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A simple field method for assessing the ecological quality of riparian habitat in rivers and streams: QBR index

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ABSTRACT

1. An index of riparian quality useful for the management of streams and rivers is presented. The purpose of the index is to provide managers with a simple method to evaluate riparian habitat quality. The index is easy to calculate and can be used together with any other index of water quality to assess the ecological status of streams and rivers. It may also be a useful tool for defining 'high ecological status' under the EC Water Framework Directive.

2. The index, named QBR, is based on four components of riparian habitat: total riparian vegetation cover, cover structure, cover quality and channel alterations. It also takes into account differences in the geomorphology of the river from its headwaters to the lower reaches. These differences are measured in a simple, quantitative way. The index score varies between 0 and 100 points.

3. The QBR index is calculated in the field through a two-sided A4 page form that may be completed in 10 min.

4. The development of the QBR index included trials in four Mediterranean stream catchments in Catalonia (NE Spain). Seventy-two sampling sites were assessed and results were used to test the index.

5. No taxonomic expertise is needed to apply the index, although some knowledge of local flora is required to differentiate between native and non-native tree species.

6. These results show that the QBR index may be used despite regional differences in plant communities. The quality ranges obtained when the index is applied are not heavily influenced by observers at the same site.

7. At present, the index is being used by different research teams and tested in a comparative study of 12 watersheds along the Mediterranean Spanish coast.

8. It is expected that the QBR index may be adapted for use in other geographical areas in temperate and semi-arid zones without changes in the index rationale.

KEY WORDS: QBR index; riparian habitat; Mediterranean streams; ecological quality

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INTRODUCTION

Riparian habitat is a key element of river functioning (Naiman *et al*., 1988; Dudgeon, 1994; Huggenberger *et al*., 1998; Tabacchi *et al*., 1998; Ward, 1998). The lateral dimension of rivers and streams, as well as most of the vertical dimension, are contained in this habitat (Ward, 1989). It can support a high biodiversity, especially in large floodplain rivers (Naiman and Décamps, 1997), protect the main channel from temporal changes and buffer large disturbances (Whiting and Pomeranets, 1997) and provide refuge and food for wildlife (Naiman *et al*., 1993; Stanford and Ward, 1993; Bodie and Semlitsch, 2000). The structure and function of this riparian habitat can either be extremely complex and heterogeneous, as in floodplain rivers, or relatively simple such as alongside headwater streams. It is, therefore, difficult to compare riparian habitats along the river continuum. As a result, the derivation of an index of riparian habitat quality is difficult.

Measurements of water quality are often used as primary biological indicators; however, they provide little information about the lateral and vertical dimensions of stream ecosystems (Bunn *et al*., 1999). Measures of the conservation status of riparian habitat are not often used to describe river 'health' and to help managers in their decisions (Naiman *et al*., 1988).

There are several methods for evaluating the biological or habitat condition of rivers (Metcalfe, 1989; Resh and McElravy, 1993; Ghetti and Ravera, 1994; Holmes *et al*., 1998; Kelly *et al*., 1998; Wright *et al*., 1998; Turak *et al*., 1999) and to assess river health and ecological integrity (Karr, 1996, 1999; Meyer, 1997; Raven *et al*., 1998a; Boulton, 1999). Fewer have been developed specifically for the characterization of riparian habitats. However, several attempts have been made to measure the conservation value of the riparian environment: e.g. using River Habitat Survey (RHS) (Raven *et al*., 1998b), System for Evaluating Rivers for Conservation (SERCON) (Boon *et al*., 1997, 1998), the RCE index (Petersen, 1992), the ISC Australian index (Ladson *et al*., 1999) the index for low-gradient non-tidal streams (US EPA, 1997), the riparian habitat quality indices used in the Rapid Bioassessment Protocols (RBP) (Barbour *et al*., 1999) or indices based on water birds to assess floodplain conditions (Lynn *et al*., 1998; Kingsford, 1999).

This paper describes the development of an index of riparian quality that can be calculated in the field using easily identified and measurable features. The index is named 'QBR' from its catalan abbreviation, 'Qualitat del Bosc de Ribera' (in English, 'Riparian Forest Quality') and its application to three catchments in NE Spain is presented.

MATERIALS AND METHODS

The QBR index

Index definition: preliminary considerations

Calculation of the QBR index in the field is made using a two-sided sheet which is completed by a field surveyor (an 'observer') who is familiar with the most common tree and shrub species found in the study areas (Appendix).

Before the QBR calculation, the main channel and floodplain zone should be differentiated (see the figure at the top of the field sheet of the appendix) identifying the bankfull zone. Although the delimitation of the riparian zone is not always easy, the observer should use all the available indicators of the riparian area, such as fluvial terraces, presence of riparian vegetation and evidence of the effects of large floods. In highly modified areas, a compromise is made between the true riparian area in the absence of human impact and the present situation where extensive agriculture or forest plantations may exist. In these cases a maximum width of 50 m is suggested. The index must be calculated in river or stream lengths of 50 m (upstream areas) or 100 m (middle and lower reaches). If a longer stretch is to be analysed, the stream should be divided into 100 m sections, and each should be studied independently. Both river banks should be considered together (e.g. for vegetation cover).

