in which the return period usually oscillates between 1,5-2 years in the permanent and more regular flow regimes, and 5-8 years in the temporal and with more variability flow regimes of semi-arid regions (Dunne & Leopold, 1978; Estrela, 1994).

Table 7. RQI Scores for assessing riparian substratum and vertical connectivity status. *Puntuaciones del RQI para evaluar la calidad del substrato de las riberas y su conectividad vertical*

<table>
<tr><td colspan="15">7. SUBSTRATUM AND VERTICAL CONNECTIVITY
Assess both margins jointly. Look for alterations of soil surface reducing natural infiltration capacity; and for alterations of substratum along soil profile that reduce original alluvial permeability, subsurface flows and groundwater connectivity. Alterations can be due to fillings that modify original soil material and seed-bank and reduce composition and diversity of native herbaceous communities: or to gravel mining that induces particle size changes or replaces original materials; or due to the presence of underground infrastructures that prevent subsurface flows.</td></tr>
<tr><th colspan="3">Very good</th><th colspan="3">Good</th><th colspan="3">Moderate</th><th colspan="3">Poor</th><th colspan="3">Bad</th></tr>
<tr>
<td colspan="3">Riparian soil and subsurface flows in natural condition.
Soil surface covered by vegetation detritus and herbaceous plants, with original seed-bank and diversity of grass communities, and non altered infiltration capacity.
Riparian substratum in natural condition, maintaining its original permeability.
Preservation of subsurface flows and groundwater natural connectivity.</td>
<td colspan="3">Riparian soil slightly modified by human actions.
Soil surface covered by vegetation detritus and grass in more than two thirds of the area. Bare zones, small trails or non-paved compacted areas due to cattle grazing, vehicles or recreation activities representing less than one third of the area, with no significant reduction of infiltration capacity along the study reach.
Substratum in natural condition, preserving natural seed-bank, herbaceous communities and original permeability.
Gravel mining and alterations to soil topography absent or of low significance, and connectivity of subsurface and groundwater flows is maintained.
No fillings or excavations.</td>
<td colspan="3">Riparian soil moderately modified by human actions.
Soil surface covered by vegetation detritus and grass in less than two thirds of the area. Soil surface ploughed, sealed or paved in less than 30 %, moderately reducing infiltration capacity.
Or soil profile has been altered in less than 30 % of riparian area, because of gravel mining (topography and substrate particle size with moderate alterations), or sediment deposits (original seed-bank altered showing abundance of pioneer opportunistic herbaceous plants or dominance of bare soil). //
Addition of inert materials, solid wastes or building debris in less than 30 % of the area moderately alters natural permeability and connectivity with subsurface and groundwater flows. //
Presence of underground infrastructures as roads or pipes (water, electricity, oil) or addition of solid wastes or building debris affects less than 30 % of the area.</td>
<td colspan="3">Riparian soil significantly modified by human actions.
Soil surface sealed, compacted or paved in 30-60% of the area, significantly reduce infiltration capacity.
Or soil profile has been altered in 30-60 % of riparian area, because of gravel mining (topography and substrate particle size with moderate alterations), or sediment deposits (original seed-bank altered showing abundance of pioneer opportunistic herbaceous plants or dominance of bare soil). // Riparian substratum substituted by inert materials, solid wastes or building debris in 30-60 % of the riparian area. //
Presence of underground infrastructures as roads or pipes (water, electricity, oil) or addition of solid wastes or building debris affects 30-60 % of the area, significantly altering subsurface flows and groundwater connectivity.</td>
<td colspan="3">Riparian soil badly modified by human actions.
Riparian soils sealed or paved in more than 60 % of the area, severely compromise infiltration of water.
Or soil profile has been deeply altered by gravel extraction, or by topography alterations degrading original soil and seed-bank in more than 60 % of the area. // Riparian substratum substituted by inert materials, solid wastes or building debris in more than 60 % of the riparian area. // Underground infrastructures as roads or pipes (water, electricity, oil) or addition of solid wastes or building debris affecting more than 60 % of the area, with strong alteration of subsurface flows and groundwater connectivity.
Use score 0 when riparian zones are completely paved or excavated containing concrete infrastructures preventing any hydrological connectivity with channel.</td>
</tr>
<tr><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
</table>

