Linking fish-based biological indicators with hydrological dynamics in a Mediterranean river: relevance for environmental flow regimes

O. Belmar[1*], N. Vila-Martínez[1,2], C. Ibáñez[1], N. Caiola[1]

[1] Marine and Continental Waters Program, IRTA, Carretera Poblenou, km 5.5, 43540 Sant Carles de la Ràpita, Catalonia, Spain

[2] Geography Department, Rovira i Virgili University, C/Joanot Martorell, 15, 43480 Vila-Seca, Catalonia, Spain

[*]Corresponding author: Oscar Belmar (oscar.belmar@irta.cat; oscarbd@um.es)

Abstract

The relationship between flow dynamics and biological communities becomes especially relevant in Mediterranean rivers. Given their natural variability and growing anthropogenic pressures, their low sections are subjected to multiple impacts. The definition of ecohydrological relationships in Mediterranean rivers may constitute a useful management tool. Historically, fishes were the first group used to assess community-level ecological quality, and different indices and metrics have been proposed. However, up to date many of these indicators have showed to be insensitive to flow regime changes or hydrological alteration. There is therefore a need to deepen into the ecohydrological relationships between such indicators and flow regimes in Mediterranean (and other) rivers. This study presents an analysis of the relationship between interannual flow regimes in the lower section of the Ebro River, defined using a set of daily and hourly hydrologic indices, and ecological quality based on fish community, assessed through indices designed to fulfill the Water Framework Directive (WFD) in Europe: the Indices of Biotic Integrity in Catalan rivers (IBICAT2010 and IBICAT2b) and the new European Fish Index (EFI+). In order to identify spatiotemporal patterns, hydrologic indices were computed using time periods of different amplitude and ecological quality was obtained in different transects along the river section, even within the same water units or ‘water masses’ (subdivisions of surface waters to fulfill the WFD in Spain). Our results showed that IBICAT2010 was the most correlated with hydrologic indices, followed by IBICAT2b and EFI+. The latter showed an almost null correlation with hydrologic indices, which may be due to issues associated with the sampling technique, the definition of transects and because it does not uses stream typologies.. Correlations among some hydrological and biological indices were observed, with temporal and spatial patterns. On one hand, daily hydrological indices showed relationship with ecological quality when they were computed using between 9 and 36 months of flow records (previous to the sampling date) whereas subdaily indices responded better to periods between 3 and 9 months of records. On the other hand, some sampling transects showed clearer relationships than others, even within the same water mass, which suggests an influence of the hydromorphologic variability on the obtained ecological quality scores.

Keywords

Ecological quality; fish indices; Ebro River; Water Framework Directive; environmental flows

Highlights

Interannual flow variability produces changes in fish-based ecological quality

Spatial and temporal scales may determine the ability to observe shifts in fishes

Observing ecohydrological relationships requires a screening of the indices to use

Potential breakpoints in ecological quality may guide water management

1. Introduction

The ‘natural flow regime paradigm’ (Poff, 1997) defined flow dynamics as one of the main drivers of ecological properties of rivers and streams. Therefore, hydrologic alteration is a potential risk for aquatic ecosystems, as it has effects on aquatic communities (Poff & Zimmerman, 2010) that may alter their characteristics even at evolutionary time scales (e.g. Mims & Olden, 2012). Specially in Mediterranean streams and rivers, subjected to a high natural hydrological variability (Gasith & Resh, 1999; Caiola et al. 2001a,b) and to many pressures frequently associated with agricultural activities, such as flow regulation by dams and water extraction for irrigation (Ferreira et al., 2007b).

The Water Framework Directive (WFD; 2000/60/EC) established the objective to achieve a ‘good ecological status’ in the water bodies of the European Union (including those artificial and heavily modified). With the aim of achieving this objective, the Directive requires the sub-division of surface waters into ‘discrete and significant elements’ or ‘water bodies’ (in Spain, ‘water masses’). However, the Directive does not provide explicit guidance on how to identify the elements that should be regarded as ‘discrete and significant’ and, as a consequence, the different water bodies may present relatively heterogeneous characteristics such as the length of the stream section.

Whereas classical approaches have focused on target species to define ecohydrological relationships (e.g. Instream Flow Incremental Methodology, IFIM; Bovee & Milhous, 1978), the WFD focuses on the assessment of community-based ecological integrity. Some studies have focused on macroinvertebrates (Buffagni et al., 2005; Bennett et al., 2011; Birk and Hering, 2006, 2009), macrophytes (Birk et al., 2006; Birk and Willby, 2010) or diatoms (Birk and Hering, 2009), but the first method to assess the biotic integrity of rivers was developed specifically for fishes (e.g., Karr, 1981; Fausch et al., 1984). Fishes not only possess a higher direct socio-economic impact than other aquatic organisms but also are key indicators of ecological condition in rivers. In comparison with other taxa, they tend to be more responsive to hydromorphological disturbances (Birk et al., 2012; Marzin et al., 2012), connectivity loss

(Schiemer, 2000; Sindilariu et al., 2006) and other stressors that act at wide spatial and temporal scales (Harris, 1995; Simon, 1999).

The first attempt to develop fish-based methods for ecological assessment in streams and rivers across the whole European Mediterranean basin, and fulfill the Water Framework Directive (WFD), was made within the EU-funded FAME (Development, Evaluation and Implementation of a Standardized Fish-based Assessment Method for the Ecological Status of European Rivers; http://fame.boku.ac.at) and EFI+ (Improvement and Spatial extension of the European Fish Index; http://efi-plus.boku.ac.at/index.htm) projects. The main output of these two projects was the new European Fish Index (EFI+), the first standardized fish-based assessment applicable across nearly the whole range of European rivers (Pont et al., 2006, 2007). It is a predictive multimetric index that derives reference conditions of individual sites from abiotic environmental characteristics and quantifies the deviation between the predicted and the observed fish assemblages (Pont et al., 2006). The metrics that integrate the index are based on functional guilds that describe the main ecological and biological characteristics of fish assemblages (Logez et al., 2013). Although such index was reasonably accurate at the European scale, its applicability varied among different biogeographical regions and countries (Pont et al., 2007; Urbanic and Podgornik, 2008; Logez et al., 2010). In Spanish Mediterranean rivers, the Mediterranean Index of Biotic Integrity or IBIMED is used as a fish-based assessment method suitable for the evaluation of ecological quality. First developed for Catalan rivers under the designation of IBICAT (Index of Biotic Integrity for Catalan rivers; Sostoa et al., 2004), an improved version of this index was developed in 2010 (IBICAT2010; Sostoa et al., 2010) before being adapted to the rest of Mediterranean Spanish rivers under the designation of IBIMED. IBICAT2010 and IBIMED are similar in the Ebro River, except for the different species, ecological guilds and thresholds of the Ecological Quality Ratio (EQR) classes. They follow a type-specific method based on eight environmental variables that were selected as the best descriptors of a river classification based on historical fish distribution. More details on the EFI+ and IBIMED may be found in Segurado et al., (2014). Finally, a type-specific variant of

IBICAT (IBICAT2b) uses between 4 and 8 metrics depending on river type and has been validated with environmental pressures both throughout Catalonia and the whole Ebro River Basin (Sostoa et al., 2010). IBICAT, its variant (IBICAT2b) and EFI+ have been described as correlated in the Ebro basin (García-Berthou & Bae, 2014).

Despite aquatic communities are in general strongly affected by hydrology, most of the methods developed for the assessment of biological quality elements are largely insensitive to flow regime changes or hydrological alteration (e.g. Poff & Zimmerman, 2010; Demars et al., 2012; Friberg 2014). For example, only 40% of the methods developed for fishes are sensitive to flow modifications (Rinaldi et al., 2013). There is a need for development of biological methods to provide metrics sensitive to hydrological pressures and alteration of flow components (European Commission, 2015), which means that further investigation of the relationships between current biological indices (and metrics) and hydrologic regimes results essential. Defining ecohydrological relationships in Mediterranean (and other) rivers constitutes a powerful tool for water management, in consonance with frameworks such as the Ecological Limits of Hydrological alteration (ELOHA; Poff et al., 2010).

Spatial and temporal scaling phenomena should be considered when establishing a monitoring program. The dimensions of variation change along spatial/temporal gradients of salinity, habitat complexity and productivity and among different levels of biological organization. Without an adequate evaluation of such variation, representative samples cannot be taken (Livingstone, 1987). In this context, for example, studies on juvenile salmonids and other fishes suggest that more than 5 years before and later are needed to detect significant changes in fish abundance after physical habitat shifts (e.g. caused by hydrological variations) unless the magnitude of change in fish abundance is large (>threefold) or the treatments and controls are extensively replicated (Bisson et al., 1997; Roni et al., 2003). Attention must be paid also to temporal resolution, as the use of hourly records together with daily flows may allow distinguishing effects caused by particular flow regime characteristics such as hydro-peaking (e.g. Macnaughton et al., 2017).

The aim of this study was to test the ability of different hydrological indices to explain changes in ecological quality assessed through fishes in the lower section of a Mediterranean river (Ebro from Flix to Tortosa). IBICAT2010, IBICAT2b and EFI+ were employed in order to compare their relationship with hydrology. The relationships between IBICAT2010 and its metrics were also assessed. Different time scales (from months to years) and data resolutions (daily and hourly) were employed for the computation of the hydrologic indices. We hypothesized a similar relationship among the three ecological indices and the hydrologic indices used (based on García-Berthou & Bae, 2014). In addition, we expected daily hydrological indices computed with the shortest time scales (counted since the moment in which the sample was taken) not to show a relationship with ecological quality given that, as stated above, previous authors highlighted the necessity of relatively long series to detect changes in fishes after habitat shifts (Bisson et al., 1997; Roni et al., 2003). Subdaily (hourly) indices were expected to respond within shorter periods than daily indices.

2. Material and methods

2.1 Study area

The study was conducted in the low Ebro River, located in the NE of the Iberian Peninsula (Catalonia, Spain; Fig. 1). The study area extends from the reservoir furthest downstream (Flix) to the upper limit of the estuary (Tortosa), where the river is about 80 km long and 150 m wide. The Ebro River is 928 km long and has a drainage area of 85 550 km^2. It is the Spanish River with the highest mean annual flow and one of the most important tributaries to the Mediterranean Sea. The main land use in the basin is agricultural with more than 10 000 km^2 of irrigation, which corresponds to approximately 90% of the water usage in the basin. The whole basin is strongly regulated by nearly 200 dams, most of them built between 1940 and 1970 (Ibáñez et al., 2012a; Nebra et al., 2011). The lower Ebro hydrology, geomorphology and ecology are strongly impacted by the existence, features and operation of such dams (Ibáñez et al., 2012a, b). Apart from the Flix reservoir, upstream of the studied section, two weirs are located in the lower Ebro: Ascó and Xerta. The former is aimed to provide water for refrigeration for a nuclear plant whereas the latter is intended for irrigation. The Flix reservoir derives most of the water income through a channel that avoids the meander located directly below the dam. Only reduced water volumes are liberated intermittently to the meander, when flow overcomes the maximum allocated to produce electricity.