For index determination, the river is divided into two sections: the main channel and the riparian area. The former is subdivided into two: the area permanently covered with flowing water (which is not considered in the scoring process), and the channel zone between the permanently flowing reach and the bankfull state (see the figure at the top of the field sheet of the appendix). Helophytes are commonly found in the zone between the instream channel and the bankfull height, and are used in the index as an element to increase its ecological value because they provide habitat and refuge for many species. This index does not consider submerged macrophytes, because instream channel characteristics are not used.

The QBR index ranges between 0 and 100 and follows the rationale of the RCE index (Petersen, 1992). It is the sum of four scores, based on four aspects of riparian quality (parts of the two-sided form in the appendix). Each aspect is initially scored with one of four values: 0, 5, 10 or 25; intermediate values cannot be scored. This initial score is then adjusted according to additional criteria established in the lower part of each of the four sections. Each criterion in the form must be considered, and more than one criterion may be applicable. If the final score is negative, it is recorded as 0. If the final score is above 25, it is recorded as 25. Negative values and values higher than 25 were excluded in order to give the same importance to each of the four parts of the index. The additional criteria were derived by the authors following an exhaustive survey of sampling stations. The scores for these additional criteria were chosen by the expert opinion of the authors according to the importance of each criterion in the streams studied.

As most of the sites were surveyed using available bridges and roads that cross the river, these are not considered as a channel alteration. Instead, the QBR index is analysed upstream or downstream from such constructions. However, other bridges or roads either parallel to the river or crossing it in the study reach, but not used to gain access to the river, are included in the analysis.

The analysis of a site takes between 10 and 20 min depending on the experience of the observer. The name of the observer is noted because the index will have a degree of subjectivity, including two sources of error: method assumptions and observer bias. The first is avoided as much as possible by the training of the observer by other experienced observers. The second source of error is analysed in this paper.

An assessment of component factors of QBR

Total vegetation cover. This is assessed both for the riparian and channel areas and includes any kind of tree, bush, shrub or helophyte. Grasses are excluded because they are annual plants and their cover may be very variable depending on the year and the hydrological conditions. Connectivity between the riparian environment and adjacent terrestrial ecosystems is considered a key element for the preservation of biodiversity and is used to refine the index score. Metalled roads are always considered as barriers between the riparian habitat and adjacent terrestrial ecosystems; where present in this area, five points for a road on each margin are subtracted from the initial value. Rough tracks, sand roads or paths <4 m wide are not considered to threaten the connectivity with terrestrial environments and therefore the initial value is not changed. Care should be taken if vegetation is scarce in the riparian area as a result of natural causes (e.g. a large flood). In the case of heavy disturbances by natural floods, the QBR value may be low and then recover in successive years. Connectivity with terrestrial environments is very important and may increase the value of this part of the survey by up to 10 points, thus balancing the low value obtained from the low cover percentage when natural disturbances of riparian habitat have occurred.

Vegetation cover structure. An assessment is made of the structural complexity of the riparian environment that may increase the biodiversity of the fluvial ecosystem, both for animals and plants. The initial score depends on the total percentage of cover due to trees (see the appendix for the percentage threshold between scores). The score may be increased by the presence of shrubs and other low-lying vegetation below the trees. The presence of helophytes or other vegetation in the channel also increases the score. Linear arrangements (mostly tree plantations) or isolated clumps of trees decrease the initial value. In this part the tree cover is the key factor, but if the trees are planted this lowers the score. On the other hand, if tree cover in the riparian zone is low but helophytes or shrubs are present in the channel, the score is increased due to the improvement of the habitat that this vegetation provides to many animals.

Cover quality. The number of tree species present in a stream reach will vary depending on river geomorphology and stream type. Three stream types are defined according to the total geomorphological score which depends on the form and slope of the riparian environment (see drawings in the field sheet of the appendix). Both margins are surveyed and their values are added. Negative values are subtracted from the geomorphological score when islands or sand bars are present in the channel. These islands or bars increase the availability of substrate to develop riparian forest and the possible presence of different species of trees (e.g. *Salix* spp.) Therefore, when subtracting one or two points from the geomorphological index, the type of riparian habitat may change from type 1 to type 2 or from type 2 to type 3, increasing the number of native tree species necessary for scoring 25 points as should be expected from areas with sand bars or islands. The presence of natural bedrock substrata increases the geomorphological score, and indicates low natural availability of soil for plant colonization. For this reason, two, four or six points are added to the geomorphological score. Thus, this score may change from type 2 to type 1 lowering the number of native tree species required as may be expected from areas where it is difficult to find soil to extend the roots.

