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1 Normalized Abundance Spectra of fish community reflect
2 hydro-peaking on a Mediterranean large River

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15 Abstract

16 The European Water Framework Directive requires the integration of body size characters as an
17 important part of fish-based bioassessment tools for freshwaters ecological status determination.
18 The study of the entire fish community size-structure provides valuable information about food web
19 capacity, food web stability and ecological efficiency of aquatic ecosystems. One of the most used
20 representations of community size structure is the Normalized Abundance Spectra (NAS) that
21 provides an approximation of the total fish abundance and food web capacity (through the
22 parameter γ -intercept) and an estimation of food web efficiency (through the slope of the linear
23 regression). In this study we explored NAS of the lower Ebro River fish community by integrating
24 data from monthly electrofishing samplings during a whole year (November 2014- October 2015).
25 We found that the percentage of total alien and alien-prey individuals were directly related with γ -
26 intercept and inversely related with slope of NAS. This is because the bulk of the community consists
27 of introduced species of small body length. Furthermore, we detected significant relationships
28 between NAS-related parameters and the hydrological variables describing diel flow oscillations and
29 daily flow variability. Based on this, we suggest that high flow variability conditions and, above all,
30 high hydro-peaking conditions, caused a diminution of the total abundance of fish and a decrease of
31 the proportion of small sized fish (i.e. lower γ -intercept and flatter slopes of NAS, respectively).
32 Finally, a significant interaction between hydro-peaking and the percentage of alien-predators
33 suggests that high hydro-peaking conditions benefit predation by facilitating predator-prey
34 encounters. This is reflected by strong linear relationship between NAS parameters and percentage
35 of piscivorous at high hydropeaking conditions that disappears at low hydro-peaking fluctuations.
36 We concluded that the high proportion of alien fishes and the presence of a hydropower generation
37 plant that operates by hydro-peaking are important factors determining fish size structure in the
38 lower Ebro River.

39 Key words

40 Size Structure, fish community, Ebro River, hydro-peaking, alien species, size spectra

41 Highlights

- 42 1- Small sized species of alien fish dominate the lower Ebro River fish community.
- 43 2- Normalized Abundance Spectra (NAS) of fish were evaluated monthly for one year.
- 44 3- NAS reflected hydro-peaking impacts on the fish community.
- 45 4- High hydro-peaking conditions may increase predatory efficiency of piscivorous fish.

46

47 1. Introduction

48 Since the implementation of the European Water Framework Directive (WFD) (European
49 Community, 2000) a huge effort has been done to find suitable bioassessment tools for the
50 assessment of freshwater ecosystems health. Indeed, the WFD requires the use of size
51 characteristics as a normative condition for fish-based bioassessment tools (Murphy et al., 2013;
52 Reyjol et al., 2014), and it is certainly true that size structures of aquatic communities are shaped by
53 biotic interactions and environmental factors, and may therefore reflect changes occurred on the
54 surrounding conditions, whether of anthropogenic or natural origin (Blanchard et al., 2017; Emmrich
55 et al., 2014; Murry and Farrell, 2014; Sprules and Barth, 2016). There are many approaches to
56 visualize the size distribution of organisms in a sample that have become increasingly popular since
57 the formulation of the biomass size spectrum theory in the mid-1960s. This theory states that in
58 aquatic ecosystems, the sum of biomass is approximately constant across equal logarithmic intervals
59 of body size from the smallest to the biggest organism (Sprules and Barth, 2016). From this idea
60 emerged the Normalized Abundance Spectra (NAS) that can be adjusted to a linear model and
61 provide information about food-web capacity (through the y-intercept of the spectrum) and
62 ecological efficiency of communities (through the slope of the spectrum) (Daan et al., 2005; Mehner
63 et al., in press; Rice and Gislason, 1996). Size structure approaches have been extensively used to
64 study the ecosystems in marine environments (Andersen and Beyer, 2006; Blanchard et al., 2017,
65 2005; Kimmel et al., 2006; Platt and Denman, 1977; Sheldon et al., 1972), and in lakes and lagoons
66 (Arranz et al., 2015; Bruce et al., 2010, 2005, Emmrich et al., 2014, 2011). But there are very few
67 studies on rivers (Benejam et al., 2018, 2015; Broadway et al., 2015; Murry and Farrell, 2014). In this
68 study we analysed Normalized Abundance Spectra (NAS) of the fish community of the lower Ebro
69 River, a Mediterranean large river in the Iberian Peninsula, to test their ability to detect
70 environmental and biotic disturbances.

71 The Ebro River is affected by several human impacts: water abstraction, dam regulation with
72 subsequent altered hydrological regime (Batalla et al., 2004) and low suspended sediments (Rovira
73 et al., 2007), industrial pollution (Benejam et al., 2010; Huertas et al., 2016), thermal pollution (Prats
74 et al., 2012, 2010), proliferation of macrophytes (Ibáñez et al., 2012) and introduction of many alien
75 fish species (Caiola et al., 2014; Elvira, 1995a, 1995b), among others. It is well known that non-native
76 fish introductions can result in local decline and even extinction of native species through different
77 mechanisms such as genetic introgression, introduction of parasites and diseases, competition for
78 habitat, habitat alteration and predation (García-Berthou, 2007). Specifically in the lower Ebro River,
79 where this study is focused, some of the new introduced species are voracious piscivorous (e.g.
80 *Silurus glanis*) that can cause critical changes in the original fish populations because many

81 indigenous species have evolved in communities with none native piscivorous fishes (Carol et al.,
82 2009; Ribeiro and Leunda, 2012). Another important source of alteration from the natural ecological
83 status in the lower Ebro River is the presence of a hydroelectric generation power plant that
84 operates by hydro-peaking. This is the procedure by which hydroelectricity is produced to cover the
85 daily fluctuating demands of the energy market and it results on a daily peaking flow regulation that
86 affects the biological dynamics of downstream communities. Many authors reported adverse
87 impacts of hydro-peaking on fish caused by, inter alia, stranding, habitat abandonment, downstream
88 displacement, inhibition of spawning, migration obstruction, habitat modification, increase of
89 physiological stress and depleted food production (Almeida et al., 2017; Boavida et al., 2015;
90 Schmutz et al., 2015; Young et al., 2011). Among all the mentioned environmental disturbances, we
91 looked for potential causes of alteration on NAS through an extensive sampling of fish stocks by
92 electrofishing.