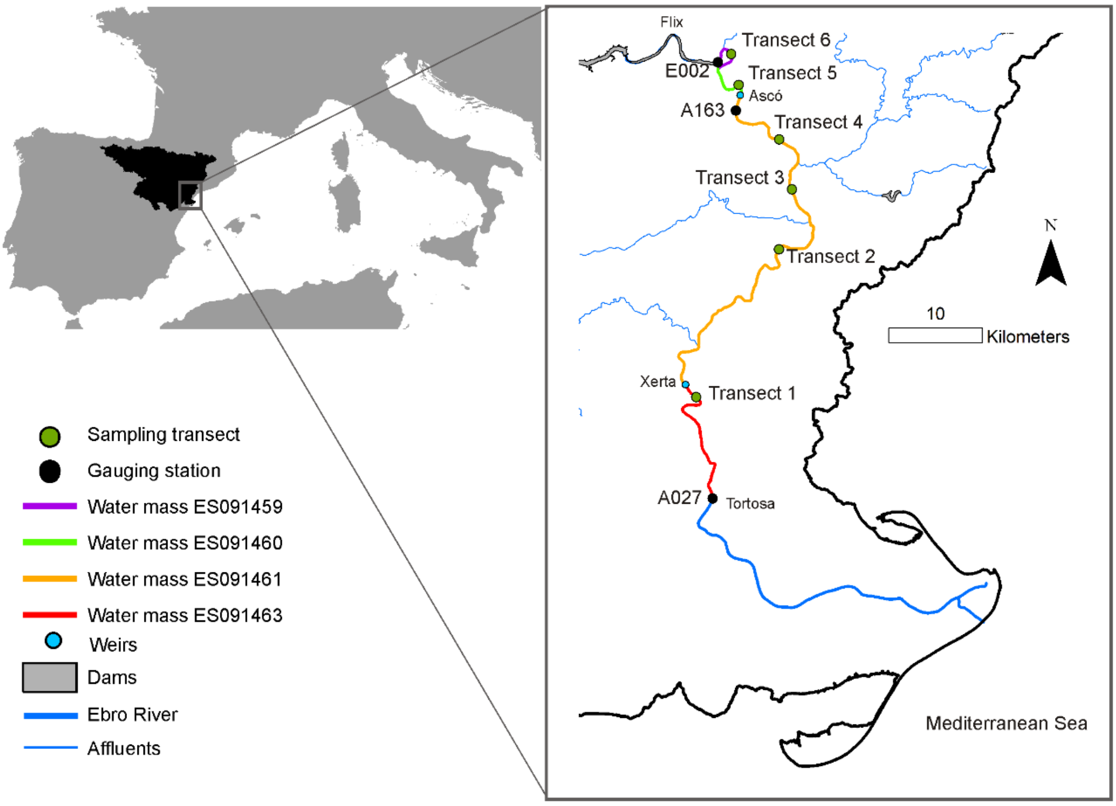

Fig. 1 Study area showing the sampling transects and gauging stations located on the water units (masses) of the low Ebro River (dams and weirs are also showed)

This river section is composed by four water masses (Fig. 1) according to the current Ebro's Water Plan: ES091463 (from the Xerta weir to Tortosa), ES091461 (from Ascó to Xerta Weir), ES091460 (from Flix to Ascó) and ES091459 (Flix meander). The water mass ES091461 is by far longer than the others (Fig. 1).

2.2 Fish and habitat data

Electrofishing data taken in six sampling transects between 2006 and 2015 allowed characterizing fish communities in the low Ebro River (Fig. 1). The sampling transects were selected randomly to avoid biases, ensuring that they covered all the hydromorphological variability in the river section observed using aerial photographs (for more details, see Caiola et al., 2014). They also provided a weighed representation of the water units or masses in the study area (as the greatest number of transects was located in the longest water mass): ES091463 (transect 1), ES091461 (transects 2, 3 and 4), ES091460 (transect 5) and ES091459 (transect 6). Transects from 1 to 5 were located in the main channel whereas transect 6 was located in the meander, directly downstream the Flix reservoir. One sample per year was taken between summer and early autumn. As the river width varies between 150 and 200 m, and CEN standards for fishing with electricity (CEN, 2003) advice that the sampling transect length should be around ten times the river width, each sampling transect had 2 km. They were sampled in 10 equidistant points located in the littoral zone (left or right bank, selected randomly). The catches of the 10 sampling points within each 2 km transect were aggregated, as the cumulative number of species in the 10 points have showed to constitute an adequate sampling effort (Caiola et al., 2014). In each transect, fish were caught with a boat-based electrofishing gear that generated up to 400 V and 10 A pulsed DC working from downstream to upstream direction. A constant distance to the river bank (5 m) and fishing time (5 min) was always maintained. Fishes from each point were kept in plastic tanks with river water for its immediate processing before the next point. The specimens were then sorted, identified to species level and counted (keeping record, if necessary, on the presence of deformities or other anomalies). Native species were returned to the river, whilst introduced alien species were eliminated with an excess of anesthetic (MS-222). The mortality of native fishes during the sampled period was negligible, restricted to only a few small individuals.

In each sampling point, habitat descriptors (depth, water velocity and riverbed dominant substrate) were recorded. Three readings of each variable were carried out. Depth was recorded with a measuring rod; water velocity was measured at a 0.6-depth with a Valeport m.001 current-meter; riverbed dominant substrate was determined visually according to a modified Wentworth scale using categories 4-10 (sand to boulder) out of the 13 particle size categories of this scale. The habitat descriptors recorded in each sampling point were expressed at transect level using the most frequent category (dominant substrate) or averaging their values (depth and water velocity). Although the former involves the loss of information, such step was necessary because one of the indices computed (EFI+) requires the dominant substrate (see details on metrics and indices below).

2.3 Fish metrics and indices

All diadromous species were removed, as the Xerta weir prevents their movement upstream and these species can only be found in the lowermost sampling transect (Fig. 1). By doing so, we ensured that this transect was comparable with the rest. Then, for each sampling transect, the IBICAT2010, IBICAT2b and EFI+ were computed. In addition, all the metrics of the IBICAT2010 based on freshwater species richness (species) and abundance (individuals) were calculated, not only those applicable to this river type (type 6). The IBICAT2b and EFI+ were calculated using the Excel templates that may be found online (http://www.invasiber.org/GarciaBerthou/ibicat2b-fish-index/ and http://efi-plus.boku.ac.at/software/insert_data.php, respectively). All indices and metrics obtained are shown in Table 1. They were also computed combining the transects 2, 3 and 4 in order to test ecohydrological relationships at a greater spatial scale for the water mass ES091461 (given its greater length) aggregating the captures collected in the three transects and correcting the result by the sampled area (to take into account the greater sampling effort). By doing so, we tested if such alternative approach may produce more accurate results in long water masses.

Type	Acronym	Description
Index	IBICAT2010	Index of Biotic Integrity in Catalan Rivers (2010)
	IBICAT2b	Index of Biotic Integrity in Catalan Rivers (2b)
	EFI+	European Fish Index
Metric	CPUEI	Density of alien individuals
	NIN_Pis	Density of native piscivorous individuals
	NIT_Inv	Density of invertiborous individuals
	NIT_Omn	Density of omnivorous individuals
	NIT_Rhe	Density of reophilic individuals
	NSI_Tol	Number of alien tolerant species
	NSN_Int	Number of native intolerant species
	NSN_Lit	Number of native litophilous species
	PIT_DELT	Percentage of individuals with deformities/lesions/parasites
	Pit_Int	Percentage of intolerant individuals
	PIT_Omn	Percentage of omnivorous individuals
	PII_Inv	Percentage of alien invertiborous individuals
	PSN_Lit	Percentage of native litophilous species
	PSN_Tol	Percentage of native tolerant species

Table 1

Indices and metrics (which belong to IBICAT2010) computed to assess ecological quality

2.4 Hydrologic records

Flow series for the period 2000-2015 were obtained by request to the automatic network of gauging stations (SAIH, ‘Sistema Automático de Información Hidrológica’) in the Ebro Basin. The series consisted on 15-minutal records belonging to two stations (Fig. 1): Tortosa (A027) and Ascó (A163); and daily data belonging to one station: Flix (E002). Using these series, hourly and daily series were generated in order to compute hydrologic indices to define the main characteristics of flow regimes. Tortosa (A027) was assigned to the water mass ES091463 (transect 1), Ascó (A163) was assigned to the water masses ES091461 (transects 2, 3 and 4) and ES091460 (transect 5) and Flix (E002) was assigned to the water mass ES091459 (transect 6).

2.5 Hydrologic indices

A set of hydrologic indices (based on Olden & Poff, 2003) were computed from daily data to characterize flow regimes (Table 2). Such indices were complemented with other indices important to examine the ecological response of fish community, based on hourly data (Bevelhimer at al., 2014). All hydrologic indices were computed using 12 months previous to sampling and, then, sequentially smaller or broader periods of hydrological records (3, 6 and 9 or 24, 36 and 48 months since the sampling date, respectively). Given their more accurate temporal resolution, those indices based on hourly data were also computed using a 1-month period of records. Finally, both daily and hourly indices were calculated using the flow records of the hydrological year (October-September) in which the samples were taken, as they are used as standard temporal frame for water management.

2.6 Relationships between hydrological regimes and ecological quality

First, Pearson correlations were used to search relationships among flow regimes, represented through the set of hydrologic indices (Table 2) and variables (water velocity and depth), and fish communities, characterized using fish indices (Table 1). The hydrologic indices computed with 12 months of records were used for this step, in order to encompass the previous annual cycle of the sampled fish communities. Pearson correlations between the IBICAT2010 and its metrics (Table 1) were also calculated in order to explore their relationship. Only correlations greater than 70% were retained in both cases. Second, using only the hydrologic indices retained in the previous step and the fish index that showed most of these correlations (the most sensitive), General Linear Models (GLMs) were employed in order to test the significance of ecohydrological relationships. Correlations between the most sensitive fish index and the hydrological indices computed with all periods of record were also computed to validate the choice of the selected period. The adjustment of the GLMs and the relationships between independent and dependent variables were examined to validate the results and determine the presence of potential breakpoints. The assumptions of Gaussian models were verified.

All analyses were developed in R (R Core Team, 2017).

Data	Acronym	Name	Meaning
Daily	MA3	Variability in daily flows	Coefficient of variation in daily flows
	MA44	Variability across annual flows	Difference between percentiles 90 and 10 divided by median
	ML13	Variability across minimum monthly flows	Coefficient of variation in minimum monthly flows
	ML14	Mean of annual minimum flows	Mean of the lowest annual daily flow divided by median
	ML23	Low flow discharge	Mean of the percentile 25 divided by median daily flows
	MH20	Mean annual maximum flows	Mean of the annual maximum flows
	FL1	Low flood pulse count	Number of drops below the percentile 25
	FL3	Frequency of low flow spells	Total number of low spells (5% of mean daily flow)
	FH3	High flood pulse count	Average of daily flows above 3 times the median daily flow
	FH5	Flood frequency	Number of flow events greater than the median per year
	DL1	Annual minima of daily discharge	Magnitude of minimum annual daily flow
	DL13	Mean of 30-day minima of daily discharge	Mean annual 30-day minimum divided by median flow
	DH12	Means of 7-day maxima of daily discharge	Mean annual 7-day maximum divided by median flow
	TL1	Julian date of annual minimum	Julian date of annual minimum
	RA8	Reversals	Number of changes between rising and falling periods
	MA5	Skewness in daily flows	Mean daily flows divided by median daily flows
	MA12	Mean October flow	Average flow in October
	MA13	Mean November flow	Average flow in November
	MH1	Mean October high flow	Maximum monthly flow in October
	MH2	Mean November high flow	Maximum monthly flow in November

Table 2
Hydrologic indices used to characterize flow regimes

Data	Acronym	Name	Meaning
Subdaily	dmin	Daily minimum	Lowest measured flow during a 24-h period
	dmax	Daily maximum	Highest measured flow during a 24-h period
	dD	Daily delta or range	Difference between daily minimum and maximum
	dSD	Daily standard deviation	Standard deviation of the 24 hourly flow values
	dramp	Maximum hourly ramp rate	Greatest hourly incremental change during 24 hours
	dpath	Daily path length	Sum of the absolute values of hour-to-hour changes in flow
	drev	Reversals	Number of changes between rising and falling periods
	drf	Rise and fall counts difference	Difference between the number of hours of rising and falling flow
	dstD	Daily standardized delta	Daily delta divided by the daily mean over each 24-h period
	dAstD	Annually standardized delta	Daily delta divided by the mean annual daily flow
	dCv	Coefficient of variation	Daily standard deviation divided by mean annual daily flow
	dstMHramp	Standardized maximum hourly ramping rate	Maximum daily ramp rate divided by the mean annual daily flow
	dflash	Richard's Barker flashiness index	Daily path length of oscillations divided by the daily mean

Table 2 (cont.)