When the type of riparian habitat has been established using the geomorphological score, the number of species of native trees present in the reach gives the cover quality score. This can be increased if the native riparian forest is continuous along the river or if the species are distributed in corridors. The value decreases if non-native trees are present or if the habitat has been modified by man (e.g. by the presence of wells, buildings or garbage dumps in the area). A list of the non-native species is needed for individual study areas. A useful list for Spain is provided in the field sheet but should be modified according to local expert knowledge in plant ecology.

River channel alterations. Man-made river channel alterations are included in the index because they are one of the main disturbances to the riparian habitat. The presence of permanent continuous structures (channelization) scores zero because permanent barriers between the riparian areas and the channel are present. When channelization, rigid structures or alluvial terraces are not continuous or are present in $<25\%$ of the site, they are considered as rigid structures and score only five points. This includes structures such as embankments, that are less penalized than rigid channels, because they may permit the presence of some plants growing between rocks and are more permeable to small animal species. The modification of alluvial terraces, constraining the width of the channel (e.g. due to agricultural activities) gives a score of 10 points, because in addition to morphological changes produced they affect the availability of water for riparian trees. Structures that protrude into the main channel, such as weirs or river crossings, score -10 points, the same as wells used for water abstraction. Bridges or areas used to gain access to the river should not be considered, because the sampling area has to be delimited upstream or downstream of these bridges.

Classes of riparian quality. After completing the analysis, the sum of the four parts gives the final QBR index. The index varies between 0 and 100. There are five quality classes of riparian habitat (Table 1) which broadly correspond to those suggested in the Water Framework Directive (European Commission, 2000). Although in the Directive riparian habitat is used only for the characterization of 'high status', this system

Table 1. Quality classes according to the QBR index

Riparian habitat quality class	QBR	Colour
Riparian habitat in natural condition	$\geqslant$95	Blue
Some disturbance, good quality	75–90	Green
Disturbance important, fair quality	55–70	Yellow
Strong alteration, poor quality	30–50	Orange
Extreme degradation, bad quality	$\leqslant$25	Red

may be useful for local managers and for restoration targets (González del Tánago and Antón, 1998). Class boundaries have been defined according to the authors' experience and their use as quality classes may be limited to the studied area and should be checked for other geographical areas.

Relationship between riparian communities and index values

The number of species and assemblages of riparian vegetation can differ greatly from the headwaters to the lower reaches of streams (Van Coller *et al*., 1997). In the three rivers studied, the riparian tree communities of the headwaters were different from those of the lowlands (Nuet *et al*., 1991). This could affect the QBR index and make it difficult to compare scores from sampling points. To correlate the QBR index with riparian tree communities during the first sampling period (1997), a list of species found at each sampling site and their relative abundance was recorded. Abundance was scored using a scale of values to indicate increasing cover (1, present; 2, abundant; 3, dominant). With this method, the presence and relative abundance of each tree species, the most abundant shrubs and the distinct helophytes in the river channel were studied. The ordination and classification of sampling stations and vegetation communities using these data was made using TWINSPAN analysis (Hill, 1979).

Evaluation of index subjectivity and observer bias

The QBR index is an easy and rapid method to assess riparian quality, and several observers can be involved in each survey and in successive surveys of the same site. However, different observers may give different index scores for the same sampling site on successive dates. As no large environmental changes in the riparian area took place during the study, the effect of disturbances are excluded, and therefore differences of the score at each site may be considered as an error due to observer's subjectivity or misinterpretation of the method.

Ten observers took part in the field work and all of them received previous training by those responsible for the index design (Munné *et al*., 1998a, b). The number of observations per observer was between 7 and 99 (Table 2). Most of the observers visited upstream and downstream reaches of all quality levels. Four

Table 2. Number of observations made by 10 observers and repetitions by each observer at a given sampling site

	Obs. 1	Obs. 2	Obs. 3	Obs. 4	Obs. 5	Obs. 6	Obs. 7	Obs. 8	Obs. 9	Obs. 10
Observations	99	18	64	47	13	10	26	22	24	7
1 time	36	12	20	27	13	10	26	18	14	7
2 times	24	3	16	10				2	5	
3 times	5	0	4	0				0	0	

observers visited some sampling points only once, while others visited the same site up to three times. As the QBR index from these repetitions was not significantly different for these observers, the mean value for each of these observers and for each site was used.

To evaluate the tendency of observers to increase or decrease the index value, the mean index value using all observers' values was calculated for each sampling site. This mean was considered the most precise value for the QBR index for this site and was compared with the values given by each observer. The differences between all the QBR values given by one observer and the mean of each sampling point was considered a measure of observer precision. The mean and the standard deviation of the difference for each observer were also calculated and the significance of the differences was tested using a Student's *t*-test. The null hypothesis was that the QBR index values given by an observer at one site are equal to the mean of all the observers of this site. Therefore, for each sampling site, the difference between the mean and the value given by each observer should be zero. This analysis was also done using all the data from the 10 observers to test whether the overall deviation from the index application was significantly different. Three types of observer bias can be identified using this analysis: optimistic (always significantly higher than the mean), doubtful (positive and negative deviations, but not significantly different from the mean), and pessimistic (always significantly lower values than the mean).