93 The main objective of the present paper is to identify the natural and anthropogenic factors
94 affecting size structure of fish community in a large Mediterranean river. In this way, we want to
95 evaluate the potential of Normalized Abundance Spectrum parameters as size-related bioindicators
96 to complement the fish-based indices currently in use.

97

98 2. Material and methods

99 2.1. Study area

100 The Ebro River is located in the NE of the Iberian Peninsula (Fig. 1a). With a total drainage area
101 of 85.569 km² and a mean annual flow of 294 m³·s⁻¹, provides valuable ecosystem services to people
102 such as water for agriculture uses (irrigation area of 906.000 ha), urban supply (basin population of
103 3.176.091) and hydro-power generation (458 stations) (Confederación Hidrográfica del Ebro, 2009).

104 In terms of hydrology the study area can be divided in two regions: the river section upstream
105 from Xerta weir that comprises the stations E05 to E02 where the mean annual flow is of
106 approximately 320 m³·s⁻¹, and the reach after Xerta weir that comprises sampling station E01. This
107 weir is the last human obstacle before the river mouth and its function is to divert water for
108 agricultural uses and human consumption. The mean annual flow in station E01 is about 280m³·s⁻¹.
109 Hydro-peaking oscillations generated in a hydroelectrical power plant located in Flix dam are
110 perceptible in all the study area (Figs. 1 and 2).

111

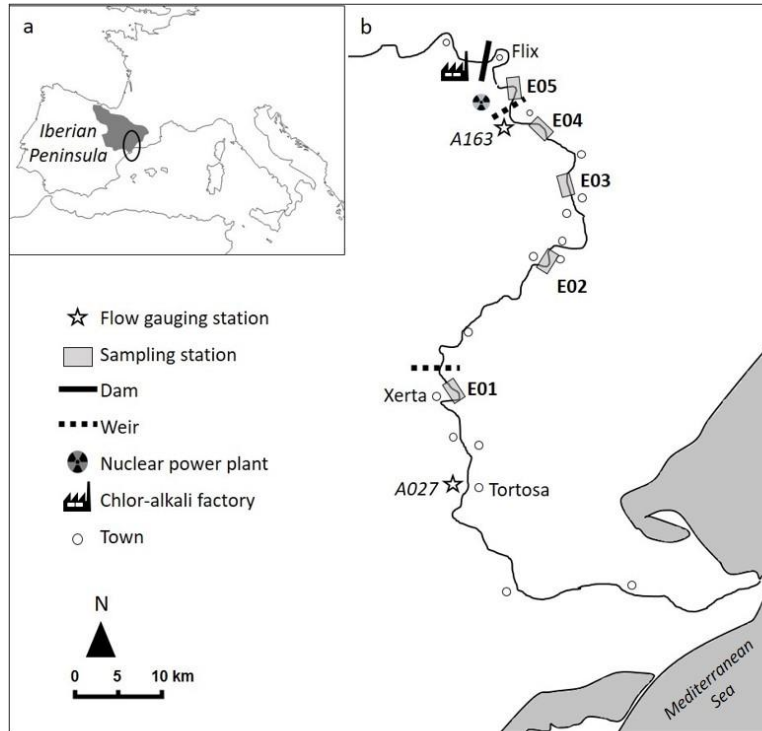


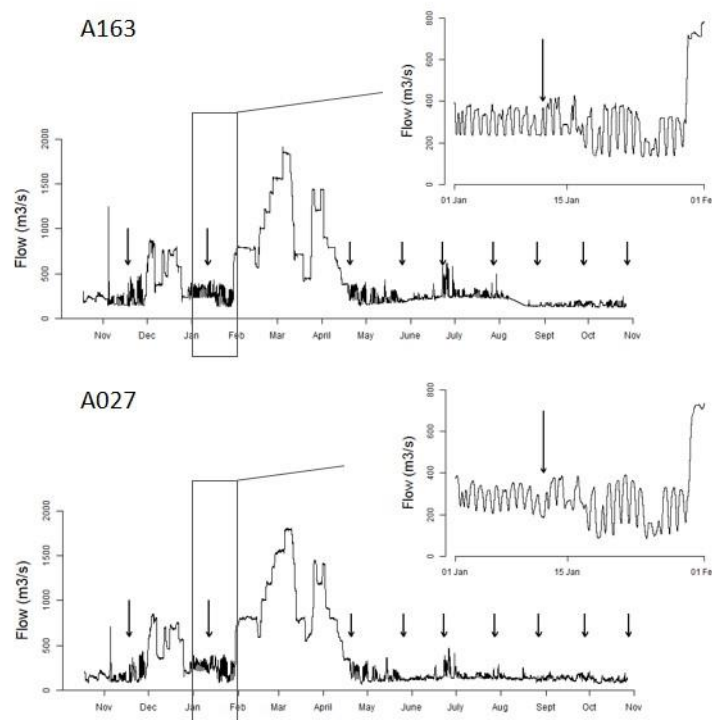
Figure 1. (a) Location of the Ebro River and (b) the five sampling stations.

2.2. Sampling

Data of fish species abundance and body size were collected by electro-fishing in 5 stations on the lower Ebro River (Fig. 1). The stations were randomly selected to cover all the hydromorphological variability of the study area (for more details see Caiola et al., 2014). Each station consisted in a 2 km length stretch to fulfil the requirements of EN 14011 European standard (CEN. European Committee for Standardization, 2003) that establishes a minimum sampling stretch length of ten times the river width (in the study area the mean width is ca. 180 m). Ten equidistant points located in the littoral zone were sampled within each station, randomly alternating left and right banks, with a total length sampled at each sampling station of about 200m. A boat based electro-fishing gear (Model: EL63IIGI, HANS GRASSL GmbH, Schönau am Königssee, Germany) was used at 600 V and 10 A pulsed D.C. The fish were collected with a dip net of 2.5 m long, 47 cm of diameter and 7 mm of mesh size. The specimens were identified to species level, counted, measured and weighted. Native specimens were returned to the river and alien fishes were sacrificed with an overdose of anesthetic (MS-222). We normalized abundances dividing by fished area and time of fishing, obtaining catches per unit effort (CPUE: individuals·ha⁻¹·min⁻¹) and biomass per unit effort (BPUE: kg·ha⁻¹·min⁻¹).