3. Results

3.1 Fish indices and metrics

Eighteen fish species were caught in the study area, most of them belonging to the families Cyprinidae, Poeciliidae and Angillidae (Annex I). Both IBICAT2010 and IBICAT2b showed values that oscillated between the two worst categories ('poor' and 'bad') for all transects and years, although the range of the numeric values obtained was different (from 1.17 to 7.29 for the former and from 1 to 2 for the latter). The EFI+ does not have categories but, taking into consideration that an undisturbed transect would have an index value close to 0.80 whereas a highly disturbed transect would show a value lower than the 25% quantile of the index distribution for undisturbed transects, it may be inferred that all transect and years can be considered as disturbed. All values were lower than 0.20. Finally, the correlation between IBICAT2010 and the other two indices (IBICAT2b and EFI+) was negligible (0.11 and -0.10, respectively) whereas the correlation between them was slightly greater and negative (-0.43).

Among the three metrics that must be used in this type of river (type 6) to calculate the IBICAT2010, no native intolerant species (NSN_Int) was found. The percentage of individuals of invertivorous alien species (PII_Inv) was correlated with the IBICAT2010 in all transects (Table 3) whereas the density of individuals belonging to alien species (CPUEI) only was correlated in transect 5. Beyond these metrics, the density of invertivorous (NIT_Inv) was correlated with IBICAT2010 in all transects except transect 2, whereas the percentage of omnivorous (PIT_Omn) showed correlation in all transects except transects 1 and 6. Other metrics showed correlation only in a few transects, such as the percentage of tolerant native species (PSN_Tol), whereas the density of native piscivorous (NIN_Pis), the percentage of individuals with deformities (PIT_DEL) and the percentage of native lithophyte species (PSN_Lit) did not show any correlation with the IBICAT2010.

Acronym	Description	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5	Transect 6	Transect 2, 3 & 4
CPUEI	Density of alien individuals	-0,58	0,00	0,33	0,19	**-0,83**	-0,43	0,46
NIN_Pis	Density of native piscivorous individuals	-0,17	-0,17	0,20	-0,18	0,42	0,49	-0,24
NIT_Inv	Density of invertiborous individuals	**-0,92**	-0,57	**-0,90**	**-0,79**	**-0,84**	**-0,95**	**-0,81**
NIT_Omn	Density of omnivorous individuals	-0,09	0,25	0,65	0,54	0,24	0,03	**0,77**
NIT_Rhe	Density of reophilic individuals	-0,29	0,57	0,30	**0,75**	0,55	0,39	**0,80**
NSI_Tol	Number of alien tolerant species	0,02	-0,37	-0,03	0,11	0,24	0,23	0,03
NSN_Lit	Number of native litophilous species	0,11	0,01	0,25	**0,85**	0,31	**0,74**	0,23
PIT_DELT	Percentage of individuals with deformities/lesions/parasites	0,02	0,31	0,36	-0,05	-0,19	-0,31	-0,07
PIT_Omn	Percentage of omnivorous individuals	0,34	**0,84**	**0,80**	**0,80**	**0,72**	0,26	**0,89**
PII_Inv	Percentage of alien invertiborous individuals	**-0,96**	**-0,95**	**-0,99**	**-0,98**	**-0,98**	**-0,97**	**-0,97**
PSN_Lit	Percentage of native litophilous species	0,31	0,49	0,41	0,61	0,51	0,66	0,62
PSN_Tol	Percentage of native tolerant species	0,39	-0,33	0,12	0,24	**0,75**	**0,76**	-0,34

Table 3

Pearson correlations between the IBICAT2010 and its metrics in the sampled transects. Correlations greater than 70% are marked in bold. Correlations for the two indices based on intolerant species or individuals are not showed because they were absent in samples

3.2 Ecohydrological relationships

Among the transects located in the main channel (transects from 1 to 5), the transect 4 showed the best relationships between IBICAT2010 and hydrologic indices (calculated using the 12 months previous to fish sampling), as the majority of the correlations were greater than 70% (Table 4). Such indices were the variability across minimum monthly flows (ML13), the mean of annual minimum flows (ML14), the low flow discharge (ML23), the high flood pulse count (FH3) and the standardized maximum hourly ramping rate (dstMHramp). All of them were negatively related to the IBICAT2010 except ML13 and FH3. The rest of transects in the main channel also showed correlations with some of these indices. Among them, the other transects located in water mass ES091461 (transects 2 and 3) showed a lower presence of elevated correlations. Transect 2 only showed correlation with the skewness in daily flows (MA5), whereas transect 3 did not show any correlation greater than 70%. Transect 1 did not show any correlation beyond such threshold either. Not all indices could be calculated in the transect out of the main channel (transect 6, located in the Flix meander), given its particular flow regime (with many days with extremely low flows). However, ML13 and FH3 were also correlated with IBICAT2010, together with the variability in daily flows (MA3), the variability across annual flows (MA44), the mean annual maximum flows (MH20) and the number of reversals (RA8).

Acronym	Name	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5	Transect 6	Transect 2, 3 & 4
z	Depth	0,59	-0,09	-0,60	**-0,86**	-0,08	**-0,84**	**-0,72**
v	Velocity	0,40	0,62	-0,49	-0,08	-0,23	-0,29	0,03
MA3	Variability in daily flows	-0,37	0,42	0,36	0,03	0,52	**-0,75**	0,23
MA44	Variability across annual flows	-0,05	0,52	0,54	0,33	0,57	**0,71**	0,51
ML13	Variability across minimum monthly flows	0,14	0,35	0,19	**0,82**	**0,76**	**0,77**	0,60
ML14	Mean of annual minimum flows	-0,22	-0,40	-0,30	**-0,93**	-0,59	N/A	**-0,71**
ML23	Low flow discharge	-0,49	-0,38	-0,24	**-0,88**	-0,61	N/A	-0,63
MH20	Mean annual maximum flows	-0,20	0,51	0,40	0,24	0,69	**0,97**	0,37
FL1	Low flood pulse count	-0,43	0,34	0,41	0,33	0,26	N/A	0,42
FL3	Frequency of low flow spells	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FH3	High flood pulse count	0,01	0,67	0,50	**0,78**	**0,78**	**0,79**	**0,81**
FH5	Flood frequency	-0,03	0,05	0,24	0,21	-0,03	-0,51	0,17
DL1	Annual minima of daily discharge	0,49	0,26	0,31	0,55	0,08	N/A	0,52
DL13	Mean of 30-day minima of daily discharge	-0,26	0,24	0,18	-0,37	0,18	0,31	0,03
DH12	Means of 7-day maxima of daily discharge	-0,18	0,36	0,44	-0,29	0,15	0,50	0,05
TL1	Julian date of annual minimum	-0,41	0,32	0,60	-0,01	0,02	-0,48	0,30
RA8	Reversals	0,26	-0,34	-0,06	-0,17	-0,21	**0,76**	-0,30
MA5	Skewness in daily flows	-0,45	**-0,73**	-0,60	-0,24	-0,42	N/A	-0,65
MA12	Mean October flow	-0,53	0,30	0,40	0,53	0,20	0,22	0,57
MA13	Mean November flow	0,04	0,16	0,25	0,59	0,17	-0,23	0,46
MH1	Mean October high flow	0,58	-0,39	-0,34	0,51	0,14	0,22	-0,10
MH2	Mean November high flow	-0,40	0,06	0,20	-0,13	0,14	-0,23	0,07

Table 4

Pearson correlations between the IBICAT2010 and hydrologic variables (habitat descriptors, daily and subdaily indices, respectively) computed using 12 months of records. Correlations greater than 70% are marked in bold. Indexes not computed due to absent or constant flow records are marked as ‘N/A’

Acronym	Name	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5	Transect 6	Transect 2, 3 & 4
dmin	Daily minimum	0,52	0,25	0,16	0,67	0,28	N/A	0,57
dmax	Daily maximum	-0,31	0,40	0,23	-0,09	0,55	N/A	0,16
dD	Daily delta or range	0,13	0,34	0,56	0,63	0,22	N/A	0,64
dSD	Daily standard deviation	0,15	0,36	0,57	0,66	0,23	N/A	0,67
dramp	Maximum hourly ramp rate	-0,13	-0,13	-0,14	-0,64	-0,01	N/A	-0,46
dpath	Daily path length	0,11	0,28	0,52	0,55	0,13	N/A	0,58
drev	Reversals	0,16	0,27	0,49	0,54	0,21	N/A	0,57
drf	Rise and fall counts difference	0,32	-0,12	-0,08	0,15	-0,21	N/A	0,04
dstD	Daily standardized delta	-0,07	0,17	0,50	0,41	-0,04	N/A	0,45
dAstD	Annually standardized delta	0,17	-0,07	0,37	-0,06	-0,40	N/A	0,07
dcv	Coefficient of variation	0,16	-0,05	0,41	-0,01	-0,41	N/A	0,13
dstMHramp	Standardized maximum hourly ramping rate	-0,19	-0,41	-0,43	**-0,90**	-0,46	N/A	**-0,75**
dflash	Richard's Barker flashiness index	-0,15	0,10	0,45	0,27	-0,16	N/A	0,35

Table 4 (cont.)

Finally, when transect 2, 3 and 4 were combined to represent the water mass ES091461, an intermediate number of indices presented high correlations: the mean of annual minimum flows (ML14), the high flood pulse count (FH3) and the standardized maximum hourly ramping rate (dstMHramp). Water depth was correlated with IBICAT2010 in transects 4 and 6, as well as in the combination of transects 2, 3 and 4.

Despite the low correlation found, IBICAT2b showed patterns similar to IBICAT2010 in terms of the hydrologic indices that were correlated with the index but there were fewer correlations greater than 70% (Annex II). The EFI+ practically did not show correlations with the selected hydrologic variables greater than 70%, except a couple of indices (MA12 and MH1) in the transect out of the main channel (transect 6).

Given the stated results, the hydrological variables selected because of their high correlation with fish indices (depth, ML13, ML14, ML23, FH3, dstMHramp) were introduced in General Linear Models (GLMs) one at a time, as they were also correlated among them, using the IBICAT2010 as predicted variable. Statistically significant results and a degree of adjustment that varied between 50 and 75% were obtained for most hydrological variables in transects 4 and 5, as well as in the combination of transects 2, 3 and 4 (Table 5). In the main channel, the significant models presented significant intercepts only when they showed an inverse relationship between the IBICAT2010 and the considered variable. In particular, water depth, the mean of annual minim flows (ML14), the low flow discharge (ML23) and the standardized maximum hourly ramping rate (dstMHramp). These variables showed potential breakpoints in transect 4 (Fig. 2): depth $\approx$ 2; ML14 $\approx$ 0.6; ML23 $\approx$ 0.7 and dstMHramp $\approx$ between 3 and 4. Such breakpoints would allow, moreover, identifying a threshold between the two different ecological categories observed (‘poor’ and ‘bad’).