Observer precision for the five quality ranges in Table 2 was also calculated because despite some differences in absolute values, the quality range given by the observers can coincide. Thus, two assessments at the same sampling point made by two observers may fall in the same quality category despite differences in the absolute score value (e.g. all values between 55 and 70 fall in the third category despite a possible maximum difference of 15 points between the lower and the higher values). Calculations were made of the number of cases in which the quality ranges were different for each observer compared with the mean of each site, and the percentage error of quality class qualification.

STUDY AREA

The QBR index has been applied to three river basins in Catalonia, NE Spain, all sharing a Mediterranean climate with a mean annual rainfall ranging from 300 to 600 mm and dry summers with low or no rainfall (Figure 1; Table 3). The altitudes of sampling stations range from a few metres above sea level to 1360 m. Only the higher parts of the Llobregat basin have a significant amount of snow fall, and the river is highly regulated due to its karstic geology and several dams in the catchment. Further details of the rivers studied can be found in Prat *et al.* (1984, 1985, 2000).

Several sampling sites were visited on the three rivers in the summer of 1997 and twice (spring and summer) during 1998 and 1999, giving a maximum number of five assessments at each site. A total of 330 observations were made by 10 different observers. This provides an opportunity to check possible index subjectivity although no specific design was made at the beginning of the study for this performance test. The number of sites analysed and the total number of observations for each basin are shown in Table 3.

Table 3. Characteristics of four basins studied for QBR index application

Basin	Length (km^2)	Area (km)	Mean discharge ($Hm^3 a^{-1}$)	Maximum altitude (m)	Sampling sites	Visits
Besòs	50	960	122	1000	27	126
Foix	30	450	9	600	18	77
Llobregat	155	4990	700	1360	27	127