131 In addition to fish community metrics, we measured several environmental factors and habitat
132 variables: water temperature ($^{\circ}\text{C}$), conductivity ($\text{mS}\cdot\text{cm}^{-1}$), dissolved oxygen ($\text{mg}\cdot\text{l}^{-1}$) and total
133 dissolved solids ($\text{mg}\cdot\text{l}^{-1}$) were measured with a multi-parameter probe (YSI model 556 MPS); water
134 depth (m) was measured using a portable depth-meter (Hondex model PS-7) and water flow velocity
135 ($\text{m}\cdot\text{s}^{-1}$) was measured with a current-meter (Global Water model FP101). The presence, absence and
136 area covered by macrophytes was recorded by visual approximation following the recommendations
137 for macrophytes assessment of the STAR project (Dawson, 2002). Daily and diel flow data series
138 available at the Ebro Water Authority (CHE) web site (<http://www.chebro.es/>) were used to
139 calculate hydrological indices (see section 2.5. Hydrological variables calculation).

140 Monthly sampling campaigns were conducted between November 2014 and October 2015. Due
141 to safety questions, we avoided sampling on December 2014, February and March 2015, when the
142 water flow at the study area was higher than $500 \text{ m}^3\cdot\text{s}^{-1}$ and it was impossible to guarantee the
143 safety of the crew.



144

145 *Figure 2. Hydrographs on gauging station A163 (upper figure) and on gauging station A027 (lower figure)*
146 *during the study period November 2014 – October 2015. Arrows indicate sampling dates. Note the*
147 *hydropeaking oscillations.*

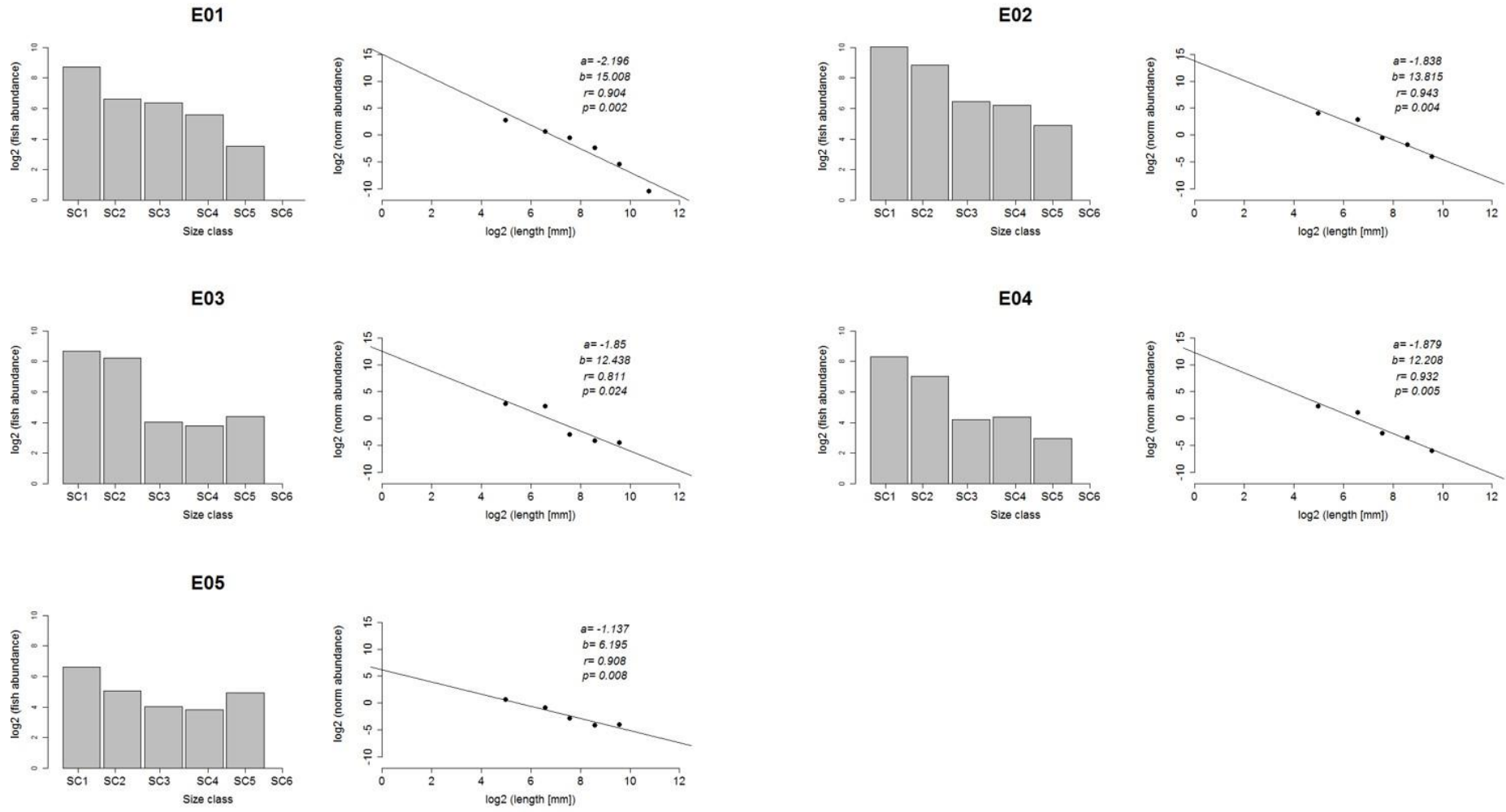
148

149 2.3. Fish size spectrum calculation

150 For each station and sampling period we modeled the Normalized Abundance Spectrum (NAS)
151 with body lengths of the entire fish community. NAS is obtained through a binning method in which
152 body size measurements are grouped into logarithmic size intervals and the abundance of
153 individuals is represented for each size class in a \log_2 - \log_2 plot. We standardized abundance by
154 dividing it by the linear width of the size interval as described on Sprules and Barth (2016). The linear
155 size spectra was calculated from NAS as the linear regression between the \log_2 midpoint of size
156 classes (abscissas) and the \log_2 of normalized abundance per size class (ordinates) (Fig. 3). We
157 considered six size classes following a \log_2 scale (1st class, $\leq 2^6=64$ mm; 2nd class, $>2^6=64$ mm to
158 $2^7=128$ mm; 3rd class, $>2^7=128$ mm to $2^8=256$ mm; 4th class, $>2^8=256$ mm to $2^9=512$ mm; 5th class,
159 $>2^9=512$ mm to $2^{10}=1024$ mm; 6th class, $>2^{10}=1024$ mm to maximum length). Electro-fishing has been
160 shown as a suitable method to estimate size structure of fish in rivers (Benejam et al., 2015).
161 However, although it has been demonstrated to be less selective than other sampling methods, it
162 can imply an underestimation of small fish in some species due to the fact that the electric field has
163 greater effects on large fish (Barbour et al., 1999; Borgström and Skaala, 1993; Millar et al., 2016).
164 For this reason, the smallest size classes were grouped in the first class (<64 mm) (Benejam et al.,
165 2015). We estimated the intercept and the slope for each linear size spectrum of the entire fish
166 community. The y-intercept of the linear size spectrum can be interpreted as an approximation of
167 food web capacity (Gaedke and Straile, 1994; Murry and Farrell, 2014) whereas the slope equals to a
168 measure of energy transfer or ecological efficiency (Emmrich et al., 2011, Mehner et al. in press). We
169 only considered for the analysis the size distributions that fit a linear spectrum, so we discarded 3
170 regressions with p values >0.1 (Arranz et al., 2015) from a total of 45 (5 stations per 9 sampling
171 campaigns).