Acronym	Name	Model	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5	Transect 6	Transect 2, 3 & 4
z	Depth	p	0,11	0,81	0,07	***0,00	0,82	*0,02	*0,02
		R^2	0,20	-0,12	0,28	0,71	-0,12	0,66	0,47
		p_int	0,59	*0,03	***0,00	***0,00	0,13	***0,00	***0,00
		slope	+	-	-	-	-	-	-
ML13	Variability across minimum monthly flows	p	0,92	0,32	0,59	***0,00	**0,01	*0,04	0,06
		R^2	-0,12	0,01	-0,08	0,63	0,52	0,51	0,29
		p_int	***0,00	**0,01	**0,01	0,43	0,10	**0,01	*0,03
		slope	+	+	+	+	+	+	+
ML14	Mean of annual minimum flows	p	0,34	0,25	0,40	***0,00	0,08	N/A	*0,02
		R^2	0,00	0,05	-0,03	0,86	0,26	N/A	0,45
		p_int	***0,00	**0,01	0,02*	***0,00	***0,00	N/A	***0,00
		slope	-	-	-	-	-	N/A	-
ML23	Low flow discharge	p	0,09	0,28	0,51	***0,00	0,06	N/A	*0,05
		R^2	0,23	0,04	-0,06	0,75	0,30	N/A	0,32
		p_int	***0,00	0,03*	0,07	***0,00	**0,01	N/A	***0,00
		slope	-	-	-	-	-	N/A	-
FH3	High flood pulse count	p	0,87	*0,04	0,14	**0,01	**0,01	*0,03	***0,00
		R^2	-0,12	0,37	0,15	0,56	0,57	0,55	0,62
		p_int	*0,02	0,60	0,38	0,34	0,64	0,20	0,84
		slope	+	+	+	+	+	+	+
dstMHramp	Standardized maximum hourly ramping rate	p	0,55	0,24	0,21	***0,00	0,18	N/A	**0,01
		R^2	-0,07	0,06	0,09	0,78	0,11	N/A	0,51
		p_int	***0,00	***0,00	***0,00	***0,00	***0,00	N/A	***0,00
		slope	-	-	-	-	-	N/A	-

Table 5

GLM models between the IBICAT2010 and hydrologic variables (p: p value; R^2: coefficient of determination; p_int: p value of the intercept; slope: sign of the coefficient). Significant p-values are highlighted with asterisks (*: ≤0,05; **: ≤0,01; ***: ≤ 0,001). Indexes not computed due to absent or constant flow records are marked as ‘N/A’

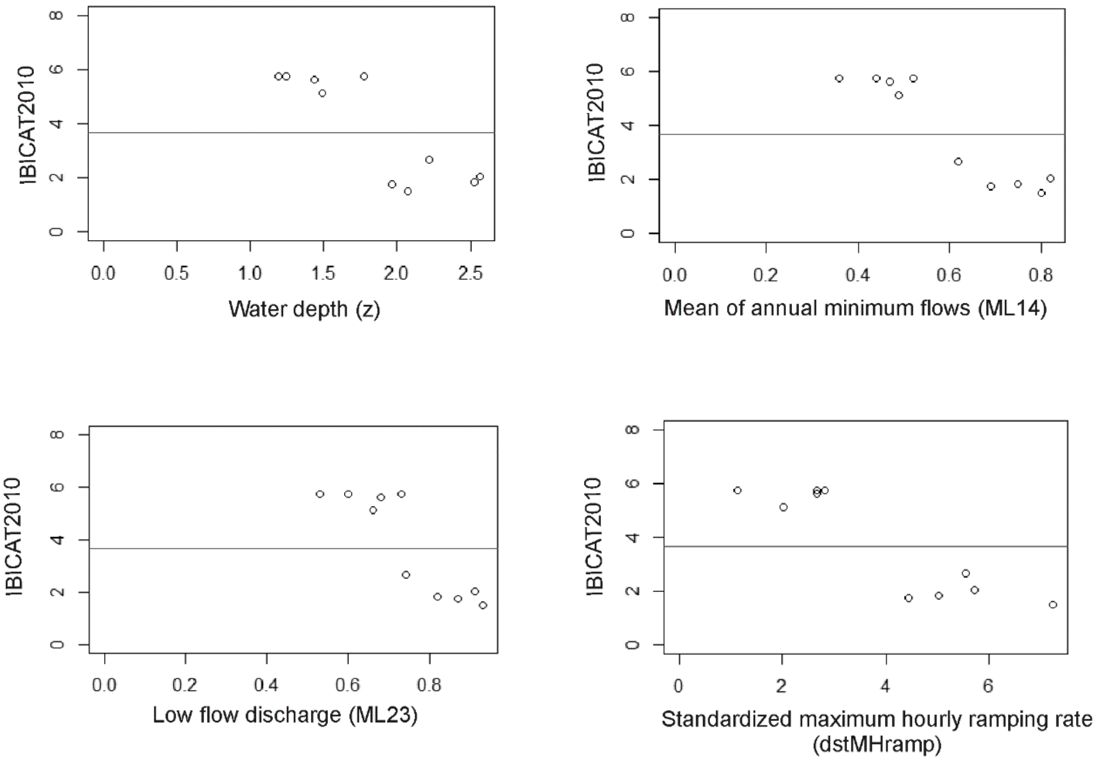

Fig. 2 Potential ecological quality breakpoints detected through the Index of Biotic Integrity in Catalan rivers 2010 (IBICAT2010), using the transect 4 and the 12-month period. The horizontal line separates the ‘poor’ and ‘bad’ status

3.3 Effects of temporal scale on ecohydrological relationships

Daily hydrologic indices that showed a correlation greater than 70% with IBICAT2010 when they were calculated with the 12 months previous to the sampling date also did when they were computed using the previous 9 months, the hydrologic year and, to a lesser extent, the previous 24 and 36 months (Annex III). Most of these correlations were found in transect 4. No correlation greater than 70% was found for any of these indices when they were computed using the 48 months previous to the sampling date, except when ML13 was computed combining transects 2, 3 and 4. Some subdaily indices (dpath and drev) also showed correlations greater than 70% (or close) when they were computed using flow series of 3, 6 and 9 months, but not using 1 month, the hydrologic year or greater periods (24, 36 and 48 months). Within the 3-month period, the number of subdaily hydrological indices with a correlation greater than 70% with IBICAT2010 was greatest (as also included dstD, dAstD, dCV and dflash).

Apart from these general patterns, other indices showed isolated correlations using other periods of computation (for example, RA8 using the 36 months previous to the sampling date or dAstD and dCV using the previous 36 and 48 months).

4. Discussion

This study analyzes the relationship between flow regimes and fish-based ecological quality in the low Ebro River, a Mediterranean watercourse subjected to severe anthropogenic stress. The approach used has several advantages: 1) it allowed comparing the results of different fish indices and their degree of response to specific hydrological indices; 2) the effect of taking into consideration distinct temporal scales and resolution for the hydrologic indices was tested. Such information may constitute a valuable tool to provide sustainable management rules for this river in particular and for similar rivers in Mediterranean (or other) areas, within a type-specific management based on frameworks such as the Ecological Limits of Hydrologic Alteration (ELOHA; Poff et al., 2010).

4.1 Quality indices and their response to hydrological regimes

Contrary to expected, the three fish indices showed different responses to hydrologic regimes. The correlation among IBICAT2010, IBICAT2b and EFI+ and the lowest performance of IBICAT2010 in the Ebro Basin highlighted by García-Berthou & Bae (2014) disappeared when only the lower Ebro was considered. The IBICAT2010 showed to be the most effective index to find relationships with flow regime. Its wider range of values may have contributed to find statistical relationships with hydrological indices more effectively. Similar values within a narrower range made more difficult the detection of statistical relationships using IBICAT2b. EFI+ showed the lowest performance, as practically no relationship with hydrologic indices was found. This may be due to three possible reasons. First, EFI+ must be used with caution when transects have been sampled by boating, especially for cyprinids such as in this case (EFI+ CONSORTIUM, 2009). Second, transect selection criteria are exigent in terms of the length that must be sampled. For a large river such as the Ebro (catchment >1000 km^2), the index may require sampling transects in river segments with a length of 10 kilometers (EFI+ CONSORTIUM, 2009), which was not done in this case because sampling was developed following CEN standards (CEN, 2003). Segments five times longer would have been a logistic problem to develop the sampling procedure. In fact, EFI+ values may decrease with increasing sampling area despite the higher observed richness, as the expected values of metrics are higher (Almeida et al., 2017). Third, this index is based on a predictive model built on environmental variables, instead of in river typologies, makes more likely the presence of 'noise' (e.g. assessing the substrate dominance in sampling sites). On the contrary, a regional fish index does not depend on the sampled area, because it does not use a predictive model (Almeida et al., 2017). The low performance of the EFI+ observed in this study seems to indicate that it is not suitable for the lower Ebro. This deserves further research, as the corresponding water agency ('Confederación Hidrográfica del Ebro') has used this index to evaluate the ecological status of streams and rivers (http://www.chebro.es).

The degree of correlation between IBICAT2010 and the metrics that must be employed in the corresponding river type (type 6) depends on the considered metric. The percentage of individuals of invertivorous alien species (PII_Inv) is responsible for most of the variation in the values obtained for the IBICAT2010. Similarly, the density of invertivorous (NIT_Inv) also showed a great correlation with the index. This importance of invertivorous to assess ecological quality is coherent with studies that highlighted their sensitivity to disturbance both in Iberian (Ferreira et al., 2007a) and non-Iberian (e.g. Tejerina-Garro & Merona, 2010) rivers. Similarly, the fact that another metrics conceived to be calculated in other river types, such as the percentage of omnivorous (PIT_Omn), was also correlated with IBICAT2010 shows their potential to be used also in this river type (type 6), under the assumption that disturbance promotes opportunistic omnivorous diets (e.g. Tejerina-Garro & Merona, 2010).

The fact that ecohydrological relationships performed differently in different transects, even within the same water mass, indicates differences in the ability of the different transects to properly represent the ecological status of the water masses and to assess the relationships between such status (IBICAT2010) and hydrologic regimes. In this context, assessing the potential effect of spatial and temporal scales results essential.

4.2 Spatial and temporal scales and their effect on the assessment of ecohydrological relationships

This study supports the conclusion that temporal and spatial dimensions of a given sampling effort can have a decisive effect on the evaluation of physical, chemical and biological factors (Livingstone, 1987). The relationships among ecological and hydrological indices herein presented provide an evaluation of spatiotemporal variation in ecohydrological relationships that may result useful in low sections of Mediterranean (or other) rivers. In addition, it allows completing previous studies that did not find spatial differences among transects using macroinvertebrate and diatom communities (Quevedo et al., 2018) or assessed the effect of spatial variation on fish community whereas they stated that more effort should be put into sampling replicate sites and understand scales of temporal variation (Gray et al., 2009). Details on the spatial and temporal patterns detected in our study area are discussed below.

The fact that the number of hydrologic indices correlated with IBICAT2010 varied among transects, even in those transects within the same water mass, evidences the spatial dependence of results. Transects were selected to be representative of the hydro-geomorphic variability of the lower Ebro River (Caiola et al. 2014), and the differences in the correlations obtained could be related to physical habitat. Intricate patterns of habitat complexity among other factors (recruitment features of individual species, predator-prey interactions and competition; Livingston et al. 1985) may have influenced the different results obtained in each transect. Depending on the objective of the corresponding monitoring program, assessing the ecological quality of long water masses through the combination of more than one transect may produce more representative results at water mass level. In this study, combining the transects 2, 3 and 4 produced ecohydrological relationships more representative of the water mass ES091461. Although such approach results more accurate at water mass level, understanding the responses of the integrant transects and the specific patterns of habitat complexity that mediate such relationships results essential. This is particularly important considering the potential breakpoints observed in the transect 4.

The relationships between flow regimes and ecological properties may be assessed at distinct temporal scales (monthly or annually) and resolutions (using daily or subdaily hydrologic indices), which becomes essential for water management (especially in regulated rivers). Whereas previous studies established that a minimum of five years is required to observe changes in fish abundance after habitat shifts (Bisson et al., 1997; Roni et al., 2003), our results indicate that shorter temporal scales (9-36 months, including the hydrologic year) are accompanied by changes in ecological quality scores (although not necessarily in ecological categories). Subdaily indices influence fish indices in shorter periods (some months of flow records), as they operate at a finer temporal resolution. The fact that indices computed with subdaily data provided significant ecohydrological relationships is relevant for managing activities such as hydropower generation, which causes flow variations within this temporal resolution. According to our results, these subdaily ecohydrological relationships will be more robust during the trimester previous to sampling, although they may be observed before.