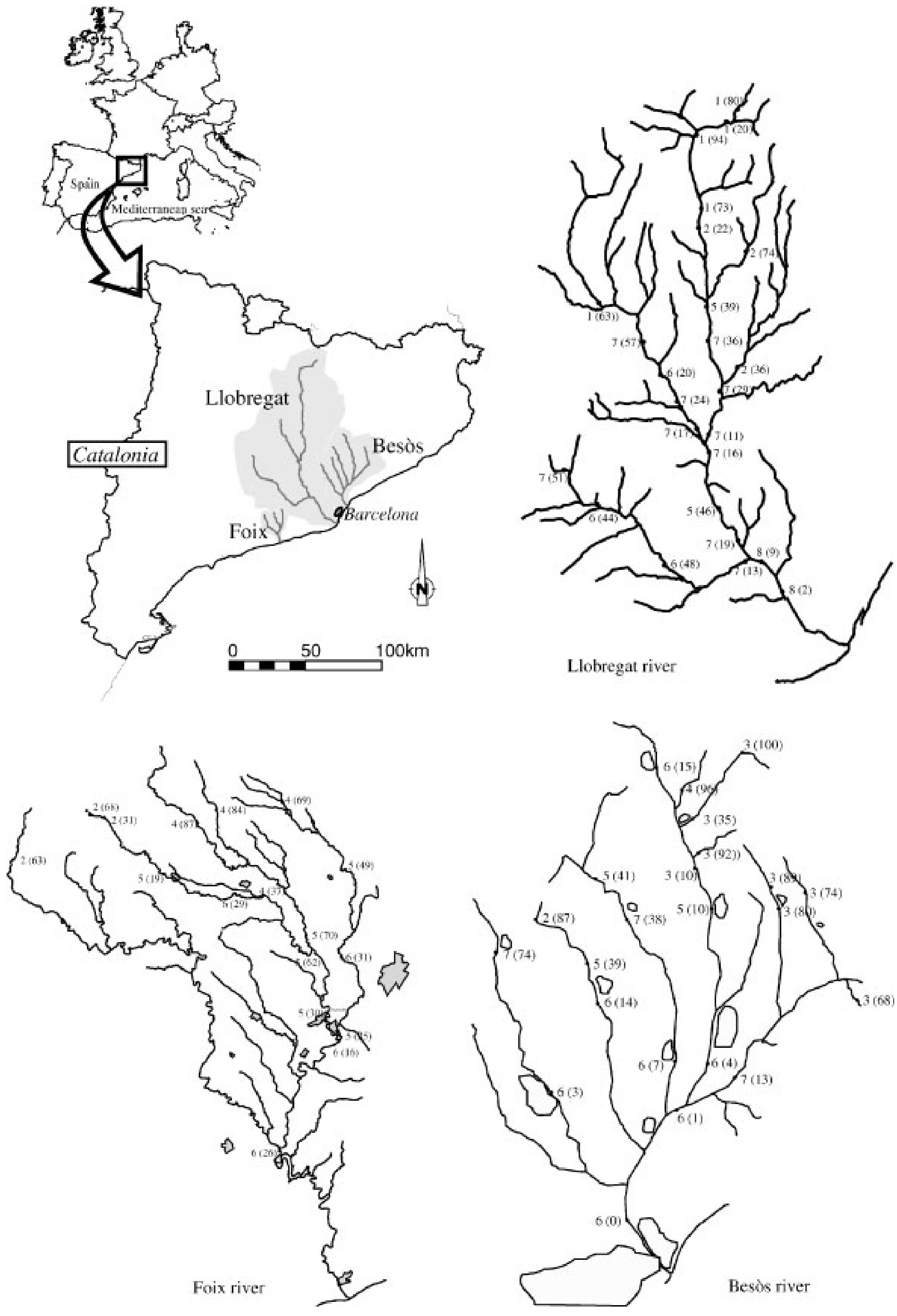

Figure 1. Classification in eight groups using a TWINSPAN analysis, and mean of riparian quality using QBR index (within the parentheses) in the Besòs, Foix and Llobregat rivers (NE Spain).

RESULTS

Communities and their ecological significance

Eighteen tree species were recorded, seven of which are considered to be non-native. Several tree, shrub and helophyte species were commonly found, while others were scarce (Table 4). One abundant non-native species (*Arundo donax*) was recorded.

From the TWINSPAN analysis, eight communities were defined (Table 5, Figure 1). Figure 1 shows how the communities are distributed for each site in each basin. Groups 1–4 are those that are predominantly

Table 4. Frequency (%) of main trees, shrubs and helophytes in the sampling sites in the three basins analysed ($n = 72$)

	Llobregat	Foix	Besòs
Trees			
Acer monspessulanum	4	0	0
Ailanthus altissima[a]	12	0	0
Alnus glutinosa	24	0	30
Celtis australis[a]	0	18	9
Corylus avellana	20	24	30
Fraxinus angustifolia	32	71	13
F. excelsior	28	18	26
Platanus × *hispanica*[a]	4	35	26
Populus alba	48	35	22
P. deltoides[a]	60	18	26
P. nigra	60	6	22
P. nigra sp. *italica*[a]	4	0	4
P. tremula	0	0	4
Robinia pseudo-acacia[a]	28	12	30
Salix alba	16	6	4
S. atrocinerea sp. *catalaunica*	0	0	4
S. babylonica[a]	4	0	0
Ulmus minor	16	35	43
Shrubs			
Clematis vitalba	32	53	48
Cornus sanguinea	24	29	22
Crataegus monogyna	20	35	17
Hedera helix	12	59	39
Rubus sp.	64	100	65
S. elaeagnos sp. *angustifolia*	28	24	4
Sambucus nigra	24	18	43
Helophytes/other vegetation types			
Arundo donax[a]	68	71	48
Equisetum sp.	8	0	4
Juncus sp.	48	53	39
Phragmites australis	52	18	26
Typha angustifolia	28	0	13

[a] Non-native species.

Table 5. Groups of riparian vegetation from TWINSPAN analysis at the sampling sites analysed

First division		Second division		Third division	
Groups	Indicator species	Groups	Indicator species	Groups	Indicator species
1, 2, 3, 4	*Clematis vitalba* *Hedera helix* *Cornus sanguinea*	1, 2	*P. alba*[a] *Crataegus monogyna*[a] *Salix elaeagnos* *C. sanguinea*	1	*Alnus glutinosa*
				2	*Rubus* sp.[a] *Ph. australis*
		3, 4	*C. vitalba*[a] *Ulmus minor* *H. helix*	3	*Rubus* sp.[a]
				4	*H. helix* (p) *Fraxinus angustifolia*
5, 6, 7, 8	*Arundo donax*[b] *Populus alba*	5, 6	*Rubus* sp.	5	*A. donax*[b] *C. vitalba* *P. alba* *U. minor* *P. deltoides*[b]
				6	*Ph. australis* *F. excelsior*
		7, 8	*Phragmites australis*[a] *P. deltoides*[b] *Typha* sp. *Robinia pseudo-acacia*[b] *P. nigra*	7	*Ph. australis*
				8	*S. alba*

The indicator species of each division are shown.
[a]The most indicative species. [b]Non-native species.

found in headwaters (in the relatively colder and humid areas of all the streams and rivers sampled), with *Alnus glutinosa* and *Fraxinus angustifolia* as the characteristic species of trees for Groups 1 and 4, respectively. The headwaters of Foix and Besòs (Groups 2 and 4) are clearly differentiated in the TWINSPAN analysis from the headwaters of the Llobregat (Group 1, in a colder and wetter area), and from those of the Besòs river in the Montseny area (Group 3, also an area with higher rainfall and lower summer temperatures). Groups 5–8 (typical taxa — poplars, willows and some introduced species) characterize the middle and lower parts of streams, which are also the most modified areas. Although helophytes appeared as indicators in several groups, they were more frequent in the lower and middle reaches (Groups 6–8) where their growth is favoured due to the higher nutrient content of the water and the presence of suitable substrate.