172 2.4. Hydrological variables calculation

173 There are two official gauging points for water flow measurement in the study area: the gauging
174 stations A163 in Ascó and A027 in Tortosa (Fig. 1). They belong to the Automatic System for
175 Hydrological Information (SAIH) of the Ebro River (Confederación Hidrográfica del Ebro, 2002) and
176 provide a flow measurement every 15 minutes. We used the A027 series as an approximation of the
177 flow on sampling station E01 and the A163 series for the sampling stations E02, E03, E04 and E05.



178

179 *Figure 3. Examples of Abundance Frequency Distributions and Normalized Abundance Spectrum: Sampling campaign of April 2015; sites E01-E05. The linear parameters*
 180 *a (slope) and b (y-intercept) are shown, as well as their r and p values.*

Index	Calculation
Daily indices	
M _A 3	Coefficient of variation in daily flows
M _A 44	Variability in daily flows divided by median monthly flow, where variability is calculated as 90 th -10 th percentile
M _L 13	Coefficient of variation in minimum flows
M _L 14	Lowest monthly flow divided by median monthly flow
M _H 17	25 th percentile from the flow duration curve divided by median daily flow
M _H 20	Monthly maximum flow
F _L 1	Number of occurrences during which the magnitude of flow remains below the 25 th percentile
F _H 5	Number of occurrences during which the magnitude of flow remains above the median daily flow
D _H 12	Mean 7-day maximum divided by median flow
R _A 8	Number of negative and positive changes in water conditions from one day to the next
M _A 5	Skewness in daily flows: Mean daily flows divided by median daily flows
Subdaily indices	
dmin	Daily minimum
dmax	Daily maximum
dD	Daily delta or range
dSD	Daily Standard deviation
dramp	Maximum hourly ramp rate
dpath	Daily path length (the geometric distance of the daily hydrograph of flow versus time)
drev	Number of changes between rising and falling periods)
drf	Rise and fall counts difference
dAstD	Annually standardized delta (monthly mean of daily delta divided by annual mean)
dCV	Coefficient of variation (daily standard deviation divided by the mean monthly daily flow)
dstMHramp	Standardized maximum hourly ramping rate (maximum daily ramp rate divided by the mean monthly daily flow)
dflash	Richards-Baker flashiness index (daily path length of oscillations divided by the daily mean over each 24-h period)

181

182 *Table 1 – Hydrological indices adapted from Olden & Poff (2003) and Bevelhimer et al (2014) for a period*
183 *of one month before date of sampling. Daily indices were calculated from a daily data series and sub-daily*
184 *indices from an hourly data series.*

185 A collection of hydrological indices adapted from literature was calculated (Table 1). The set of
186 daily indices were described in Olden and Poff (2003) as key variables to characterize the
187 hydrological regime for our type of river (with snow and rain influence) while avoiding redundancy.
188 We included adapted descriptors of magnitude of flow events (M_A3, M_A44, M_L13, M_L14, M_H17 and
189 M_H20), frequency of flow events (F_L1 and F_H5), duration of flow events (D_H12) and the rate of change
190 in flow conditions (R_A8). We also included the skewness in daily flows (M_A5), described by Kinsolving
191 and Bain (1993) as important in the response of fish to anthropogenic flow alterations. Sub-daily
192 indices were proposed by Bevelhimer et al. (2014) as good descriptors of diel flow variations such as
193 the produced by power generation plants. Among them, there are two descriptors of magnitude
194 (dmin and dmax) and one descriptor of the frequency of oscillations (drev). The rest are different
195 ways of expressing the amplitude of flow fluctuations (dD, dSD, dramp, dpath, drf, dAstD, dCV,

196 dstMHramp, dflash). We adapted all the indices to assess flow variations in a short temporal scale
197 and calculated them for the period of one month before each sampling.

198 2.6. Biotic factors

199 To assess how the presence of alien species affects the size structure of the community, three
200 biotic factors were considered: percentage of alien individuals, percentage of alien-piscivorous
201 individuals (over total catches) and percentage of alien-prey individuals (over total catches). It
202 should be noted that the only native piscivorous fish that we found was the sea bass (*Dicentrarchus*
203 *labrax*), a marine species that occasionally migrate between freshwater and the sea (in both
204 directions), for feeding purposes. We only fished 12 individuals of this species, always in the transect
205 E01 (the station furthest downstream), so we could say that the piscivorous population is almost
206 entirely constituted by alien fish (Table 2).

207 To calculate the number of piscivorous, juvenile individuals considered too young to feed on
208 fish, were subtracted for each predator species. That is: only individuals greater than 120 mm were
209 considered piscivorous for *Perca fluviatilis* (Kottelat and Freyhof, 2007) and *Sander lucioperca*
210 (Aparicio et al., 2016), while this threshold was 50 mm for *Silurus glanis* (Copp et al., 2009) and
211 *Micropterus salmoides* (García-Berthou, 2002). To determine the percentage of alien-prey
212 individuals, all the non-piscivorous alien fishes were considered susceptible to predation, so we
213 calculated it as the subtraction of percentage of alien minus percentage of alien-piscivorous.