4.3 Relevance for the establishment of ecological flow regimes in the Ebro Basin

Our study supports previous publications stating that the effect of flow regimes on biological communities is due mainly to the magnitude and variability of flows (see Belmar et al., 2013a for an example with macroinvertebrates), given that flow extremes, their relationship with mean flows and the period in which such variations take place showed to be related to fish-based ecological quality. Flow regime extremes are important for fish communities because they are responsible for the instability of habitat conditions, which plays in favor of opportunistic species. In fact, a recent study (Sabo et al., 2017) has used flow variance to design an algorithm for a managed hydrograph to explore the effect of designed flows on fishery yield. Our study shows that attention must be paid to the specific hydrologic metrics used. Less than half a dozen (depending on the considered transect) out of the 19 daily indices showed a correlation greater than 70%. Similarly, two out of 13 subdaily indices provided such correlations with different time scales. Therefore, the choice of the specific indices to assess ecohydrological relationships results critical for water management. In this context, the hydrologic indices used to define environmental flows by the Water Administration (‘Confederación Hidrográfica del Ebro’) may require revision. The study developed in the Ebro Basin (MARM, 2008) used six hydrologic indices based on the magnitude and variability of flows. Although such study involved the use of habitat simulation in a posterior stage, this relatively reduced number of hydrologic indicators was not tested against ecological data, as they are variations of simple metrics available in bibliography.

4.4 Future challenges

Further research may allow improving the way to predict composition and structure of aquatic communities from hydrologic variables. Changes on ecosystems caused by external forces tend to occur in synchrony rather than as individual pressures (Ormerod et al., 2010). Therefore, there is a need to improve our knowledge of the links between changes in flow, channel morphology and water quality, and to assess whether impacts are additive, synergistic or antagonistic. This may be achieved in future extending field data collection to incorporate more sites where single and multiple pressures exist or undertaking manipulative experiments in which single variables are changed whilst others are held constant (Acreman et al., 2014). In addition, given that alterations to single external pressures (such as flow) may interact in complex ways with internal processes (such as biotic interaction and trophic relationships that govern flows of energy and carbon and thus also control ecosystem type, health and status), there is a need to address the challenges of combining flow effects with internal ecosystem dynamics. Finally, the consequences of extreme hydrological events must also be taken into consideration. Flood and low flow events may cause greater impacts in river ecosystems than changes in flow means (Woodward et al., 2016), as the magnitude and frequency of high and low flows regulate numerous ecological processes (Poff et al., 1997). By being able to define relationships between hydrologic extremes and fish community, we could also establish relationships with other factors. For example, Belmar et al., (2018) showed that mature forests were associated with less extreme flow events, which might allow defining connections between land cover at catchment scale and fish communities.

From a management perspective, the set of hydrologic indices presented in this study may be used to estimate the effectiveness of environmental flow regimes already designed or to propose management strategies. Nevertheless, the assessment and implementation of environmental flow regimes in low river sections and estuaries would require broader analyses to take into consideration additional factors (Ibáñez & Prat, 2003) such as other organisms (e.g. birds), impacts on socioeconomic activities (e.g. coastal fisheries) and even other types of flows (solid flows or sediments). In this context, hydrologic series estimated under different scenarios based on forecasted climatic tendencies and management strategies would allow anticipating future values of hydrologic indices and, therefore, changes in ecological quality and socioeconomic activities.

Acknowledgements

This study was developed through an agreement on the ecological status of the low Ebro River and its estuary between IRTA ('Institut de Recerca i Tecnologia Agroalimentàries') and ACA ('Agència Catalana de l'Aigua'), which acted as financial supporter. Nuria Vila was supported by IRTA and 'Universitat Rovira i Virgili' through the scholarship program 'Martí i Franqués' (2014PMF-PIPF-81). We wish to thank 'Confederación Hidrográfica del Ebro' for providing their flow records, Carles Alcaraz for his helpful comments during the first stages of the study and David Mateu and Lluis Jornet for the fieldwork conducted.

References

Acreman, M., Overton, I., King, J., Wood, P.J., Cowx, I., Dunbar, M.J., Kendy, E. and Young, W. (2014) The changing role of ecohydrological science in guiding environmental flows. Hydrological Sciences Journal 59(3-4), 433-450.

Almeida, D., Alcaraz-Hernández, J.D., Merciai, R., Benejam, L. and García-Berthou, E. (2017) Relationship of fish indices with sampling effort and land use change in a large Mediterranean river. Science of the Total Environment 605-606(Supplement C), 1055-1063.

Belmar, O., Barquín, J., Álvarez-Martínez, J.M., Peñas, F.J. and Jesus, M.D. The role of forest maturity in extreme hydrological events. Ecohydrology 2018;e1947.

Belmar, O., Velasco, J., Gutiérrez-Cánovas, C., Mellado-Díaz, A., Millán, A. and Wood, P.J. (2013) The influence of natural flow regimes on macroinvertebrate assemblages in a semiarid Mediterranean basin. Ecohydrology 6(3), 363-379.

Bennett, C., Owen, R., Birk, S., Buffagni, A., Erba, S., Mengin, N., Murray-Bligh, J., Ofenbock, G., Pardo, I., van de Bund, W., Wagner, F. and Wasson, J.G. (2011) Bringing European river quality into line: an exercise to intercalibrate macro-invertebrate classification methods. Hydrobiologia 667(1), 31-48.

Bevelhimer, M.S., McManamay, R.A. and O'Connor, B. (2015) Characterizing sub-daily flow regimes: implications of hydrologic resolution on ecohydrology studies. River Research and Applications 31(7), 867-879.

Birk, S., Bonne, W., Borja, A., Brucet, S., Courrat, A., Poikane, S., Solimini, A., van de Bund, W., Zampoukas, N. and Hering, D. (2012) Three hundred ways to assess Europe's surface waters: An almost complete overview of biological methods to implement the Water Framework Directive. Ecological Indicators 18(Supplement C), 31-41.

Birk, S. and Hering, D. (2006) Direct comparison of assessment methods using benthic macroinvertebrates: a contribution to the EU Water Framework Directive intercalibration exercise. Hydrobiologia 566, 401-415.

Birk, S. and Hering, D. (2009) A new procedure for comparing class boundaries of biological assessment methods: A case study from the Danube Basin. Ecological Indicators 9(3), 528-539.

Birk, S., Korte, T. and Hering, D. (2006) Intercalibration of assessment methods for macrophytes in lowland streams: direct comparison and analysis of common metrics. Hydrobiologia 566, 417-430.

Birk, S. and Willby, N. (2010) Towards harmonization of ecological quality classification: establishing common grounds in European macrophyte assessment for rivers. Hydrobiologia 652(1), 149-163.

Bisson, P.A., Reeves, G.H., Bilby, R.E. and Naiman, R.J. (1997) Pacific Salmon & their Ecosystems, pp. 447-474, Springer.

Bovee, K.D. and Milhous, R. (1978) Hydraulic simulation in instream flow studies: theory and techniques. IFIP No. 5, US Fish and Wildlife Service.

Buffagni, A., Erba, S., Birk, S., Cazzola, M., Feld, C., Ofenbeck, T., Murray-Bligh, J., Furse, M., Clarke, R. and Hering, D. (2005) Towards European Inter-calibration for the Water Framework Directive: Procedures and Examples for Different River Types from the EC Project STAR.

Caiola N., Vargas M. J. and Sostoa A. (2001a) Feeding ecology of the endangered Valencia toothcarp, Valencia hispanica (Actinopterygii: Valenciidae). Hydrobiologia 448: 97-105.

Caiola N., Vargas M. J. and Sostoa A. (2001b) Life history pattern of the endangered Valencia toothcarp, Valencia hispanica (Actinopterygii: Valenciidae) and its implications for conservation. Archive für Hydrobiologie 150: 473-489.

Caiola, N., Ibáñez, C., Verdú, J. and Munné, A. (2014) Effects of flow regulation on the establishment of alien fish species: A community structure approach to biological validation of environmental flows. Ecological Indicators 45, 598-604.

CEN (2003) Water quality-sampling of fish with electricity. CEN, European Standard EN 14011, 2003.

Demars, B.O., Potts, J.M., Tremolieres, M., Thiebaut, G., Gougelin, N. and Nordmann, V. (2012) River macrophyte indices: not the Holy Grail! Freshwater Biology 57(8), 1745-1759.

EFI+ Consortium (2009) Manual for the application of the new European Fish Index EFI+. A fish-based method to assess the ecological status of European running waters in support of the Water Framework Directive.

Fausch, K.D., Karr, J.R. and Yant, P.R. (1984) Regional Application of an Index of Biotic Integrity Based on Stream Fish Communities. Transactions of the American Fisheries Society 113(1), 39-55.

Ferreira, T., Caiola, N., Casals, F., Oliveira, J. and De Sostoa, A. (2007a) Assessing perturbation of river fish communities in the Iberian Ecoregion. Fisheries Management and Ecology 14(6), 519-530.

Ferreira T., Oliveira J. M., Caiola N., Sostoa A., Casals F., Cortes R., Economou A., Zogaris S., Garcia-Jalón D., Ilhéu M., Martínez-Capel F., Pont D., Rogers C., Prenda J. (2007b). Ecological traits of fish assemblages from Mediterranean Europe and their responses to human disturbance. Fisheries Management and Ecology 14: 473-481.

Friberg, N. (2014) Impacts and indicators of change in lotic ecosystems. Wiley Interdisciplinary Reviews: Water 1(6), 513-531.

García-Berthou, E. and Bae, M.-J. (2014) Aplicación de los peces como indicadores en la cuenca del Ebro en cumplimiento de la Directiva marco del agua. Área de Calidad de Aguas. Confederación Hidrográfica del Ebro.

Gasith, A. and Resh, V.H. (1999) Streams in Mediterranean climate regions: Abiotic influences and biotic responses to predictable seasonal events. Annual Review of Ecology and Systematics 30, 51-81.

Gray, C., Rotherham, D., Chapman, M., Underwood, A. and Johnson, D. (2009) Spatial scales of variation of assemblages of fish in coastal lakes sampled with multi-mesh gillnets: implications for designing research surveys. Fisheries Research 96(1), 58-63.

Harris, J.H. (1995) The use of fish in ecological assessments. Australian Journal of Ecology 20(1), 65-80.

Ibáñez, C., Alcaraz, C., Caiola, N., Rovira, A., Trobajo, R., Alonso, M., Duran, C., Jiménez, P.J., Munné, A. and Prat, N. (2012a) Regime shift from phytoplankton to macrophyte dominance in a large river: Top-down versus bottom-up effects. Science of the Total Environment 416(Supplement C), 314-322.

Ibáñez, C., Caiola, N., Rovira, A. and Real, M. (2012b) Monitoring the effects of floods on submerged macrophytes in a large river. Science of the Total Environment 440(Supplement C), 132-139.

Ibáñez, C. and Prat, N. (2003) The environmental impact of the Spanish national hydrological plan on the lower Ebro river and delta. International Journal of Water Resources Development 19(3), 485-500.

Karr, J.R. (1981) Assessment of Biotic Integrity Using Fish Communities. Fisheries 6(6), 21-27.

Livingston, R.J. (1987) Field sampling in estuaries: the relationship of scale to variability. Estuaries 10(3), 194-207.

Livingston, R.J., Diaz, R.J. and White, D.C. (1985) Field validation of laboratory-derived multispecies aquatic test systems, United States Environmental Protection Agency, Office of Research and Development, Environmental Research Laboratory, Gulf Breeze.

Logez, M., Bady, P., Melcher, A. and Pont, D. (2013) A continental-scale analysis of fish assemblage functional structure in European rivers. Ecography 36(1), 80-91.

Logez, M., Pont, D. and Ferreira, M.T. (2010) Do Iberian and European fish faunas exhibit convergent functional structure along environmental gradients? Journal of the North American Benthological Society 29(4), 1310-1323.

Macnaughton, C.J., McLaughlin, F., Bourque, G., Senay, C., Lanthier, G., Harvey-Lavoie, S., Legendre, P., Lapointe, M. and Boisclair, D. (2017) The effects of regional hydrologic alteration on fish community structure in regulated rivers. River Research and Applications 33(2), 249-257.