Table 6. Number of sampling sites and observations for each riparian quality class in three Mediterranean basins

QBR index	Besòs	Foix	Llobregat	Total	%
Sampling sites ($n = 72$)					
$\geqslant 95$	3	0	2	5	6.9
75–90	6	2	4	12	16.6
55–70	2	5	3	10	13.8
30–50	3	6	6	15	20.8
$\leqslant 25$	13	5	12	30	41.6
Observations ($n = 330$)					
$\geqslant 95$	15	0	7	22	6.6
75–90	27	10	16	53	16
55–70	5	19	15	39	11.8
30–50	17	25	30	72	21.8
$\leqslant 25$	62	23	59	144	43.6

QBR index values

The QBR index values were grouped in ranges of quality (Table 6). The QBR index of 45 sampling localities was lower than 50, implying that the riparian environments were of poor quality at many sites in the three catchments studied.

No significant differences were found in the percentages of sites and observations for each quality class (Table 6). Low values were found predominantly downstream (Figure 1), but were also occasionally found upstream independent of the differences in vegetation species composition between upper and lower stream reaches.

The highest values recorded in Groups 5–8 (middle and lower parts of the catchments) were consistently lower than those of Groups 1–4, but high and low values are found in each of the eight groups defined by TWINSPAN. This indicates that QBR evaluates the habitat quality independent of the floristic composition at each site (sites with alder may have lower value than others with poplar in accordance with the rationale of the QBR index).

Observer bias

The result of the Student's *t*-test performed to analyse the significance of the standard deviation from the mean QBR value for each of the 10 observers (Table 7) shows that the null hypothesis (that is, the average deviation of each observer from the overall mean QBR value for each site equals zero) can be significantly rejected ($p < 0.05$) for two of the 10 observers (Observers 1 and 6), and accepted ($p < 0.05$) for the remaining eight. Observers 1 and 6 change the QBR significantly values compared with the mean of all observers. Observer 1 scores lower values than the mean with low standard error, and Observer 6 tends to higher values with high standard error. Although high standard errors were recorded for one of the observers, the mean deviation of total observations of all observers from the mean QBR value for each sampling site was not significant ($p < 0.05$) (Table 7). The sum of the differences from the mean value of each observer compared with the mean value of all observers was relatively low (from -3.5 to 12.3) (Table 7) and the highest value of the standard deviation was 16.2.

The differences in the QBR quality classes determined by each observer were compared (Table 8); of 330 cases, 229 were correctly placed (69.4%) and in most of the others the difference was only one class (12.7%

Table 7. Number of observations, mean, standard deviation and mean standard deviation from QBR values for each observer, and significance level from the Student's t-test for each observer

Observer	Observations	Mean	S.D.	S.E.	t	p
Obs. 1	65	−3.5	10.3	1.2	−2.76	0.008
Obs. 2	15	−1.7	12.3	3.2	−0.05	0.959
Obs. 3	40	1.1	10.2	1.6	0.68	0.500
Obs. 4	37	−0.2	10.0	1.6	−0.10	0.922
Obs. 5	13	0.2	10.4	2.9	0.06	0.953
Obs. 6	10	12.3	9.4	3.0	4.14	0.003
Obs. 7	26	−1.5	9.4	1.8	−0.81	0.426
Obs. 8	20	3.5	7.6	1.7	2.07	0.052
Obs. 9	19	−1.3	16.2	3.7	−0.35	0.732
Obs. 10	7	2.9	7.9	3.0	0.96	0.373
Total	252	−0.2	10.9	0.7	−0.24	0.808

Table 8. Percentage and number of observations correctly placed in each QBR class by 10 observers

	Obs. 1	Obs. 2	Obs. 3	Obs. 4	Obs. 5	Obs. 6	Obs. 7	Obs. 8	Obs. 9	Obs. 10	Total
Observations	99	18	64	47	13	10	26	22	24	7	330
sup 3	0	0	0	0	0	0	0	0	0	0	0
sup 2	0	1	2	1	0	0	0	0	1	0	5
sup 1	12	2	10	6	4	5	3	3	6	1	52
Correctly placed	72	12	41	35	8	5	20	19	11	6	229
inf 1	14	3	10	5	1	0	3	0	6	0	42
inf 2	1	0	1	0	0	0	0	0	0	0	2
inf 3	0	0	0	0	0	0	0	0	0	0	0
% correct	72.7	66.7	64.1	74.5	61.5	50.0	76.9	86.4	45.8	85.7	69.4

Number of observations with class higher (sup 1, sup 2, sup 3) or lower (inf 1, inf 2, inf 3) than the global mean are indicated.

lower, and 15.7% higher). In only seven cases was there a difference of two quality classes and no observations of three. No significant event took place in the streams during the study and therefore no structural changes can explain a large change in the QBR index on two consecutive visits (except in one case). Changes occurred more frequently in the intermediate classes (58% of the changes) and less frequently in the upper or lower classes (18% and 17%, respectively) (Table 9).