214 2.7. Statistical Analyses

215 To check for relationships between the response variables y-intercept of NAS (food web
216 capacity) and slope of NAS (food web efficiency) and the potential explanatory variables
217 (macrophyte coverage, water temperature, conductivity, dissolved oxygen, total dissolved solids,
218 water depth, water velocity, percentage of alien fish, percentage of alien-piscivorous, percentage of
219 alien-prey and the hydrological indices on Table 1), we performed simple lineal regressions with
220 autocorrelation structures for time and space when necessary. The large number of explanatory
221 variables that we wanted to include in the analysis prevented us from applying multiple regressions
222 and thus, we performed simple lineal regressions in this first step. As our sampling design consists of
223 several observations along time within each river stretch, it results on a data set with a possible lack
224 of independence, both spatial and temporal. To deal with this limitation we used Mixed Effects
225 Models with river reach as random factor and tested the inclusion of temporal auto-correlation
226 structures to improve the models as described in Zuur et al. (2009). Firstly, we tested 5 types of auto
227 correlation structures: AR-1, linear correlation, Gaussian correlation, exponential correlation and

Species	Common name	Reproduction	Spawning time	Migration	Habitat	Feeding	Status	First detected	Total	CPUE	BPUE
<i>Anguilla anguilla</i>	Eel	Pelagophilic ³	late winter or spring ⁷	Diadromous ^{1,2}	Eurytopic ¹	Omnivorous ¹	N	-	1879	321.2	75.45·10 ³
<i>Dicentrarchus labrax</i>	Seabass	Pelagophilic ⁵	January-March ⁷	Amphidromous ⁵	Limnophilic ⁷	Piscivorous ⁵	N	-	12	1.7	0.88·10 ³
<i>Gobio lozanoi</i>	Iberian gudgeon	Polyphilic ⁵	May-July ⁷	Resident ¹	Rheophilic ²	Invertivore ²	N	-	332	54.6	0.11·10 ³
Undetermined Mullet	Mullet	Pelagophilic ⁵	-	Amphidromous ⁵	Limnophilic ⁷	Detritivorous ⁵	N	-	398	56.1	8.14·10 ³
<i>Luciobarbus graellsii</i>	Ebro barbel	Litophilic ⁵	May-July ⁷	Potamodromous ⁵	Limnophilic ⁵	Omnivorous ⁵	N	-	85	10.9	2.72·10 ³
<i>Salaria fluviatilis</i>	Freshwater blenny	Litophilic ^{2,3}	May-August ⁷		Eurytopic ⁵	Invertivore ^{2,3}	N	-	746	200.9	1.49·10 ³
<i>Squalius laietanus</i>	Catalan chub	Litophilic ²	April-July ⁷	Potamodromous ⁵	Rheophilic ²	Omnivorous ²	N	-	1371	203.1	2.95·10 ³
<i>Alburnus alburnus</i>	Bleak	Litophilic ⁴	April-June ⁷	Potamodromous ⁵	Limnophilic ⁵	Omnivorous ²	A	1992	18567	2661.9	113.95·10 ³
<i>Carassius auratus</i>	Goldfish	Phytophilic ^{2,3}	May-July ⁷	Potamodromous ⁶	Limnophilic ⁵	Omnivorous ^{2,3}	A	s.XVII	174	24.5	10.49·10 ³
<i>Cyprinus carpio</i>	Common carp	Phytophilic ^{2,3}	May-July ⁷	Resident ¹	Limnophilic ¹	Omnivorous ^{1,2,3}	A	s. XVI	343	48.4	188.34·10 ³
<i>Gambusia holbrooki</i>	Eastern mosquitofish	Ovoviviparous ³	May-September ⁷	Resident ¹	Limnophilic ^{1,2}	Invertivorous ^{2,3}	A	1921	1448	273.8	0.33·10 ³
<i>Lepomis gibbosus</i>	Sunfish	Polyphilic ³	May-June ⁷	Resident ¹	Limnophilic ^{1,2}	Invertivorous ^{1,2,3}	A	80's	113	15.0	0.44·10 ³
<i>Micropterus salmoides</i>	Largemouth black bass	Polyphilic ³	late spring or early summer ⁷	Resident ¹	Limnophilic ^{1,2}	Piscivorous ^{1,2,3}	A	1955	1	0.1	0.04·10 ²
<i>Pseudorasbora parva</i>	Razbora	Polyphilic ⁵	April-June ⁷		Limnophilic ⁷	Omnivorous ²	A	1999	1118	157.7	0.82·10 ³
<i>Perca fluviatilis</i>	European perch	Phytophilic ⁵	April-May ⁷	Resident ⁵	Limnophilic ⁵	Piscivorous ²	A	1970	35	4.9	0.16·10 ³
<i>Rutilus rutilus</i>	Roach	Polyphilic ⁷	April-June ⁷		Limnophilic ⁵	Omnivorous ²	A	80's	528	74.5	4.48·10 ³
<i>Scardinius erythrophthalmus</i>	Rudd	Phytophilic ²	April-June ⁷		Limnophilic ²	Omnivorous ²	A	1910-13	79	11.1	0.60·10 ³
<i>Silurus glanis</i>	Wels catfish	Phytophilic ^{2,7}	April-June ⁷		Limnophilic ⁷	Piscivorous ²	A	1974	213	30.0	101.37·10 ³
<i>Sander lucioperca</i>	Zander	Litophilic ⁵	March-April ⁷	Potamodromous ⁵	Limnophilic ⁵	Piscivorous ⁵	A	1990	203	28.6	2.37·10 ³

228 Table 2 – Latin names, common names, reproductive, migratory, habitat and feeding behaviours, status referred to the Ebro River (N= native; A= alien), total catches,
229 mean CPUEs and mean BPUEs. Blank means no classified (1-Alexandre et al, 2013; 2- Garcia-Berthou et al, 2015; 3- Magalhaes et al, 2008; 4- Pinder AC, 2001; 5- Odreix et
230 al, 2014; 6- Riede K, 2004; 7- Aparicio et al, 2016)

231 spherical correlation. Once we knew the best temporal auto-correlation expression we proceeded to
232 choose the best model comparing: a) a linear regression model without any autocorrelation; b) a
233 linear regression model with the best autocorrelation structure for time; c) a mixed effects model
234 with river reach as random factor and d) a mixed effects model with river reach as random factor
235 and the best autocorrelation structure for time. The models were adjusted using the R package nlme
236 (Pinheiro et al., 2017; R Core Team, 2016) and compared with the Akaike Information Criterion (AIC)
237 (Akaike, 1974). The most parsimonious model (with the lowest AIC) was selected each time.

