FINAL PROJECT

Master's degree in Ecology, Environmental Management and Restoration

Effects of flow intermittence on fish fauna in Mediterranean-climate rivers

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UNIVERSITAT DE BARCELONA

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Abstract

Intermittent rivers are those that suffer a recurrent interruption of flow. These are especially abundant in the Mediterranean area and are characterized by a predictable hydrological sequence of drying and flooding. Although the fish fauna is adapted to this flow variability, it may be threatened by anthropogenic impacts and the climate change effects. In this study we first tested the response to flow intermittence and anthropogenic impacts of species density, richness and mean body length of fish communities from different Mediterranean streams and rivers using Random Forest models and Linear Mixed Models. Besides, we investigated the effects of year-to-year flow variability on community composition and population dynamics of fish fauna from intermittent streams located in a protected area as a case study, in order to understand the role of dry season refugia and recruitment. Our results showed that flow intermittence negatively affected fish density and species richness, especially when combined with the anthropogenic impacts. Contrarily, it did not affect the mean body length of the fish community. The assessment of the effects of the year-to-year variability showed that the community's composition and abundance differed between dry and wet years, although the existence of refugia allowed most of the autochthonous species to persist during the drought. In conclusion, this study provides evidence of the response of the communities in front of the flow variability and on the species-specific responses to extreme environmental conditions, necessary to improve the freshwater biodiversity conservation in front of the flow reduction due to climatic and anthropogenic causes.

Resum

Els rius intermitents són aquells que pateixen una interrupció recurrent del cabal. Aquests són especialment abundants a l'àrea Mediterrània, on es caracteritzen per presentar una seqüència predictible d'assecament, durant l'estiu, i una època de riuades, que es dóna a la tardor i a l'hivern. La ictiofauna d'aquests rius està adaptada a la variabilitat del cabal però podria estar amenaçada degut als impactes antropogènics i als efectes del canvi climàtic. En aquest estudi, en primer lloc, vam estudiar la resposta de la densitat, riquesa i mida corporal mitjana de les comunitats de peixos dels rius Mediterranis a la intermitència del cabal i als impactes antropogènics, per mitjà de models Random Forest i Models Lineals Mixtes. A més, com a cas d'estudi, vam investigar els efectes de la variabilitat interanual en el cabal sobre la composició i dinàmica de les comunitats de peixos de rius intermitents situats dins d'una àrea protegida, amb l'objectiu d'entendre el paper dels refugis i del reclutament. Els resultats van mostrar que la intermitència en el cabal afectava negativament a la densitat i riquesa de les espècies, especialment quan es combinava amb impactes antropogènics. D'altra banda, aquesta no afectava la mida corporal mitjana de la comunitat. L'avaluació dels efectes de la variabilitat interanual va mostrar que l'abundància i composició de les comunitats diferien entre anys secs i humits, tot i que l'existència de refugis va permetre la persistència de la majoria de les espècies autòctones durant el període de sequera. En conclusió, aquest estudi proporciona informació sobre la resposta de les comunitats en front de la variabilitat del cabal i sobre la resposta de cada una de les espècies davant condicions ambientals extremes, que és necessària per a millorar la conservació de la biodiversitat dels sistemes aquàtics continentals davant la davallada del cabal per causes climàtiques i antropogèniques.

Contents

1. Introduction

Intermittent rivers and ephemeral streams are those that suffer a recurrent interruption of flow, also known as seasonal, temporary, non-perennial, or episodic (Datry *et al*., 2014). This typology of rivers are present on every continent and it is estimated that they cover more than 70% of the world river network (Lowe and Likens, 2005), a number that is expected to rise due to human water uses and the effects of the climate change (Larned *et al*., 2010).

In the Mediterranean climate area, intermittent rivers are especially abundant and characterized by a predictable hydrological sequence of drying (during summer and early autumn), and flooding (during autumn and winter), whose intensity shows year-to-year variability mainly due to fluctuations in rainfall (Gasith and Resh, 1999; Bonada *et al*., 2007). During the dry season, the river can dry out completely or become a series of disconnected pools, whereas during the wet season these habitat patches are reconnected after flow resumption (Gasith and Resh, 1999). In addition, flow variability can also be spatial, as these rivers may present dry and wet sections at the same time depending on local hydromorphological conditions (Bonada *et al*. 2007; Cid *et al*. 2017). Thus, organisms that live in these highly-dynamic ecosystems face a broad range of environmental conditions, so they must present different resistance and resilience strategies to persist in these ecosystems (Bogan *et al.,* 2017).