DISCUSSION

The relative simplicity of the QBR index allows its calculation in a few minutes, which is an advantage over other methods which are more time consuming (e.g. RHS: Raven *et al*., 1998b). The QBR index is designed only for riparian zones because it measures the habitat quality from the banks of streams and rivers. The

Table 9. Observations correctly placed in each QBR class by all observers together (inf and sup have the same meaning as in Table 8)

Quality level		Total	%
5	inf 2	1	5
	inf 1	4	18
	0	**17**	**77**
4	inf 2	0	0
	inf 1	10	19
	0	**36**	**68**
	sup 1	7	13
	sup 2	0	0
3	inf 2	1	2
	inf 1	12	29
	0	**16**	**38**
	sup 1	12	29
	sup 2	1	2
2	inf 2	0	0
	inf 1	16	23
	0	**42**	**61**
	sup 1	8	12
	sup 2	3	4
1	**0**	**116**	**82**
	sup 1	24	17
	sup 2	1	1

index is independent of other river features which are used in other indices that evaluate riparian zones together with other basin characteristics such as the river bed or general conservation values (e.g. Petersen, 1992; US EPA, 1997; Boon *et al*., 1997, 1998; Raven *et al*., 1998b; Ladson *et al*., 1999). The QBR index can also be used together with other metrics to obtain a measure of integrated quality value in streams such as the Llobregat, Besòs, Tordera and Foix in NE Spain (e.g. Prat *et al*., 1999).

Quality indices must be comprehensive and cover a wide range of conditions and geographical areas (Karr, 1999). In riparian habitats, two of the most common determining factors are geographical differences in plant community composition and the development of vegetation related to the geomorphological structure of the river. Within the geographical area studied, the QBR index proved to be independent of regional differences in riparian plant community types, as shown from a comparison between the TWINSPAN analysis of plant communities and the QBR values. It is not necessary to identify all the riparian vegetation to species level in order to calculate the QBR index, but a knowledge of native and non-native trees is needed as these are used to determine part of the QBR value. In other metrics that rely on detailed species composition to evaluate riparian quality, the use of the index is limited to the region for which it was designed (e.g. for NW Spanish Mediterranean areas — Polo and Vilar, 1991).

Variations caused by riparian geomorphology along the river continuum may lead to miscalculations in quality indices as riparian structure determines vegetation. For instance, the number and the identity of plant species of large floodplains are different from those found in headwaters, and this may prevent the same index being used along a river basin. The QBR index takes into account differences in the geomorphology of the river from its headwaters to lower reaches and these differences are measured in a simple semi-quantitative way in the field form. The QBR index can be applied to any river with a forested riparian zone, but, obviously, not in high mountain areas above the tree line where no trees are present.

Current approaches for determining the quality of river ecosystems rely on a 'reference' condition (Reynoldson *et al*.; 1997, Bailey *et al*., 1998), and on a definition of ecotypes or regions where the value of the metrics used may be different (Hughes *et al*., 1994; Bryce and Clarke, 1996). Reference status is often difficult to assess for some sites, especially in lowland floodplain river systems because of the lack of pristine sites and process models that can predict the impact of natural and human disturbances (Thoms *et al*., 1999). The QBR index uses simple measures (total vegetation cover and tree composition), and may be helpful in defining quality values in riparian habitats in the absence of reference conditions. This index may be a useful tool for providing expert advice under the Water Framework Directive.

Subjectivity is always a problem in applying quality indices to rivers (Boulton, 1999). However, the results of this study show that the QBR has a reasonable bias in its calculation when the same site is evaluated by different observers. The highest errors were produced for the less-trained people and may be solved by more intensive training. This has been noted in exercises with students of the University of Barcelona although no statistical evidence can be presented here. Until now the index has been successfully applied to several areas of Spain, despite differences in floristic composition. The QBR index has also been used in the semi-arid region of SE Spain by changing only the tree and shrub species required for Part 3 (e.g. Suárez-Alonso and Vidal-Abarca, 2000). The QBR index has also been tentatively used in Argentina (Toscano *et al*., in press), and adapted to be applied in high mountain areas of the Pyrenees (Carrascosa and Munné, 2000). One of the authors (Bonada) has used this index in Mediterranean streams of South Western Australia and South Africa (Cape Province), with only small changes related to tree species composition (both native and non-native).