238 In a second step, from the initial set of hydrological variables, we considered only those that
239 were significantly related with size spectra parameters in the previous analysis to investigate
240 possible multiplicative effects between hydrology and biotic factors. To avoid redundant tests, we
241 first calculated the correlation matrix for all factors and discarded correlated hydrological indices
242 with $r > 0.6$. Then, interactions were tested for all the possible combinations between the three
243 biotic factors (percentage of alien, percentage of alien-prey and percentage of alien-piscivorous) and
244 the three uncorrelated hydrological indices (dAstD, F_{L1} and M_{A5}), with models of the type:

245 Response variable ~ hydrological factor + biotic factor + hydrological factor : biotic factor

246 Where “response variable” refers to y-intercept of NAS (food web capacity) and slope of NAS
247 (food web efficiency). To avoid multicollinearity, the predictors were centered before the calculation
248 of the interaction term by subtracting their means. We applied the same model selection procedure
249 than before.

250

251 3. Results

252 3.1. Fish community composition

253 The study area was clearly dominated by alien fishes, with an average of 79.7% of alien
254 individuals and 82.2% of alien biomass abundances. The bleak (*Alburnus alburnus*) was the most
255 abundant species in number of individuals, followed by the European eel (*Anguilla anguilla*).
256 Common carp (*Cyprinus carpio*) and again, the bleak, were the most abundant in terms of biomass.
257 In regards to feeding functional group, most of the fish were omnivorous (86.4%), followed by the
258 invertivorous (10.2%), the piscivorous (1.8%) and the detritivorous (1.5%) (Table 2).

259 Concerning average fish size, native individuals were on average 42.93 ± 3.77 mm bigger than
260 the community mean, while alien fish were 15.47 ± 2.57 mm smaller. As expected, alien-piscivorous
261 had a large mean body length, 344.97 ± 25.07 mm above average, and alien-preys had a mean size
262 26.16 ± 2.2 mm below average.

263 3.2. Effects of environmental and biotic variables on size structure

264 As shown on Table 3, y-intercept of NAS (food web capacity) was negatively related with
 265 hydrological indices describing the amplitude of sub-daily flow oscillations (dD, dSD, dpath, and
 266 dAstD) and their frequency (drev), hydrological variables estimating high (F_{H5}) and low (F_{L1}) flow
 267 events frequency and the skewness in daily flows (M_{A5}). Thus, the greater the flow variability, the
 268 lower the y-intercept of NAS (food web capacity), indicating a fewer total abundance of fish in the
 269 entire community when hydrological oscillations were high. Furthermore, y-intercept of NAS was
 270 also negatively related with the percentage of alien piscivorous fish. This has a direct interpretation,
 271 since we can expect that a higher number of piscivorous would imply higher prey consumption, and
 272 so, a diminution of total abundance (i.e. y-intercept or food web capacity). In the other hand, y-
 273 intercept was positively related with the percentage of total alien individuals and percentage of
 274 alien-prey, indicating that these groups of organisms contribute to increase the total number of fish,
 275 and so, the amount of energy available in the ecosystem.

<i>Response variable</i>	<i>Predictor</i>	<i>AIC₀</i>	<i>AIC_f</i>	<i>Model</i>	<i>Estimate</i>	<i>SE</i>	<i>p_value</i>	<i>R²</i>
<i>y-intercept of NAS (food web capacity)</i>	<i>dD</i>	219.53	201.72	M2	-0.034	0.011	<0.01	0.52
	<i>dSD</i>	217.37	199.96	M2	-0.091	0.030	<0.01	0.53
	<i>dpath</i>	220.93	200.82	M2	-0.019	0.005	<0.001	0.54
	<i>drev</i>	217.37	202.24	M2	-0.074	0.024	<0.01	0.56
	<i>dAstD</i>	207.17	189.76	M2	-13.461	4.360	<0.01	0.52
	<i>F_{L1}</i>	219.25	202.18	M2	-0.100	0.022	<0.001	0.40
	<i>F_{H5}</i>	219.57	204.37	M2	-0.087	0.018	<0.001	0.31
	<i>M_{A5}</i>	204.75	184.90	M2	-15.056	3.326	<0.001	0.63
	<i>% alien</i>	205.95	183.58	M3	0.118	0.022	<0.001	0.31
	<i>% alien prey</i>	205.98	183.52	M3	0.113	0.021	<0.001	0.22
<i>slope of NAS (food web efficiency)</i>	<i>% alien piscivorous</i>	212.06	195.00	M3	-0.724	0.333	<0.05	0.05
	<i>dD</i>	55.14	43.57	M2	0.004	0.001	<0.01	0.49
	<i>dpath</i>	56.63	44.45	M4	0.002	0.001	<0.05	0.01
	<i>drev</i>	53.71	41.96	M4	0.006	0.003	<0.05	0.52
	<i>dAstD</i>	43.02	31.45	M2	1.672	0.570	<0.01	0.49
	<i>F_{L1}</i>	54.57	40.91	M4	0.011	0.005	<0.05	0.00
	<i>M_{A5}</i>	43.04	29.96	M2	1.289	0.439	<0.01	0.53
	<i>% alien</i>	45.87	28.13	M4	-0.014	0.003	<0.001	0.22
	<i>% alien prey</i>	45.95	28.39	M4	-0.013	0.003	<0.001	0.22

276
 277 *Table 3 – Results of the models adjusted between single predictors and the response variables y-intercept*
 278 *of NAS (food web capacity) and slope of NAS (food web efficiency). Only significant models are shown. The*
 279 *column “Model” indicates: M2) Mixed Effects Model with river reach as random factor and an autocorrelation*
 280 *structure for time; M3) Generalized Least Squares Model with a corLin autocorrelation structure for time and*
 281 *M4) Generalized Least Squares Model with an AR-1 autocorrelation structure for time. AIC, Akaike information*
 282 *criteria; SE, Standard error. R² corresponds to a linear regression of fitted versus real values.*

283

284 The slope of NAS (food web efficiency) was significantly and positively related with some
 285 hydrological indices describing the amplitude (dD, dpath and dAstD), and frequency (drev) of sub-
 286 daily flow oscillations and daily flow variability (F_{L1} and M_{A5}) (Table3), suggesting a diminution of the
 287 proportion of small sized fishes when flow variability was high. The slope (food web efficiency) was
 288 strongly and negatively related with the percentage of total alien individuals and percentage of
 289 alien-prey that means that a higher percentage of these groups lead to higher relative abundances
 290 of small fishes, and so, steeper slopes of NAS.