The Mediterranean stream fish fauna inhabiting intermittent rivers is adapted to this high environmental variability, presenting life-history traits such as high recruitment, high tolerance to abiotic stressors and, in some species, the ability of moving along the river to find adequate dry season pools before the onset of the dry season (Kerezsy *et al.,* 2017; Magoulick and Kobza, 2003; Figure 1). In any case, the persistence of fish is totally dependent on the presence of suitable pools that may act as potential dry season refugia (Pires *et al*., 2014; Bond *et al.,* 2015). During an especially dry year or after multi-year drought period, in which there is no reconnection of the pools, the maintenance of fish populations relies on the quality of these refugia (e.g. dissolved oxygen, water temperature) and the species recruitment rate (Magalhães *et al.,* 2007).

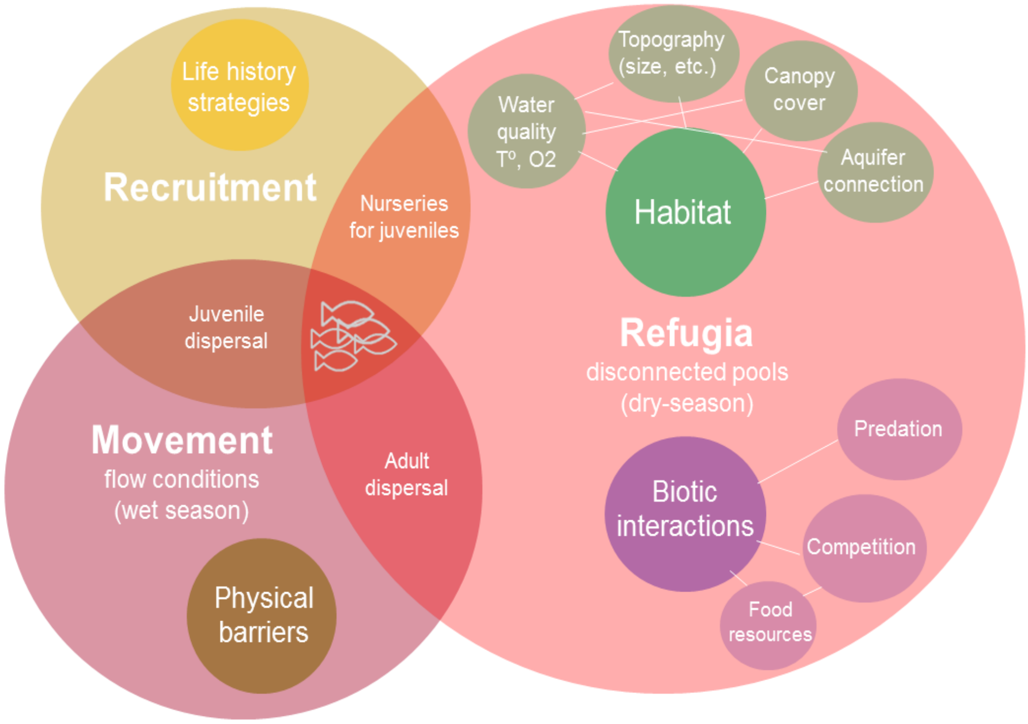

Figure 1. Main factors for the persistence of fish fauna in Mediterranean intermittent rivers. The role of refugia is especially important during the dry season and may serve as potential source of fish colonizers after flow resumption, contributing to adult dispersal (movement). The local conditions of refugia during the dry season (habitat, increased biotic interactions) may also affect recruitment.

The persistence of fish in intermittent streams and rivers can also be affected by anthropogenic impacts. These commonly consist of hydrological (water extraction and flow perennialization), physical and chemical (e.g. habitat degradation, construction of barriers that interrupt the longitudinal continuity of the river, pollution) and biological alterations (e.g. allochthonous species introduction, native species extirpation), that in many cases have been observed to cause the reduction and/or disappearance of the native species (Chiu *et al.,* 2017). For instance, in Mediterranean streams and rivers, habitat degradation and invasive species have been described as the main factors causing the alarming biodiversity decline that has been observed in the last decades, which has been especially critical for the fish species and its most diverse family, the cyprinids (Hermoso *et al.,* 2011; IUCN, 2009). In this context, it is essential to better understand the effects of flow intermittence and anthropogenic impacts on freshwater biodiversity and the interaction between them, in order to increase our prediction ability and improve the conservation management in intermittent streams.