Table 8. Interpretation of total RQI score values and proposal of river management options. *Interpretación de los valores totales de RQI y propuestas de gestión.*

RQI value	Riparian status	Management options
150-130	Very good	Riparian attributes in natural conditions, without threats in their functioning. Great interest in ***Conservation and Protection***, to maintain current status and prevent future alterations of riparian systems
129-100	Good	Most of the attributes are in good or very good conditions and one or two can be altered. Riparian systems need ***Protection*** measures to prevent potential new impacts and ***Restoration*** measures to achieve full integrity of riparian functions. Eliminate pressures and impacts as much as possible.
99-70	Moderate	Several attributes are moderately altered. Riparian systems require ***Restoration*** measures to assure proper hydrological and ecological functioning. Eliminate or Reduce pressures and impacts as much as possible.
69-40	Poor	Most attributes are moderately altered. Riparian systems need ***Rehabilitation*** or ***Restoration*** measures, to improve and recover hydrological and ecological riparian functions. Reduce pressures and impacts as much as possible and design compensation measures to ameliorate environmental conditions.
39-10	Bad	Several attributes are poorly altered. Riparian systems need ***Rehabilitation*** or ***Restoration*** measures to reintroduce or gradually improve hydrological and ecological riparian functions. Reduce pressures and impacts as possible and ameliorate the social perception of river degradation.
< 10	Very bad	Most of the attributes are badly altered. Riparian systems need new ***Rehabilitation*** or ***Remediation*** works, to recreate and reintroduce riparian functions. Improve environmental conditions for good potential status and ameliorate the social perception of river degradation.

In each study site, field data should be systematically recorded using the data sheets of Annex I. For riparian system assessment, Tables 1 to 3 should be applied to each river bank separately. Six scores will result. Tables 4 to 7 should be applied to integrate the riparian status of both margins. Here, four additional scores will be obtained. The final result of the RQI at each study site is then obtained by summing these 10 score values. The summed values will range from 130-150 (best status) to less than 10 (worst or very bad conditions). Depending on the study objectives and constraints, one or several study sites can be used to represent the overall status of each river reach surveyed.

Appropriate maps can provide edited versions of the results. Maps of each attribute scored may be prepared to reflect the more frequent or extensive limiting factors for riparian areas within the basin studied. Maps of the total RQI values are useful to represent the global quality of each riparian area and to show the locations of the best-preserved river reaches.

Management options related to global-quality classes are suggested in Table 8. More detailed restoration or rehabilitation strategies and measures may be derived from the information shown on individual maps of the riparian attributes assessed. Overlaying the RQI value maps with other Geographical Information Systems (GIS) layers, such as land use, protected areas (such as those protected under the European Habitat Directive), flow regulation structures, urbanisation density, water quality, etc., may help to relate the present riparian status to potential sources of degradation. This approach may also help to establish criteria and to develop a rationale for planning rehabilitation or restoration programmes and priorities.

RQI METHODOLOGY APPLICATIONS

The initial version of the RQI methodology was applied in several regions and basins of the Iberian Peninsula to demonstrate the usefulness and potential applications of the method. The