291 *3.3. Interactions between hydrological and biotic factors*

292 In the second part of the analysis, we investigated possible multiplicative effects between
 293 hydrology and biotic factors. To avoid redundant tests and given the high degree of autocorrelation
 294 among variables shown in Table 4, we selected dAstD as a descriptor of sub-daily flow, and F_{L1} and
 295 M_{A5} as indicators of daily regime flow and discarded dD, dSD, dpath, drev and F_{H5} for being highly
 296 correlated with the first.

	dD	dSD	dpath	drev	dAstD	F _{L1}	F _{H5}	M _{A5}	% alien	% alien prey	% alien piscivorous
dD	-	0	0	0	0	0.709	0.718	0.002	0.54	0.667	0.284
dSD	0.948	-	0	0	0	0.994	0.551	0.009	0.88	0.996	0.26
dpath	0.942	0.869	-	0	0	0.11	0.137	0	0.926	0.953	0.363
Drev	0.788	0.747	0.860	-	0	0.082	0.051	0	0.337	0.368	0.311
dAstD	0.987	0.922	0.915	0.773	-	0.715	0.683	0.001	0.281	0.37	0.377
F _{L1}	0.061	-0.001	0.257	0.278	0.060	-	0	0	0.262	0.246	0.122
F _{H5}	0.059	-0.097	0.239	0.310	0.067	0.711	-	0.005	0.069	0.077	0.076
M _{A5}	0.485	0.407	0.625	0.628	0.495	0.596	0.434	-	0.404	0.444	0.721
% alien	-0.100	-0.025	-0.015	-0.156	-0.175	-0.182	-0.290	-0.136	-	0	0
% alien prey	-0.070	-0.001	0.010	-0.146	-0.146	-0.188	-0.283	-0.124	0.996	-	0
% alien piscivorous	-0.174	-0.182	-0.148	0.164	-0.143	0.249	0.284	0.058	-0.616	-0.652	-

297
 298 *Table 4– Correlation matrix of the independent variables that showed significant relationship with size*
 299 *related variables in simple models. The shaded matrix contains Spearman’s r values; the open matrix contains p*
 300 *values. In bold significantly correlated coefficients (r>0.6 and p<0.05).*

301 As shown in Table 5, a highly significant multiplicative effect was found between dAstD and the
 302 percentage of alien-piscivorous fish when modelling their effects on the response variables derived
 303 from NAS (y-intercept or food web capacity and slope or food web efficiency). These results mean
 304 that the level of one factor (in this case dAstD that describes hydropeaking) modifies the way in
 305 which the other factor (here, percentage of alien-piscivorous) affects the response variable. To
 306 visualize these results, we represented in Figure 4 the y-intercept of NAS (food web capacity) and
 307 slope of NAS (food web efficiency) as a function of the percentage of alien-piscivorous grouping data
 308 in high dAstD (values above their mean) and low dAstD (values below their mean). The variables
 309 dAstD and percentage of alien-piscivorous interact in such a way that in situations of high dAstD that
 310 indicate high hydropeaking oscillations, the relationship between the percentage of piscivorous and
 311 the y-intercept of NAS (trophic chain capacity) was strong ($p < 0.01$ and $R^2 = 0.44$), whereas under low
 312 dAstD conditions (i.e. low diel oscillations of flow), the linearity between these two parameters was
 313 lost. Similarly, the slope of NAS (trophic chain efficiency) presented a significant linearity with the
 314 percentage of piscivorous in high dAstD conditions ($p < 0.01$ and $R^2 = 0.43$) but no linearity was found
 315 in periods of low dAstD. The interactions between the other hydrological variables (F_{L1} and M_{A5}) and
 316 the rest of biotic factors (percentage of alien species and percentage of alien-prey) were no
 317 significant.

318

Response variable	Significant predictors	Model	AIC ₀	AIC _f	Estimate	SE	p value	R ²
y-intercept of NAS (food web capacity)	% of piscivorous	M1	195.75	176.32	-1.491	0.385	<0.001	0.74
	dAstD				-22.376	4.387	<0.001	
	% of pisc.*:dAstD*				-17.052	4.619	<0.001	
slope of NAS (food web efficiency)	% of piscivorous	M1	41.68	24.16	0.146	0.047	<0.001	0.71
	dAstD				2.489	0.532	<0.001	
	% of pisc.*:dAstD*				2.184	0.560	<0.001	

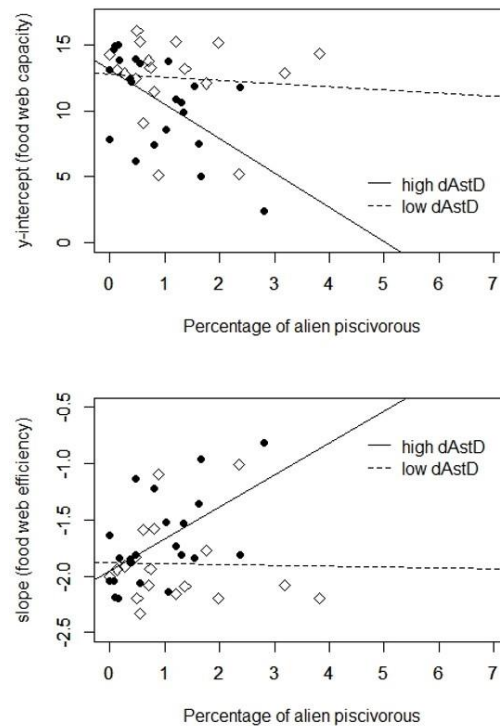
319

320 *Table 5 – Results of the models showing hydrological index dAstD, predatory pressure (% of piscivorous*
 321 *fishes) and their interaction affecting y-intercept of NAS (food web capacity) and slope of NAS (food web*
 322 *efficiency). AIC, Akaike information criteria; SE, Standard error; R² corresponds to a linear regression of fitted*
 323 *versus real values; M1 means Mixed Effects Model with river reach as random factor. (*) Indicates that*
 324 *predictors were centred to avoid autocorrelation.*

325

326

327



329

330 *Figure 4. The response of y-intercept of NAS (food web capacity) and slope of NAS (food web efficiency) to*
 331 *the percentage of piscivorous is dAstD depending. Note the different grades of regression in high and low*
 332 *dAstD conditions.*

333

334 4. Discussion

335 Our results confirm the high abundance of introduced fish species in the Ebro River previously
 336 reported by Almeida et al. (2017), Aparicio et al. (2016), Caiola et al. (2014), Elvira (1995a, 1995b)
 337 and López et al. (2012) among others. When we looked at how these species were represented in
 338 the size structure, we found that, although there were very large introduced species such as the
 339 Wels catfish (*Silurus glanis*) and de common carp, the most abundant alien species were
 340 characterized for being small sized fish with very high reproduction rates such as the bleak and the
 341 mosquitofish (*Gambusia holbrooki*). More concretely, 78% of small fish (lengths below the mean
 342 length of the entire community) were alien individuals while only a 22% were native fish. This high
 343 proportion of small introduced fish is related with higher values of food web capacity (i.e. higher y-
 344 intercept of NAS, calculated from the entire fish community) and lower food web efficiency (i.e.
 345 steeper slopes of NAS, calculated from the entire fish community). Thus, according to the models, an
 346 increase of the percentage of total alien individuals was related with an increase of food web
 347 capacity (i.e. total abundance), as well as with a decrease of food web efficiency and a greater