Protected areas are an important tool in conservation although in most of the cases they have not been designed for protecting freshwater biodiversity (Carrizo *et al.,* 2017), and even less for protecting freshwater biodiversity in intermittent rivers (Acuña *et al.,* 2014; Lake *et al.,* 2017). Traditionally, most protected areas have been located in isolated places with a low level of human impacts. In the case of river systems, this usually corresponds to the headwaters, where biological communities are already characterized by presenting low species diversity and reduced abundances compared to the lower stretches of the streams (Meyer *et al.,* 2007; Richardson and Danehy, 2007). Besides, these populations are usually spatially isolated due to the physical barriers present along the rivers, which may provoke increased risk of extinction due to genetic or stochastic effects and the loss of recolonization and demographic support from downstream populations (Letcher *et al.,* 2007). In the case of the intermittent streams, the identification and the protection of the dry season refugia has been already observed to be particularly important (Hermoso *et al.,* 2013), and it may be critical at headwaters. Nevertheless, with the expected increase in the intermittence of Mediterranean river's flow due to the climate change and water use, the species settled in these habitats are expected to suffer a reduction of their distribution area that, without the adequate protection measures, may lead them to extinction (Markovic *et al.,* 2014; Carrizo *et al.,* 2017).

In this study, we first investigated the response of the fish from different Mediterranean streams and rivers to flow intermittence and anthropogenic impacts using the species abundance, richness and mean body length as indicators. On the one hand, we expected that flow intermittence would be the main factor influencing fish fauna metrics (Benejam *et al.,* 2010; Merciai, 2016), and that this would be especially important in headwaters (Meyer *et al.,* 2007; Richardson and Danehy, 2007). On the other hand, we also expected an interaction between flow intermittence and anthropogenic impacts, the latter exerting a lower effect under flow intermittence because the intermittent streams biota is more tolerant to harsh conditions than the inhabitant of perennial streams (Boulton *et al.,* 2000). Second, we tested for the effects of year-to-year flow variability on community composition and population dynamics of fish fauna from intermittent streams located in a protected area as a case study, in order to understand the role of dry season refugia and recruitment in fish conservation.

2. Materials and methods

2.1. Effects of the flow intermittence and anthropogenic disturbances in Mediterranean fish

2.1.2. Study sites and dataset

In this section, we used data collected during the LIFE+ TRivers project (TRivers, 2014). The sampling took place during spring, summer and autumn 2015 in 25 sites across a gradient of flow intermittence, altitude and human impacts. Sites ranged from 6 to 1100 m.a.s.l. and drained over calcareous geology.

Fish were sampled by electrofishing using a portable unit which generated up to 200 V and 3 A pulsed D. C in an upstream direction. After caught, all fish were anaesthetized using tricaine methanesulfonate (MS-222) and sized in length (mm). Next, the wet habitat was quantified and other measures were obtained: the QBR index (Riparian Forest Quality; Munné *et al.,* 2002), the aquatic state (i.e. disconnected pools or flow *sensu* Gallart *et al.,* 2017), the discharge and a series of variables that describe the river's physicochemical characteristics (temperature, pH, dissolved oxygen and conductivity). In addition, the number of present impacts described in Sánchez-Montoya *et al.* (2009) of each site were recorded. The TREHS (Temporary Rivers Ecological and Hydrological Status) open access software was used to classify each site as perennial or intermittent. TREHS provides information on the degree of flow permanence of a site and its hydrological status (i.e. natural or altered flow regime) based on historical data, models, interviews or observations obtained from *in situ* inspections or from aerial or terrestrial photographs (Gallart *et al.,* 2017). TREHS was used to obtain the coefficients Mf (Flow persistence), Mp (Pool-state persistence) and Md (Dry-state persistence), which integrates information about the intermittent flow regime of the streams over the years. The degree of flow intermittence during the study period was obtained from temperature data loggers installed at each site from April 2015 until December 2015 to obtain the following quantitative measures of flow intermittence: (1) the number of days the stream had been formed by disconnected pools before sampling (variable named "pools"), (2) the total number of days the stream was formed by disconnected pools during the study period ("pools2"), (3) the number of days the stream had been completely dry before sampling ("dry"), (4) the total number of days the stream was completely dry during the study period ("dry2") and (5) the total number of days the stream did not flow during the study period ("Zero flow days"), which equals to the sum of pools2 and dry2.