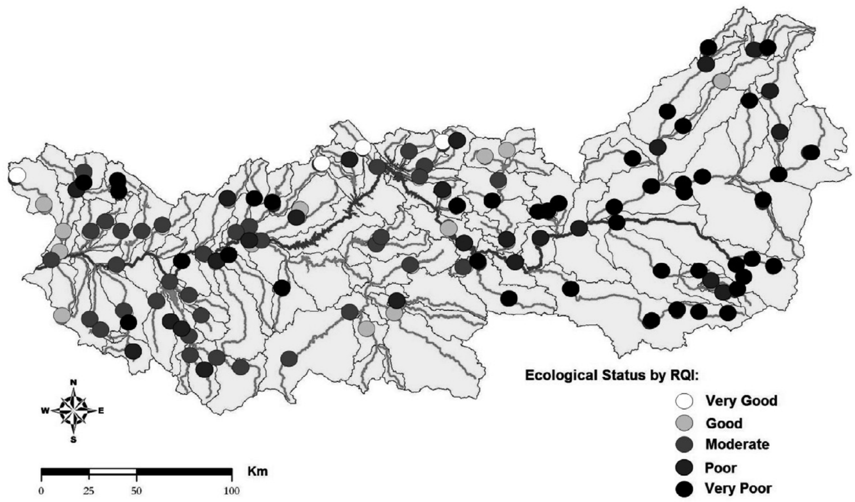

Figure 1. Map of Riparian Quality of the Guadiana Basin using the RQI methodology in 120 study-sites (González del Tánago *et al*., 2004). *Mapa de calidad de las riberas de la Cuenca del Guadiana utilizando la metodología RQI en 120 lugares de estudio (González del Tánago* et al.*, 2004).*

index was initially used in the Guadiana basin. This analysis involved a study of 130 surveyed stations and allowed the diagnosis of the status of the fluvial riparian systems at basin scale (González del Tánago *et al*., 2004). Figures 1 and 2 shows the results of this work, including the spatial relationships between riparian quality and land use. The best-preserved sections corre-

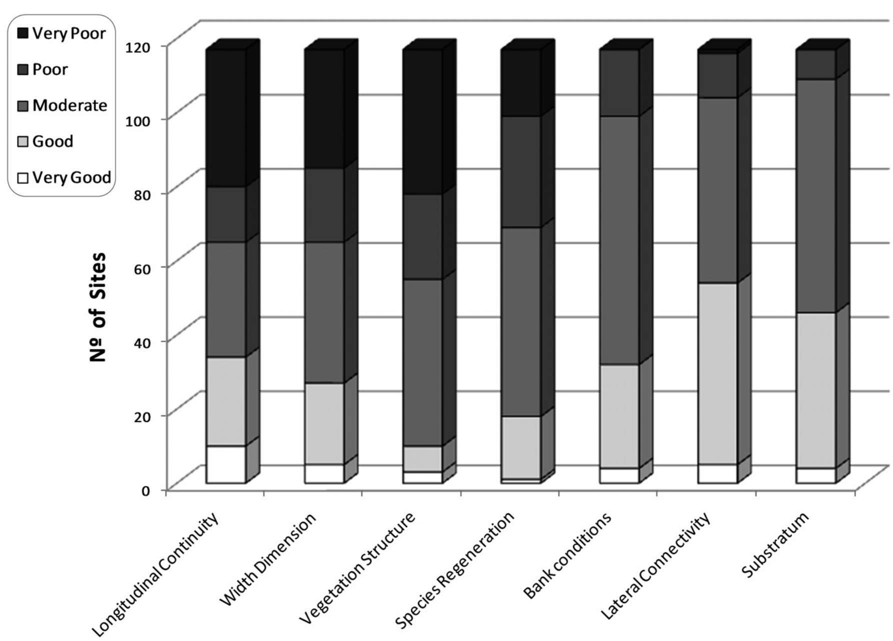

Figure 2. Status of each riparian attribute assessed by the RQI in the 120 study-sites of the Guadiana Basin (González del Tánago *et al*., 2004). *Estado de cada uno de los atributos de las riberas estudiados con el RQI en 120 estaciones de la Cuenca del Guadiana (González del Tánago* et al.*, 2004).*

spond to the upper reaches of forest streams located in Montes de Toledo. The most-degraded reaches are located in La Mancha (Ciudad Real), where river channel dredging and alignment in flat valleys were carried out for agricultural purposes during the 1970s, causing further incision processes, and in several reaches of the Guadiana tributaries, where fragmentation or reduction in lateral connectivity owing to agriculture and flow regulation occurred with greater effect. Based on these results, the creation of buffer strips along lowland rivers to increase the continuity and extension of the riparian corridor was considered one of the most urgent measures for the rehabilitation of riparian zones in the Guadiana Basin. The basin should be protected by controlling grazing and agricultural practices to promote the regeneration of native woody species.