MARM (2008) Consultoría y asistencia para la realización de las tareas necesarias para el establecimiento del régimen de caudales ecológicos y las de las necesidades ecológicas de agua de las masas de agua superficiales continentales y de transición de la parte española de la demarcación hidrográfica del Ebro, y de las demarcaciones hidrográficas del Segura y del Júcar. Dirección General del Agua.

Marzin, A., Archaimbault, V., Belliard, J., Chauvin, C., Delmas, F. and Pont, D. (2012a) Ecological assessment of running waters: Do macrophytes, macroinvertebrates, diatoms and fish show similar responses to human pressures? Ecological Indicators 23, 56-65.

Marzin, A., Archaimbault, V., Belliard, J., Chauvin, C., Delmas, F. and Pont, D. (2012b) Ecological assessment of running waters: Do macrophytes, macroinvertebrates, diatoms and fish show similar responses to human pressures? Ecological Indicators 23(Supplement C), 56-65.

Mims, M.C. and Olden, J.D. (2012) Life history theory predicts fish assemblage response to hydrologic regimes. Ecology 93(1), 35-45.

Nebra, A., Caiola, N. and Ibáñez, C. (2011) Community structure of benthic macroinvertebrates inhabiting a highly stratified Mediterranean estuary. Scientia Marina 75(3), 577-584.

Olden, J.D. and Poff, N.L. (2003) Redundancy and the choice of hydrologic indices for characterizing streamflow regimes. River Research and Applications 19(2), 101-121.

Ormerod, S.J., Dobson, M., Hildrew, A.G. and Townsend, C.R. (2010) Multiple stressors in freshwater ecosystems. Freshwater Biology 55(1), 1-4.

Poff, N.L., Allan, J.D., Bain, M.B., Karr, J.R., Prestegaard, K.L., Richter, B.D., Sparks, R.E. and Stromberg, J.C. (1997) The natural flow regime. BioScience 47(11), 769-784.

Poff, N.L., Richter, B.D., Arthington, A.H., Bunn, S.E., Naiman, R.J., Kendy, E., Acreman, M., Apse, C., Bledsoe, B.P. and Freeman, M.C. (2010) The ecological limits of hydrologic alteration (ELOHA): a new framework for developing regional environmental flow standards. Freshwater Biology 55(1), 147-170.

Poff, N.L. and Zimmerman, J.K.H. (2010) Ecological responses to altered flow regimes: a literature review to inform the science and management of environmental flows. Freshwater Biology 55(1), 194-205.

Pont, D., Hugueny, B., Beier, U., Goffaux, D., Melcher, A., Noble, R., Rogers, C., Roset, N. and Schmutz, S. (2006) Assessing river biotic condition at a continental scale: a European approach using functional metrics and fish assemblages. Journal of Applied Ecology 43(1), 70-80.

Pont, D., Hugueny, B. and Rogers, C. (2007) Development of a fish-based index for the assessment of river health in Europe: the European Fish Index. Fisheries Management and Ecology 14(6), 427-439.

Quevedo, L., Ibáñez, C., Caiola, N., Cid, N. and Hampel, H. (2018) Impact of a reservoir system on benthic macroinvertebrate and diatom communities of a large Mediterranean river (lower Ebro river, Catalonia, Spain). Limnetica 37(2), 209-228.

R Core Team, (2017) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Rinaldi, M., Belletti, B., Van de Bund, W., Bertoldi, W., Gurnell, A., Buijse, T. and Mosselman, E. (2013) Review on eco-hydromorphological methods. Deliverable of the EU FP7 REFORM project. http://www.reformrivers.eu/ 1, 2007-2013.

Roni, P., Beechie, T. and Pess, G. (2003) Prioritizing potential restoration actions within watersheds, pp. 94-114.

Sabo, J., Ruhi, A., Holtgrieve, G., Elliott, V., Arias, M., Ngor, P.B., Räsänen, T. and Nam, S. (2017) Designing river flows to improve food security futures in the Lower Mekong Basin. Science 358(6368), eaao1053.

Schiemer, F. (2000) Fish as indicators for the assessment of the ecological integrity of large rivers. Proceedings of the International Conference ‘Assessing the Ecological Integrity of Running Waters’ (Vienna, Austria, 9–11 November 1998). Jungwirth, M., Muhar, S. and Schmutz, S. (eds), pp. 271-278, Springer Netherlands, Dordrecht.

Segurado, P., Caiola, N., Pont, D., Oliveira, J., Delaigue, O. and Ferreira, M. (2014) Comparability of fish-based ecological quality assessments for geographically distinct Iberian regions. Science of the Total Environment 476, 785-794.

Simon, T.P. (1999) Assessing the sustainability and biological integrity of water resources using fish communities, CRC Press, Boca Ratón.

Sindilariu, P.-D., Freyhof, J. and Wolter, C. (2006) Habitat Use of Juvenile Fish in the Lower Danube and the Danube Delta: Implications for Ecotone Connectivity. Hydrobiologia 571(1), 51-61.

Sostoa, A., Caiola, N. and Casals, F. (2004) A new IBI (IBICAT) for local application of the EU Water Framework Directive.

Sostoa, A.d., Caiola, N., Casals, F., García-Berthou, E., Alcaraz Cazorla, C., Benejam Vidal, L., Maceda-Veiga, A., Solà, C. and Munné, A. (2010) Ajust de l'índex d'Integritat Biòtica (IBICAT) basat en l'ús dels peixos com a indicadors de la qualitat ambiental als rius de Catalunya.

Tejerina-Garro, F.L. and Mérona, B.d. (2010) Flow seasonality and fish assemblage in a tropical river, French Guiana, South America. Neotropical ichthyology 8(1), 145-154.

Urbanic, G. and Podgornik, S. (2008) Testing some European fish-based assessment systems using Slovenian fish data from the Ecoregion Alps. Natura Sloveniae 10(2), 47-58.

Woodward, G., Bonada, N., Brown, L.E., Death, R.G., Durance, I., Gray, C., Hladyz, S., Ledger, M.E., Milner, A.M., Ormerod, S.J., Thompson, R.M. and Pawar, S. (2016) The effects of climatic fluctuations and extreme events on running water ecosystems. Philosophical Transactions of the Royal Society B-Biological Sciences 371: 20150274.

Annex I CPUEs or captures per effort unit (individuals/hectare) of the fish species sampled, sorted by family (in bold letter)

	CPUEs
Anguillidae	**2064**
Anguilla anguilla	2064
Atherinidae	**85**
Atherina boyeri	85
Blenniidae	**391**
Salaria fluviatilis	391
Centrarchidae	**570**
Lepomis gibbosus	545
Micropterus salmoides	25
Cyprinidae	**16028**
Alburnus alburnus	12056
Carassius auratus	70
Cyprinus carpio	373
Gobio lozanoi	152
Luciobarbus graellsii	85
Pseudorasbora parva	982
Rutilus rutilus	1517
Sander lucioperca	378
Scardinius erythrophthalmus	71
Squalius laietanus	344
Poeciliidae	**6261**
Gambusia holbrooki	6261
Siluridae	**184**
Silurus glanis	184

Annex II Pearson correlations between the hydrologic variables computed using 12 months of records and a) IBICAT2b or b) EFI+ (correlations greater than 70% are in bold letter). Meaning of indices in Table 2. Indexes not computed due to absent or constant flow records are marked as 'N/A'

a) Hydrologic variable	IBICAT2b						
	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5	Transect 6	Transect 2, 3 & 4
Depth	0.03	-0.44	-0.01	**-0.80**	-0.43	-0.40	-0.44
Velocity	-0.11	-0.48	0.07	0.09	-0.45	0.01	0.03
MA3	0.00	-0.63	-0.57	-0.15	-0.17	**-0.93**	-0.65
MA44	0.44	-0.12	-0.33	0.13	0.23	**0.85**	-0.18
ML13	**0.71**	0.34	-0.23	**0.74**	0.57	0.40	-0.01
DL1	-0.66	0.53	0.51	0.31	0.33	N/A	0.45
ML14	-0.29	-0.57	-0.20	**-0.86**	-0.53	N/A	-0.32
ML23	-0.07	-0.44	-0.14	**-0.78**	-0.42	N/A	-0.20
MH20	0.26	-0.52	-0.49	0.04	-0.07	0.59	-0.51
FL1	0.45	-0.04	0.10	0.31	-0.15	N/A	0.26
FH3	0.30	0.20	0.00	0.65	0.45	**0.74**	-0.08
FH5	0.25	-0.04	-0.01	-0.17	-0.04	-0.56	0.11
DL13	0.67	-0.21	-0.29	-0.21	0.27	0.70	-0.30
DH12	0.55	-0.49	-0.08	-0.41	-0.30	**0.78**	-0.04
TL1	0.22	-0.27	-0.10	-0.13	-0.25	-0.10	0.16
RA8	-0.30	-0.28	-0.43	-0.29	-0.38	0.67	0.11
MA5	0.25	-0.19	-0.65	-0.31	-0.13	N/A	-0.34
MA12	-0.52	0.28	0.11	0.37	0.28	0.17	0.18
MA13	-0.22	0.32	0.16	0.42	0.15	**-0.79**	0.30
MH1	0.02	0.26	-0.25	0.55	-0.03	0.18	0.35
MH2	-0.38	-0.42	**-0.74**	-0.16	-0.08	**-0.79**	-0.54
dmin	-0.57	**0.77**	0.46	**0.81**	0.65	N/A	0.57
dmax	0.34	-0.61	-0.55	-0.13	-0.04	N/A	-0.68
dD	0.14	0.43	0.16	0.50	0.26	N/A	0.54
dSD	0.08	0.46	0.17	0.51	0.30	N/A	0.54
dramp	-0.34	**-0.87**	-0.59	-0.57	-0.58	N/A	-0.57
dpath	0.12	0.42	0.16	0.45	0.21	N/A	0.55
drev	0.19	0.39	0.03	0.51	0.26	N/A	0.49
drf	0.67	0.65	0.52	0.10	0.39	N/A	0.65
dstD	0.10	0.34	0.09	0.27	0.11	N/A	0.52
dAstD	-0.31	0.08	-0.01	-0.08	-0.24	N/A	0.45
dCV	-0.32	0.15	0.04	-0.09	-0.16	N/A	0.47
dstMHramp	-0.25	-0.61	-0.22	**-0.71**	-0.54	N/A	-0.39
dflash	0.09	0.29	0.09	0.18	0.04	N/A	0.51

Annex II (cont.)

b)	EFI+						
Hydrologic variable	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5	Transect 6	Transect 2, 3 & 4
Depth	0.00	-0.04	0.10	0.69	0.58	0.51	0.13
Velocity	0.00	0.35	0.24	0.14	0.24	-0.34	0.63
MA3	0.00	0.50	0.06	-0.16	-0.26	0.41	-0.03
MA44	0.00	0.48	0.29	-0.45	-0.41	-0.52	-0.28
ML13	0.00	0.38	0.35	-0.35	-0.11	-0.67	0.29
DL1	0.00	-0.02	0.00	-0.32	0.08	N/A	-0.08
ML14	0.00	-0.13	0.03	0.46	0.13	N/A	-0.38
ML23	0.00	-0.14	0.07	0.34	0.05	N/A	-0.41
MH20	0.00	0.61	0.04	-0.20	-0.25	-0.17	0.01
FL1	0.00	0.58	-0.04	-0.03	0.14	N/A	0.41
FH3	0.00	0.34	0.02	-0.53	-0.35	-0.51	0.29
FH5	0.00	0.10	-0.20	-0.34	-0.02	0.65	-0.52
DL13	0.00	0.16	0.40	-0.25	-0.66	-0.57	-0.48
DH12	0.00	0.37	-0.12	-0.09	-0.36	-0.62	-0.60
TL1	0.00	0.51	-0.06	-0.30	-0.21	0.57	-0.20
RA8	0.00	0.43	0.22	0.23	0.39	-0.26	-0.22
MA5	0.00	-0.36	0.14	0.15	0.35	N/A	0.33
MA12	0.00	0.19	-0.01	-0.49	-0.11	**0.73**	0.11
MA13	0.00	0.24	0.02	-0.21	0.24	-0.11	0.30
MH1	0.00	0.20	0.01	0.23	0.52	**0.73**	0.48
MH2	0.00	0.52	0.55	-0.08	-0.01	-0.11	0.15
dmin	0.00	-0.02	0.08	-0.39	-0.18	N/A	0.29
dmax	0.00	0.47	0.12	-0.11	-0.38	N/A	-0.06
dD	0.00	0.36	0.14	-0.48	-0.08	N/A	0.06
dSD	0.00	0.34	0.13	-0.53	-0.11	N/A	0.03
dramp	0.00	0.48	0.12	0.50	0.16	N/A	0.02
dpath	0.00	0.33	0.15	-0.43	-0.03	N/A	0.09
drev	0.00	0.45	0.31	-0.38	-0.04	N/A	0.18
drf	0.00	-0.24	0.19	-0.07	0.08	N/A	-0.47
dstD	0.00	0.27	0.13	-0.43	-0.02	N/A	-0.07
dAstD	0.00	0.20	0.09	-0.18	0.06	N/A	-0.07
dCV	0.00	0.11	0.06	-0.29	0.00	N/A	-0.20
dstMHramp	0.00	-0.10	-0.06	0.60	0.17	N/A	-0.10
dflash	0.00	0.23	0.14	-0.37	0.00	N/A	-0.07