From the fish field data, we obtained the richness (as the number of species in the community), the total fish density and the mean body length (BL) of the catch and of autochthonous and autochthonous cyprinids (Table A1.1 and A1.2). Densities were calculated by dividing the number of captured individuals by the sampled area and corrected by the species capturability (Table A1.3; ACA, 2006). The list, abbreviation and description of all the predictors and variables considered are available at the Table A1.4.

2.1.2. Data analysis

The data analysis was carried out following the protocol described in Feld *et al.* (2016). The preliminary exploration of the data matrix (Table A1.1 and A1.2) led to the elimination of the outliers and the transformation of some of the variables to meet normality. Then, the predictor variables were standardized. The VIF (Variance Inflation Factor), the observation of the scatter plots between the variables and the Pearson correlation values (Table A1.5 and A1.6) were used to select the most informative predictors and therefore, avoid collinearity and model overfitting.

The selected explanatory variables were included in the Random Forests (RF) models, which were used to explore the importance of the predictors on the response variables. This technique consists on the construction of an ensemble predictor by averaging over a group of binary trees. Each of these trees are created from an independent subsample of the data, where at each node of the tree a randomly selected subset of variables are chosen as candidate variables to split on (Ishwaran, 2007). This makes this method suitable for modeling responses that show complex relationships and to perform better than other regression techniques when facing multicollinearity and low sample size (Breiman, 2001).

The RF algorithm gives the percentage of the explained variability and calculates the prediction error, obtained by testing the prediction on the data that was not selected for each tree construction. The variables are ranked by their Variable Importance (VIMP), calculated as the difference between the prediction error when this variable is deleted compared to the prediction error with the original predictor. The marginal effect of each predictor can be plotted, and represents the change in the response variable when the value of the predictor varies while the others are kept in their mean value.

We chose the most important predictors according to our hypothesis and to the RF results and used them to fit a Linear Mixed Model (LMM). This kind of models allow to assess the effects of fixed and random effects together and are especially useful when repeated measures of the same statistical units (e.g. subjects, groups) are taken (Cnaan *et al.,* 1997). The type of model that was fitted is classified as a random intercept model, which is characterized by allowing the formula intercept to vary between the different statistical units, which are taken as random factors, that in our case, correspond to the streams (variable named Code_Site). In addition, in order to test our hypothesis, in the LMM we also considered the interactions between the zero flow days and the altitude and between the zero flow days and the number of impacts. Next, the R function *dredge* was used to test all the possible models with the included variables and to rank them according to their AIC (Akaike Information Criterion), which measures the goodness of fit with a penalty for model overfitting. Then, the R function *model.avg* selected the best models from the *dredge* output and created the average model, calculating the predictor's coefficients and p-values. The coefficients of the model and its components indicated the existence and type of interaction, being this additive, synergistic, antagonistic or opposite (Feld *et al.,* 2016). Finally, the goodness of fit was calculated as the weighted R^2m (R^2 considering only the fixed effects) and the R^2c (R^2 of the fixed and random effects together) of the models used to construct the averaged one.

All these statistical analyses were carried out in in R 3.4.3 (R. Core Team, 2017). The VIF calculation was done with *usdm* package (Naimi *et al.,* 2014); the Random Forest analyses were performed using the *RandomForestSRC* package (Ishwaran and Kogalur, 2018) and the Linear Mixed Models were fitted with *lme* function from the *nlme* package (Pinheiro *et al.,* 2018).

2.2. A case study of Mediterranean fish populations from intermittent streams in protected areas

2.2.1. Study area and field work

This work was carried out in three headwater streams located in Sant Llorenç del Munt i l'Obac Natural Park (Catalonia, Northeastern Spain) (Figure 2): the Castelló stream, which belongs to the Besòs River basin, and the Nespres and the Talamanca streams, from the Llobregat River basin. These water courses present a typical Mediterranean climate with irregular and intense precipitation, mostly concentrated in winter but also in spring and autumn, whereas summer tends to be very dry (Rodríguez Lozano *et al.,* 2016). The vegetation in this area is dominated by *Quercus ilex L.* and *Pinus* *halepensis Miller* and the geology is mainly karstic, with highly permeable substrate. Therefore, the effects of the rainfall in the rivers flow can disappear in a short period of time (Bonada *et al.* 2007). Apart from the natural temporal fluctuation, the flow in the river network of the Park is also considerably modified in some parts by the existence of dams and the water extraction for different human activities (Aparicio *et al.,* 2000).