The RQI index was also applied for different purposes in other regions. Francés *et al.* (2009) have used the RQI to compare riparian conditions under natural and regulated flow regimes. In the region of La Rioja, Alonso *et al*. (2007) have applied this index to assess the riparian conditions as an important component of the physical habitat of fish communities. Iturriaga (2007) has made a statistical comparison of RQI with two other Spanish indices, QBR (Munné *et al*., 1998) and IFH (Pardo *et al*. 2002). This work was carried out in the rivers of Navarra. This analysis found that RQI was correlated to a certain extent with QBR and IFH. The resulting R^2 values were 0.79 and 0.67, respectively. Nevertheless, RQI was considered more useful, as it explicitly takes into account longitudinal continuity, natural regeneration and lateral and vertical connectivity. The other indices do not include these factors, which are considered crucial for assessing the maintenance and functionality of riparian corridors.

DISCUSSION

The proposed RQI methodology represents a useful tool for the characterisation and quick assessment of the environmental conditions present in riparian systems. This method helps in the diagnosis and the design of restoration strategies by furnishing a checklist of the main riparian components affected by human activities.

The RQI index takes into account the major components of the structure and functioning of riparian zones, and it offers more complete criteria for riparian assessment than those included in previously available methods. It accounts for the main riparian components performing the ecological and hydrological functions of the riparian zone, and it incorporates river dynamics and natural riparian vegetation regeneration as important attributes that reflect not only the present status but also possible future conditions, given the current circumstances of flow regime, land use or channel management.

The assessment of several riparian attributes has been improved in the new version of RQI. In addition, different levels of fragmentation vs. longitudinal continuity are now considered. The length and the land-use intensity of open patches are referenced as the main indicators of riparian structural connectivity (Goodwin, 2003: Calabrese & Fagan, 2004). Local erosion and sedimentation processes under specific conditions are considered in the new version of RQI as indicators of river mobility and “naturalness.” These characteristics indicate good to very good status in several cases, according to Corenblit *et al*. (2007), whereas they could have been interpreted as river instability and scored as fair or bad conditions in the previous version of the Index.

Other improvements in this new version of RQI are the simplification of the assessment of vegetation structure. Different vegetation bands are no longer distinguished because their identification may be rather subjective. The presence of large woody debris on banks and floodplains has been added to indicate lateral connectivity and good to very good riparian status.

Finally, additional suggestions have been included. The new version recommends that some information be collected prior to performing the field work, and that the survey sites be selected according to the study objectives using aerial and satellite photographs. The improvements of the new version of RQI methodology can assist in its application, enlarging the awareness of the users who perform riparian system diagnosis and evaluation.

The RQI index was designed to be suitable for a wide range of Iberian river types, including permanent and temporary streams, in both the Mediterranean and the Atlantic climates and for basin areas up to 100 000 km^2. It has been applied to many different rivers under very distinct hydrological and morphological conditions. However, it is not used for ephemeral streams, whose riparian vegetation may respond to different factors. It is important to note that the "very good" or reference conditions of the seven attributes measured are always referred to the river type and that the criteria to assess the gradual degradation of riparian systems correspond to physical processes occurring everywhere. These characteristics suggest that the RQI methodology could be adapted easily to other conditions not yet tested, including very large rivers (basin area > 100 000 km^2), tidal-influenced reaches, boreal-alpine rivers, and more. The specific conditions present in each case should be taken into account by considering different natural features and degradation responses.

The systematic application of the RQI methodology allows riparian-quality maps to be constructed at different spatial scales in response to an overall assessment of RQI score or an individualised assessment of the riparian attributes throughout the basin. It can be applied at different times to compare quantitative data on riparian characteristics in different years, thereby facilitating the evaluation of riparian recovery or degradation after human interventions and offering many valuable criteria for ecological post-project appraisals.

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ANNEX I

FIELD DATA SHEET FOR CHARACTERIZING AND ASSESSING RIPARIAN CONDITIONS

River: ______________ Code station: ______________ Date: ______________

Observer: ______________________________

Limits of River segment:

GPS beginning ______________ GPS end: ______________

Valley and channel cross-section:

1. Dimensions of Land with Riparian Vegetation	**Right margin**	**Left margin**
Confinement of margin (C: confined; U: unconfined)		
Maximum/Minimum width with riparian vegetation (m)	/	/
Average width of riparian corridor (m)		
Average width of active channel (m)		
Distance between active channel bank and adjacent up-slope (m)		
Adjacent land use (Forest, Agriculture, Urban area, Roads, Others)		
SCORE:		