Annex III Correlations between the IBICAT2010 and the hydrologic indices computed for 3, 6, 9, 24, 36 and 48 months of records, as well as for the hydrologic year (values greater than 70% are in bold type; daily and subdaily indices are separated by double line). Hydrologic indices (meaning in Table 2) are followed by a termination that indicates the period used. Indices not computed due to absent or constant flow records are marked as 'N/A'

Hydrologic index	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5	Transect 6	Transect 2, 3 & 4
MA3_3	-0.06	0.06	0.01	-0.07	0.23	-0.48	-0.14
MA44_3	-0.11	0.04	-0.06	-0.04	0.26	0.07	-0.11
ML13_3	-0.24	-0.07	-0.12	-0.33	0.11	N/A	-0.31
DL1_3	0.45	0.65	0.44	0.38	0.41	N/A	0.59
ML14_3	0.10	0.24	0.28	-0.05	-0.20	N/A	0.27
ML23_3	0.04	0.24	0.23	-0.15	-0.10	N/A	0.27
MH20_3	-0.19	-0.02	-0.10	-0.28	0.17	-0.09	-0.26
FL1_3	0.20	0.29	0.30	0.58	0.52	N/A	0.56
FH5_3	-0.24	0.50	0.44	0.56	0.49	-0.44	**0.72**
DL13_3	-0.25	0.38	0.40	0.01	0.06	N/A	0.40
DH12_3	-0.33	0.33	0.43	-0.13	0.08	0.17	0.21
TL1_3	-0.55	0.18	-0.01	-0.46	0.24	-0.48	-0.13
RA8_3	0.13	0.13	0.20	0.14	0.02	-0.49	0.17
MA5_3	-0.30	-0.26	-0.06	-0.07	-0.30	N/A	-0.22
MA12_3	-0.53	0.30	0.40	0.53	0.20	0.22	0.57
MA13_3	0.04	0.16	0.25	0.59	0.17	-0.23	0.46
MH1_3	0.58	-0.39	-0.34	0.51	0.14	0.22	-0.10
MH2_3	-0.40	0.06	0.20	-0.13	0.14	-0.23	0.07
MA3_6	-0.11	0.26	0.14	-0.33	0.15	-0.64	-0.11
MA44_6	0.01	0.29	0.22	-0.10	0.15	0.14	0.03
ML13_6	0.60	-0.12	-0.20	0.42	0.28	N/A	0.02
DL1_6	0.64	0.44	0.31	0.59	0.26	N/A	0.63
ML14_6	-0.33	0.09	0.18	-0.44	-0.33	N/A	-0.02
ML23_6	-0.22	-0.12	0.00	-0.21	-0.30	N/A	-0.09
MH20_6	0.07	0.24	0.11	-0.19	0.22	-0.11	-0.06
FL1_6	-0.24	0.41	0.38	0.66	0.53	N/A	0.65
FH5_6	-0.35	0.22	0.34	0.17	0.04	-0.66	0.26
DL13_6	-0.46	0.28	0.27	-0.30	-0.08	0.30	0.16
DH12_6	-0.45	0.29	0.37	-0.45	-0.13	0.22	-0.07
TL1_6	0.50	0.01	-0.07	-0.19	0.15	-0.48	-0.06
RA8_6	0.02	0.03	0.18	0.08	0.08	-0.04	0.09
MA5_6	N/A	-0.32	-0.14	-0.20	-0.27	N/A	-0.18
MA12_6	-0.53	0.30	0.40	0.53	0.20	0.22	0.57
MA13_6	0.04	0.16	0.25	0.59	0.17	-0.23	0.46
MH1_6	0.58	-0.39	-0.34	0.51	0.14	0.22	-0.10
MH2_6	-0.40	0.06	0.20	-0.13	0.14	-0.23	0.07

Annex III (cont.)

Hydrologic index	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5	Transect 6	Transect 2, 3 & 4
MA3_9	-0.55	0.40	0.37	-0.04	0.48	-0.64	0.21
MA44_9	-0.62	0.39	0.47	0.17	0.47	0.66	0.41
ML13_9	0.05	0.26	0.16	**0.77**	0.70	0.60	0.52
DL1_9	0.57	0.29	0.26	0.55	0.09	N/A	0.53
ML14_9	-0.54	-0.28	-0.19	**-0.87**	-0.48	-0.25	-0.55
ML23_9	**-0.70**	-0.21	-0.10	**-0.80**	-0.46	-0.25	-0.44
MH20_9	-0.20	0.51	0.40	0.24	0.69	**0.97**	0.37
FL1_9	-0.36	0.06	0.06	0.32	-0.05	N/A	0.13
FH5_9	-0.62	0.21	0.32	0.05	0.06	**-0.73**	0.25
DL13_9	**-0.74**	0.00	0.00	-0.68	-0.10	-0.08	-0.27
DH12_9	**-0.76**	0.20	0.30	-0.60	-0.04	0.56	-0.18
TL1_9	-0.28	0.43	0.68	-0.01	0.05	-0.48	0.40
RA8_9	0.33	-0.18	-0.02	-0.28	-0.14	0.48	-0.30
MA5_9	N/A	-0.52	-0.40	-0.06	-0.12	N/A	-0.31
MA12_9	-0.53	0.30	0.40	0.53	0.20	0.22	0.57
MA13_9	0.04	0.16	0.25	0.59	0.17	-0.23	0.46
MH1_9	0.58	-0.39	-0.34	0.51	0.14	0.22	-0.10
MH2_9	-0.40	0.06	0.20	-0.13	0.14	-0.23	0.07
MA3_year	-0.38	0.48	0.42	0.13	0.56	**-0.75**	0.32
MA44_year	-0.10	0.60	0.58	0.45	0.62	**0.71**	0.61
ML13_year	0.14	0.42	0.26	**0.90**	**0.75**	**0.90**	0.69
DL1_year	0.37	0.27	0.29	0.61	0.16	N/A	0.57
ML14_year	-0.29	-0.40	-0.33	**-0.88**	-0.63	N/A	-0.69
ML23_year	-0.54	-0.42	-0.31	-0.68	-0.53	N/A	-0.56
MH20_year	-0.20	0.51	0.40	0.24	0.69	**0.97**	0.37
FL1_year	-0.34	0.02	0.16	0.60	0.13	N/A	0.36
FH3_year	0.05	0.62	0.44	**0.75**	**0.82**	**0.80**	**0.75**
FH5_year	-0.47	-0.06	0.24	0.21	-0.19	-0.56	0.18
DL13_year	-0.25	0.29	0.11	-0.42	0.10	0.30	-0.02
DH12_year	-0.27	0.50	0.51	0.15	0.52	**0.75**	0.38
TL1_year	-0.70	0.20	0.55	0.05	-0.25	N/A	0.30
RA8_year	0.18	-0.24	0.13	-0.28	-0.43	**0.75**	-0.22
MA5_year	0.11	-0.66	-0.46	-0.19	-0.42	N/A	-0.53
MA12_year	-0.53	0.30	0.40	0.53	0.20	0.22	0.57
MA13_year	0.04	0.16	0.25	0.59	0.17	-0.17	0.46
MH1_year	0.58	-0.39	-0.34	0.51	0.14	0.22	-0.10
MH2_year	-0.40	0.06	0.20	-0.13	0.14	-0.23	0.07

Annex III (cont.)

Hydrologic index	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5	Transect 6	Transect 2, 3 & 4
MA3_24	-0.29	0.52	0.42	0.22	0.44	N/A	0.44
MA44_24	0.12	0.68	0.56	0.47	0.48	N/A	**0.71**
ML13_24	0.13	0.53	0.51	**0.75**	0.56	N/A	**0.79**
DL1_24	**0.79**	0.25	0.24	0.17	0.35	N/A	0.29
ML14_24	-0.09	-0.11	-0.20	**-0.72**	-0.35	N/A	-0.43
ML23_24	-0.43	-0.27	-0.31	-0.63	-0.52	N/A	-0.47
MH20_24	-0.45	0.39	0.47	0.30	0.32	N/A	0.41
FL1_24	-0.43	0.22	0.31	0.48	0.33	N/A	0.45
FH3_24	0.16	0.56	0.48	**0.85**	**0.76**	N/A	**0.79**
FH5_24	-0.26	-0.23	0.12	-0.06	-0.27	N/A	-0.13
DL13_24	-0.04	0.50	0.33	0.06	0.19	N/A	0.41
DH12_24	-0.36	0.70	0.68	0.06	0.29	N/A	0.50
TL1_24	0.02	-0.11	-0.14	-0.21	0.15	N/A	-0.30
RA8_24	0.06	-0.61	-0.31	-0.61	-0.58	N/A	-0.67
MA5_24	-0.70	-0.34	-0.10	0.02	-0.18	N/A	-0.11
MA12_24	0.08	-0.29	-0.23	0.32	0.07	N/A	-0.06
MA13_24	-0.01	-0.29	-0.15	0.20	0.05	N/A	-0.09
MH1_24	0.26	-0.34	0.09	-0.35	-0.64	N/A	-0.23
MH2_24	**-0.72**	-0.16	-0.20	-0.12	-0.15	N/A	-0.19
MA3_36	-0.22	0.66	0.43	0.47	0.62	N/A	0.59
MA44_36	-0.02	**0.86**	0.67	0.67	**0.72**	N/A	**0.89**
ML13_36	-0.04	0.57	0.44	0.68	0.55	N/A	**0.77**
DL1_36	0.65	0.33	0.38	-0.14	0.12	N/A	0.26
ML14_36	0.19	0.04	-0.18	-0.58	-0.16	N/A	-0.32
ML23_36	-0.02	-0.14	-0.31	-0.55	-0.23	N/A	-0.46
MH20_36	-0.57	-0.08	-0.12	0.42	0.33	N/A	0.04
FL1_36	0.10	-0.33	-0.06	-0.40	-0.36	N/A	-0.32
FH3_36	-0.04	0.53	0.58	**0.78**	0.62	N/A	**0.77**
FH5_36	-0.08	-0.21	0.13	-0.34	-0.23	N/A	-0.23
DL13_36	-0.02	**0.71**	0.39	0.35	0.55	N/A	0.62
DH12_36	0.20	0.45	0.43	-0.10	0.09	N/A	0.17
TL1_36	-0.36	0.02	0.04	-0.44	-0.09	N/A	-0.23
RA8_36	0.44	-0.63	-0.46	**-0.86**	-0.67	N/A	**-0.86**
MA5_36	**-0.72**	-0.38	-0.18	-0.15	-0.29	N/A	-0.24
MA12_36	**0.73**	-0.13	0.14	-0.45	-0.40	N/A	-0.24
MA13_36	0.36	-0.01	0.21	-0.56	-0.42	N/A	-0.27
MH1_36	-0.13	-0.45	-0.61	-0.59	-0.45	N/A	-0.60
MH2_36	0.63	-0.12	-0.02	0.21	-0.23	N/A	-0.06

Annex III (cont.)