348 proportion of small fish. The same happened with the percentage of alien-prey since the correlation
349 between total alien and alien-prey was very high ($r=0.996$). These results indicate that total and prey
350 alien fish contribute to increase the amount of energy available in the ecosystem. Presumably, if the
351 community were exclusively composed of autochthonous species, there would be fewer proportion
352 of small sized individuals (there would be no *Gambusia holbrooki* nor *Pseudorasbora parva*) and the
353 NAS would present flatter slopes and lower y-intercept values, although this is something that we
354 cannot guarantee since all the trophic dynamics would be altered and the community would be
355 totally different from the current one.

356 Among the hydrological variables that we included in the analysis, only those describing
357 variability of flow conditions were significantly related with fish community size structure. F_{H5} and
358 F_{L1} are the occurrences of high and low extreme flow events while M_{A5} gives an idea of the
359 asymmetry in the distribution of flow measurements. The others are directly linked to diel flow
360 variability, and they can be considered hydro-peaking descriptors (Bevelhimer et al., 2014) that take
361 higher values when the amplitude of flow sub-daily oscillations increase (dD , dSD , $dpath$, $dAstD$) or
362 the frequency of fluctuations is higher ($drev$). A hydroelectric power plant that operates through
363 hydro-peaking to cover daily rises of energy demand is located 4 km upstream from the station E05.
364 Although the hydro-peaking was not constant during the whole year, it persisted for long periods
365 with average ranges of flow fluctuation between $165 \text{ m}^3 \cdot \text{s}^{-1}$ (in February) and $79 \text{ m}^3 \cdot \text{s}^{-1}$ (in July). The
366 negative relationship between hydrological indices and food web capacity can be read as a decrease
367 of total fish abundance and the portion of small fish in conditions of high hydropeaking. Other
368 authors previously observed a decrease of small sized fishes and juveniles in the river banks
369 immediately downstream hydroelectric power stations that operate by hydro-peaking (Bain et al.,
370 1988; Bond and Jones, 2015; Enders et al., 2017). The causes reported to explain this decline are
371 several: Jones (2013) found a reduced population of benthic invertebrates in the margin area
372 influenced by dewatering, and Bond and Jones (2015) hypothesized that this could lead to a lack of
373 benthivorous fishes and juveniles that would move to deeper waters looking for more feeding
374 resources. Enders et al (2017) pointed to the loss of suitable habitat, increased mortality or altered
375 behaviour of small-bodied fishes as the causes of their observations, but they also pointed out that
376 desiccation and scouring of spawning locations during the incubation period could suppose a big loss
377 of individuals for the next generation. Our results further suggest that the decrease of total fish
378 abundance and of small fish at high hydropeaking conditions may have consequences on the whole
379 food web capacity.

380 Our results also showed that another biotic factor was significantly related with food web
381 capacity and efficiency: the percentage of alien-piscivorous fish. As stated for the first time by Elton
382 (1927) in the beginnings of trophic ecology, the predatory-prey interaction is size-dependent in a
383 manner that big fishes feed on the smaller ones. Thus, a big presence of piscivorous will reduce by
384 consumption, the number of small sized fishes and this fact will be reflected on the shape of body-
385 size distributions (Allen et al., 2006). Similar trends have been observed by other researchers in
386 marine environments, (Bianchi, 2000; Rice and Gislason, 1996) as well as in lakes (Emmrich et al.,
387 2011) and rivers (Murry and Farrell, 2014). But going deeper into the linkage of predation and size
388 structure, our results suggest that hydro-peaking has a multiplicative effect on this relationship, so
389 that under conditions of high flow oscillations, the predation by alien-psicivorous may become more
390 efficient, triggering to a higher modification of size spectrum parameters (Fig. 4). Under low hydro-
391 peaking conditions, the linearity between the amount of predators and size spectrum parameters
392 was lost, suggesting a low efficiency of predation. This could be explained, as Boavida et al. (2013)
393 and Bond and Jones (2015) suggested, by the action of flow fluctuation caused by hydro-peaking
394 that would force small fishes to avoid the riverbed area that is continuously wetted and dried,
395 moving to deeper waters where the encounters with larger piscivorous would be more frequent.
396 Also Bain et al (1988) proposed the increase of predation risk in shallow areas during high flows as
397 one of the most important causes of the reduction of small fish in high hydro-peaking conditions.

398 To summarize, we found that some descriptors of flow variability as well as the biotic factors
399 alien fish, alien prey and alien piscivorous, significantly affected the fish community size structure,
400 while environmental variables such as temperature, conductivity, dissolved oxygen, dissolved solids,
401 water depth, water velocity and the presence of macrophytes, did not show any significant
402 relationship with size structure. Nevertheless, other authors demonstrated that environmental
403 variables such as water temperature can deeply affect the size structure of fish communities,
404 especially when dominated by cyprinids, as is the case (Mills & Mann, 1985; Wolter, 2007). The fact
405 that our data did not reflect this relationship or others, may be due to a narrow range of variability
406 of these environmental factors in our study area and period. Therefore, it would be very interesting
407 to expand the analysis, both spatially and temporally, to detect other factors that can affect the fish
408 community size structure but that couldn't be identified in the present work.

409

410 5. Conclusions

411 This study suggest that hydro-peaking may negatively affect the populations of small fishes in
412 the lower Ebro River. Furthermore, it shows that Normalized Abundance Spectra of the fish

413 community in the lower Ebro River is highly determined by the presence of alien species, and thus
414 they have the potential to be developed as indicators of these two alterations (alien invasions and
415 hydro-peaking). In addition, although more investigation is required to better understand it, we
416 observed a possible interaction between hydro-peaking and the presence of piscivorous fish that
417 would make fish community size structure more susceptible to change by the action of predation in
418 high hydropeaking conditions. These results should be taken into account by water authorities and
419 hydropower managers when designing possible mitigation measures for hydro-peaking impacts on
420 fish, since it has been demonstrated that not only affects certain individuals, but can also alter the
421 trophic dynamics of the community.

422

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