2. Longitudinal Continuity and Coverage of Riparian Corridor	**Right margin**	**Left margin**
Continuous forest (CF) / Vegetation Patches (VP) / Isolated trees or shrubs (IT, IS)		
Canopy (> 5 m height) cover (%)		
Understory (1-5 m height) cover (%)		
Ground (< 1 m height) cover (%)		
If fragmented, average vegetation patches length (m)		
If fragmented, average distance between consecutive patches (m)		
If fragmented, land use in open areas		
SCORE:		

3. Composition and Structure of Riparian vegetation	**Right margin**	**Left margin**
Predominant vegetation associations		
Tree species: Name and abundance class		
Shrub species: Name and abundance class		
Ground species: Name and abundance class		
Shadow and climbing plants: Name and abundance class		
Exotic woody species: Name and cover (%)		
Coverage of *Rubus* or reeds (%)		
Coverage of ruderal or invasive herbaceous species (%)		
Coverage of *Arundo donax* (%)		
Health status of main native woody species (Good, Fair, Bad)		
SCORE:		

Abundance classes: 4: Dominant; 3: Abundant; 2: Frequent; 1: Scarce; + Occasional

4. Age diversity and Natural Regeneration	**Both margins**
Species with seedlings (<1year, <0.25 m height)	
Species with youngs (aprox. 0.25-1.0 m height, or < 1.5 cm diameter for trees)	
Species with adults (aprox. 1.0-5.0 m height, 1.5-3 cm diameter for trees)	
Species with mature (aprox. > 5.0 m height, >3 cm diameter for trees)	
Species with dead trees: Name and abundance class	
Regeneration sites: Channel banks, Proximal area, Distal area, Total area	
Regeneration prevented by: Flow regulation / Cattle grazing / Ploughing / Herbicides / Soil compaction / Pavement / Others	
SCORE:	

5. Bank conditions	**Both margins**
Bank material (Bedrock, Gravel, Sand, Fine sediments, Composite strata)	
Bank shape (Natural, Reprofiled, Reveted, Embanked, Concreted, Other) Draw a simplified profile	
Banktop height (m)	
Bankside slope (Uniform (V:H) / Composite (V:H)	
Bank vegetation cover (%)	
Dead wood and vegetation debris (Abundant, Present, Occasional, Absent)	
Bank stability (Stable, with local instability, Unstable)	
Channel processes description: Equilibrium, Narrowing, Widening	
Bank length affected by vertical accretion/incision (%)	
Bank length affected by undecutting/mass failure (%)	
Bank length with revetments/bio-engineering (%)	
SCORE:	

6. Floods and Lateral Connectivity	**Both margins**
Flow regime status (Natural, Regulated: Slightly, Moderately, Significantly)	
If regulated, main purposes (Irrigation, Hydroelectricity, Water supply)	
Annual floods timing (natural conditions, only in summer, at any time)	
Restrictions to riparian flood access (Bank elevation, channel deepening, levees)	
Embankments: Height (m)/Distance from active channel bank (m)	
Estimated frequency of banktop overflows (one each 1-2 y, 5 y, 10 y, 25 y, > 25 y)	
Estimated frequency of proximal riparian area flooding (one each 1-2 y, 5 y, 10 y, 25 y, > 25 y)	
Estimated frequency of distal riparian area flooding (one each 1-2 y, 5 y, 10 y, 25 y, > 25 y)	
Abundance of dead wood and woody branches transported by floods (None, Occasional, Abundant, Very abundant)	
Location of dead wood and woody branches transported by floods (Only at banks, In proximal riparian areas, In distal areas, everywhere)	
SCORE:	

7. Substratum and Vertical Connectivity	**Both margins**
Predominant soil surface cover (rocks, wood, leaf litter, grass, bare soil, others)	
Coverage of vegetation detritus and grass (%)	
Coverage of bare soil compacted or paved (%)	
Intensity of cattle grazing (None, not significant, moderate, intense, very intense)	
Herbaceous communities (Natural, Abundant /Dominant opportunistic species)	
% of area affected by gravel mining or excavations	
% of area affected by sediment fillings	
% of area affected by solid wastes and building debris	
Present underground infrastructures (None, Pipes, roads, buildings, others) (% area affected)	
SCORE:	