The QBR index is intended for use by environmental managers and planners at national and regional levels and can be used to report on the riparian condition of streams. The index has been used in research and monitoring programmes in the region of Barcelona (Prat *et al*., 1999, 2000) and other basins along the Mediterranean coast. In other areas of Spain, it has been used to assess the long-term effectiveness of rehabilitation programmes (González del Tánago and Antón, 1998). These authors calculated the cost of river rehabilitation in the region of Madrid according to the actual value of QBR compared with the objective which was fixed to a future QBR value close to 95. It can also be used for post-project evaluation (Landers, 1997). The classification of riparian quality using the QBR index can be easily mapped along rivers using GIS tools (Muller, 1997; Narumalani *et al*., 1997) and other systems (e.g. Neale, 1997).

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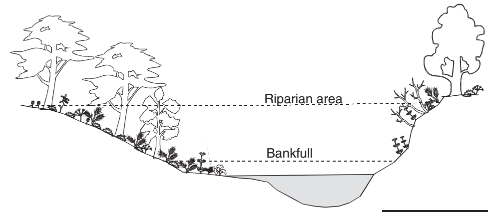
APPENDIX: *FIELD SHEET*

QBR INDEX

Riparian habitat quality



Score of each part cannot be negative or exceed 25

Station	
Date	

Section 1: Total riparian cover Section 1 Score

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

Section 2: Cover structure Section 2 Score

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

Section 3: Cover quality *(the geomorphological type should be first determined[a])* Section 3 Score

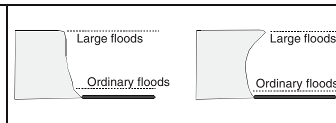
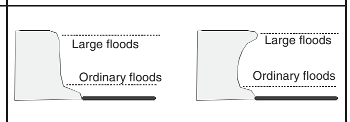
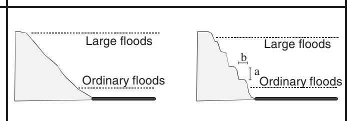
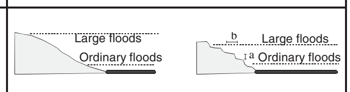
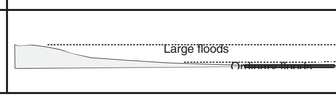
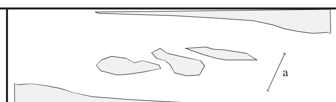
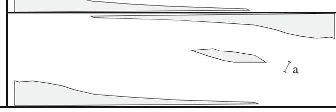
Score		***Type 1***	***Type 2***	***Type 3***
25	Number of native tree species	>1	>2	>3
10	Number of native tree species	1	2	3
5	Number of native tree species	0	1	1 – 2
0	Absence of native trees	-		
+ 10	If the tree community is continuous along the river and covers at least 75% of the edge riparian area			
+ 5	The tree community is nearly continuous and covers at least 50% of the riparian area			
+ 5	If the riparian community is structured in gallery			
+ 5	When the number of shrub species is	>2	>3	>4
− 5	If there are some man-made buildings in the riparian area			
− 5	If there are some isolated species of non-native[b] trees			
− 10	Presence of communities of non-native[b] trees			
− 10	Presence of garbage			

Section 4: Channel alteration Section 4 score

Score	
25	Unmodified river channel
10	Fluvial terraces modified and constraining the river channel
5	Channel modified by rigid structures along the margins
0	Channelized river
– 10	River bed with rigid structures (e.g., wells)
– 10	Transverse structures into the channel (e.g., weirs)

Final score (sum of four section scores)	

[a] **Type of the riparian habitat (to be applied at level 3, cover quality)**
The score is obtained by addition of the scores assigned to left and right river margins according to their slope. This value can be modified if islands or hard substrata are present.

		Score	
Slope and form of the riparian zone		Left	Right
Very steep, vertical or even concave (slope >75°), very high, margins are not expected to be exceeded by floods. *Slope is the angle subtended by the line between the top of the riparian area and the edge of the ordinary flooding of the river.*		**6**	**6**
Similar to previous category but with a bankfull which differentiates the ordinary flooding zone from the main channel.		**5**	**5**
Slope of the margins between 45° and 75°, with or without steps. (*a*>*b*)		**3**	**3**
Slope between 20° and 45°, with or , with or without steps. (a < b)		**2**	**2**
Slope <20°, large riparian zone.		**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 can make impossible the presence of plants with roots			
> 80%		Not applicable	
60 – 80%		+ 6	
30 – 60%		+ 4	
20 – 30%		+ 2	
Total Score			

Geomorphological type according to the total score

>8	**Type 1**	Closed riparian habitats. Riparian trees, if present, reduced to a small strip. Headwaters.
5 − 8	**Type 2**	Headwaters or midland riparian habitats. Forest may be large and originally in gallery.
<5	**Type 3**	Large riparian habitats, and potentially extensive forests. Lower courses.

[b] **Non-native tree species in the study area**
(This should be listed for each study area)

e. g. in the studied area of Catalonia the following species are considered non-native: *Populus deltoides, Populus* x *canadensis, Populus nigra* ssp. *italica, Salix babilonica, Ailanthus altissima, Celtis australis, Robinia pseudo-acacia, Platanus* x *hispanica.*