Hydrologic index	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5	Transect 6	Transect 2, 3 & 4
MA3_48	N/A	**0.72**	0.69	0.61	0.65	N/A	**0.73**
MA44_48	N/A	0.66	0.54	0.42	0.66	N/A	0.65
ML13_48	N/A	0.53	0.40	0.59	0.59	N/A	**0.70**
DL1_48	N/A	0.39	0.20	-0.12	0.31	N/A	0.18
ML14_48	N/A	0.22	-0.11	-0.35	0.09	N/A	-0.10
ML23_48	N/A	-0.18	-0.33	-0.62	-0.35	N/A	-0.49
MH20_48	N/A	-0.11	0.26	-0.15	-0.26	N/A	-0.17
FL1_48	N/A	-0.33	-0.06	-0.40	-0.36	N/A	-0.32
FH3_48	N/A	0.42	0.65	0.57	0.37	N/A	0.57
FH5_48	N/A	-0.21	0.13	-0.34	-0.23	N/A	-0.23
DL13_48	N/A	**0.74**	0.47	0.42	0.68	N/A	**0.72**
DH12_48	N/A	0.38	0.40	-0.16	0.08	N/A	0.11
TL1_48	N/A	-0.09	-0.27	-0.51	-0.16	N/A	-0.47
RA8_48	N/A	-0.55	-0.40	**-0.92**	**-0.73**	N/A	**-0.83**
MA5_48	N/A	-0.22	0.03	-0.16	-0.22	N/A	-0.15
MA12_48	N/A	-0.01	-0.14	**-0.77**	-0.22	N/A	-0.41
MA13_48	N/A	-0.22	-0.39	-0.55	-0.07	N/A	-0.46
MH1_48	N/A	0.55	0.34	0.05	0.31	N/A	0.36
MH2_48	N/A	-0.44	-0.36	-0.08	-0.08	N/A	-0.34
dmin_1	**0.70**	0.24	0.18	0.48	0.14	N/A	0.35
dmax_1	0.27	0.17	-0.02	0.31	0.49	N/A	0.20
dD_1	0.51	0.02	-0.16	0.55	0.57	N/A	0.19
dSD_1	0.54	-0.02	-0.18	0.54	0.56	N/A	0.16
dramp_1	0.21	0.16	0.00	0.30	0.43	N/A	0.22
dpath_1	0.53	0.05	-0.12	0.60	0.58	N/A	0.24
drev_1	0.35	0.14	-0.03	0.58	0.63	N/A	0.33
drf_1	0.38	-0.17	-0.07	0.15	-0.21	N/A	0.04
dstD_1	0.21	0.20	0.02	0.67	**0.70**	N/A	0.41
dAstD_1	0.21	0.21	0.03	**0.71**	**0.71**	N/A	0.43
dCV_1	0.27	0.16	-0.02	**0.70**	0.69	N/A	0.39
dstMHramp_1	0.09	0.28	0.12	0.38	0.47	N/A	0.36
dflash_1	0.17	0.23	0.06	**0.73**	0.70	N/A	0.46

Annex III (cont.)

Hydrologic index	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5	Transect 6	Transect 2, 3 & 4
dmin_3	0.42	-0.14	-0.21	0.44	0.04	N/A	0.60
dmax_3	-0.12	-0.08	-0.13	-0.21	0.14	N/A	-0.12
dD_3	0.19	-0.07	-0.15	0.41	0.39	N/A	0.04
dSD_3	0.22	-0.07	-0.15	0.42	0.37	N/A	0.03
dramp_3	0.04	0.15	0.11	-0.02	0.27	N/A	0.06
dpath_3	0.21	0.01	-0.10	0.56	0.50	N/A	0.14
drev_3	0.29	0.25	0.08	**0.80**	**0.72**	N/A	0.34
drf_3	0.15	0.09	0.20	0.15	-0.05	N/A	-0.01
dstD_3	0.18	0.33	0.21	**0.86**	**0.73**	N/A	0.34
dAstD_3	0.14	0.53	0.44	**0.86**	**0.74**	N/A	0.55
dCV_3	0.22	0.49	0.41	**0.82**	0.69	N/A	0.53
dstMHramp_3	0.13	0.42	0.42	0.06	0.25	N/A	0.20
dflash_3	0.14	0.43	0.33	**0.92**	**0.74**	N/A	0.42
dmin_6	**0.74**	-0.13	-0.22	0.44	0.03	N/A	0.61
dmax_6	0.01	0.13	-0.06	-0.19	0.20	N/A	-0.14
dD_6	0.18	0.24	0.16	0.65	0.49	N/A	0.35
dSD_6	0.19	0.21	0.15	0.64	0.46	N/A	0.33
dramp_6	-0.15	0.02	-0.25	-0.26	0.20	N/A	-0.23
dpath_6	0.13	0.29	0.24	**0.71**	0.54	N/A	0.45
drev_6	0.16	0.41	0.34	**0.84**	0.68	N/A	0.57
drf_6	0.11	-0.07	-0.07	0.29	0.01	N/A	0.01
dstD_6	-0.14	0.43	0.38	0.63	0.61	N/A	0.44
dAstD_6	-0.36	0.49	0.45	0.46	0.54	N/A	0.46
dCV_6	-0.37	0.46	0.43	0.43	0.50	N/A	0.32
dstMHramp_6	-0.40	0.01	-0.24	-0.38	0.01	N/A	-0.30
dflash_6	-0.31	0.47	0.46	0.53	0.57	N/A	0.54
dmin_9	0.66	0.00	-0.08	0.39	-0.08	N/A	0.57
dmax_9	-0.31	0.35	0.27	0.23	0.63	N/A	0.18
dD_9	0.32	0.32	0.43	**0.77**	0.41	N/A	0.54
dSD_9	0.35	0.27	0.41	**0.72**	0.32	N/A	0.57
dramp_9	-0.34	-0.11	-0.27	-0.27	0.26	N/A	-0.37
dpath_9	0.28	0.32	0.50	**0.73**	0.33	N/A	0.50
drev_9	0.35	0.35	0.50	**0.75**	0.35	N/A	0.55
drf_9	0.27	-0.01	0.05	0.37	-0.04	N/A	-0.01
dstD_9	0.02	0.27	0.42	0.52	0.36	N/A	0.31
dAstD_9	0.27	-0.09	0.24	-0.09	-0.27	N/A	-0.07
dCV_9	0.35	-0.14	0.18	-0.13	-0.31	N/A	-0.02
dstMHramp_9	-0.33	-0.39	-0.54	**-0.74**	-0.33	N/A	-0.64
dflash_9	-0.18	0.19	0.41	0.30	0.21	N/A	0.25

Annex III (cont.)

Hydrologic index	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5	Transect 6	Transect 2, 3 & 4
dmin_year	0.43	-0.35	-0.35	0.22	-0.25	N/A	0.60
dmax_year	-0.31	0.35	0.27	0.23	0.63	N/A	0.16
dD_year	0.15	0.38	0.59	0.63	0.34	N/A	0.63
dSD_year	0.17	0.35	0.58	0.59	0.28	N/A	0.66
dramp_year	-0.12	-0.38	-0.24	-0.67	-0.24	N/A	-0.47
dpath_year	0.13	0.35	0.59	0.54	0.26	N/A	0.56
drev_year	0.18	0.39	0.57	0.58	0.33	N/A	0.55
drf_year	0.38	0.44	0.37	0.54	0.27	N/A	0.03
dstD_year	-0.03	0.26	0.55	0.37	0.20	N/A	0.41
dAstD_year	-0.02	-0.02	0.36	0.21	-0.06	N/A	0.26
dCV_year	0.02	-0.05	0.35	0.17	-0.11	N/A	0.30
dstMHramp_year	0.03	-0.31	0.11	-0.24	-0.31	N/A	-0.14
dflash_year	-0.10	0.21	0.50	0.19	0.08	N/A	0.33
dmin_24	**0.74**	0.05	0.03	0.52	0.17	N/A	0.38
dmax_24	-0.50	0.30	0.27	0.16	0.24	N/A	0.27
dD_24	-0.09	0.05	0.26	0.32	0.14	N/A	0.28
dSD_24	-0.08	0.07	0.27	0.36	0.16	N/A	0.31
dramp_24	-0.09	0.10	0.06	-0.32	-0.10	N/A	-0.15
dpath_24	-0.14	0.00	0.21	0.28	0.08	N/A	0.23
drev_24	-0.07	-0.01	0.19	0.31	0.07	N/A	0.25
drf_24	0.33	0.03	-0.04	-0.02	0.16	N/A	0.02
dstD_24	-0.29	-0.18	0.10	0.01	-0.14	N/A	-0.03
dAstD_24	-0.20	-0.50	-0.24	-0.55	-0.58	N/A	-0.55
dCV_24	-0.13	-0.49	-0.25	-0.56	-0.55	N/A	-0.56
dstMHramp_24	-0.20	-0.34	-0.40	**-0.79**	-0.50	N/A	-0.67
dflash_24	-0.41	-0.22	0.05	-0.03	-0.19	N/A	-0.06
dmin_36	0.61	0.21	0.17	0.28	0.18	N/A	0.40
dmax_36	-0.53	-0.05	-0.09	0.44	0.34	N/A	0.06
dD_36	-0.22	0.04	0.33	-0.05	-0.06	N/A	0.11
dSD_36	-0.17	0.06	0.34	0.01	-0.02	N/A	0.16
dramp_36	0.07	-0.25	-0.32	0.00	0.05	N/A	-0.34
dpath_36	-0.23	0.02	0.30	-0.07	-0.10	N/A	0.11
drev_36	-0.23	0.03	0.27	0.03	-0.08	N/A	0.18
drf_36	-0.15	0.35	0.31	-0.25	0.11	N/A	0.20
dstD_36	-0.45	-0.16	0.15	-0.37	-0.29	N/A	-0.18
dAstD_36	-0.06	-0.47	-0.27	**-0.87**	-0.67	N/A	-0.70
dCV_36	-0.07	-0.47	-0.31	**-0.88**	-0.68	N/A	-0.69
dstMHramp_36	-0.01	-0.40	-0.53	-0.46	-0.26	N/A	-0.63
dflash_36	-0.57	-0.15	0.14	-0.40	-0.33	N/A	-0.16

Annex III (cont.)

Hydrologic index	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5	Transect 6	Transect 2, 3 & 4
dmin_48	N/A	0.42	0.23	0.26	0.32	N/A	0.50
dmax_48	N/A	-0.07	0.29	-0.15	-0.25	N/A	-0.14
dD_48	N/A	0.15	0.32	-0.40	-0.10	N/A	-0.07
dSD_48	N/A	0.17	0.36	-0.34	-0.07	N/A	-0.01
dramp_48	N/A	-0.31	0.00	-0.42	-0.47	N/A	-0.46
dpath_48	N/A	0.17	0.33	-0.38	-0.10	N/A	-0.02
drev_48	N/A	0.23	0.35	-0.20	-0.01	N/A	0.15
drf_48	N/A	0.43	0.18	-0.05	0.39	N/A	0.24
dstD_48	N/A	0.02	0.19	-0.69	-0.27	N/A	-0.27
dAstD_48	N/A	-0.23	-0.08	**-0.90**	-0.58	N/A	-0.58
dCV_48	N/A	-0.17	0.02	**-0.84**	-0.47	N/A	-0.47
dstMHramp_48	N/A	-0.44	-0.27	-0.52	-0.58	N/A	-0.60
dflash_48	N/A	0.04	0.20	-0.64	-0.29	N/A	-0.21