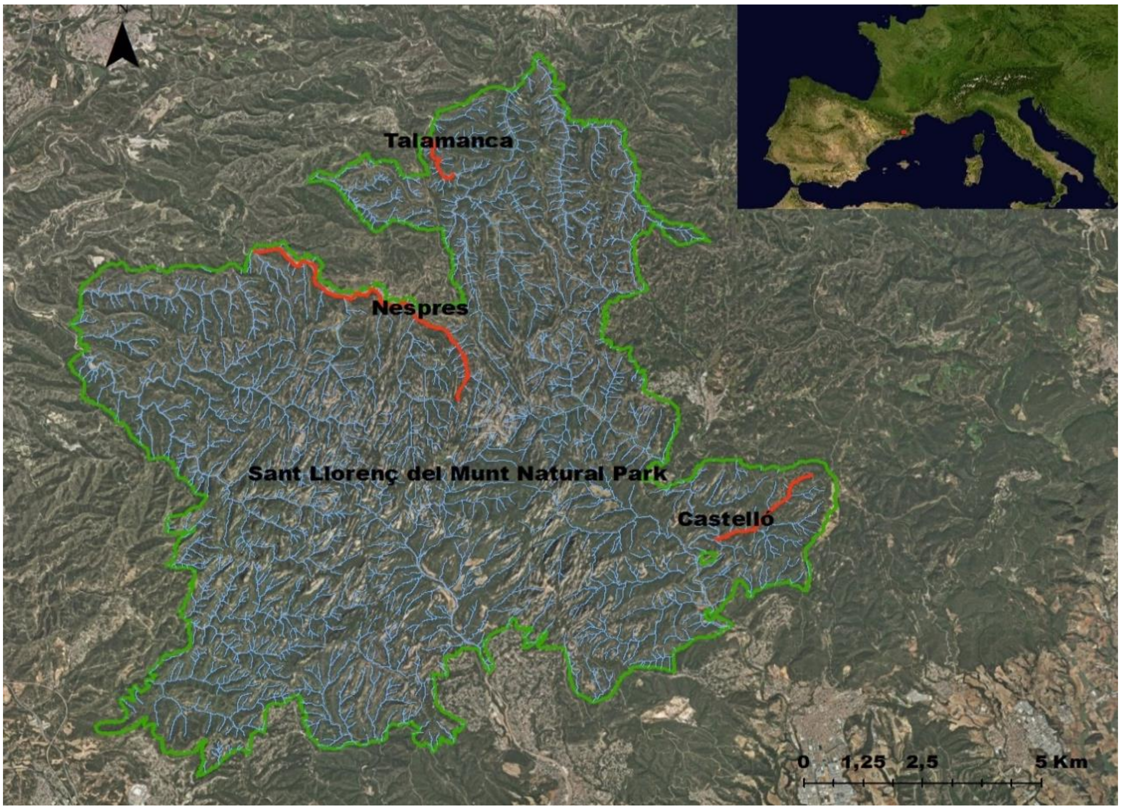

Figure 2. Geographical situation and limits of the Park and the studied streams (in red).

The field work took place in July 2016, which was dry year within a four-year drought period, and July-August 2018, which was the first wet year after the drought and allowed the flow resumption (Figure A2.1). It consisted in the fish sampling of a representative section for each stream (70 meters long in Nespres, 80 meters in Castelló and 110 m in Talamanca) (Figure A2.2). These stretches were mainly dominated by bedrock as substratum, included zones with different degree of solar exposition and were delimited by physical barriers (i.e. falls, steep riffles or dense reed beds, roads), that may prevent fishes to move upstream.

The selected stream sections were sampled using portable electrofishing equipment. Once the individuals were caught, they were anaesthetized using tricaine methanesulfonate (MS-222) and then they were sized in length. This procedure was performed out of the water so it had to be quick to avoid the death of the individuals.

The fish were kept in an aerated bucket until they recovered and were released at the same point they had been captured.

In order to quantify the available habitat for the fish fauna, we measured the width and depth at three evenly spaced points at every meter of the stream section. Physicochemical conditions (temperature, dissolved oxygen, conductivity and pH) were recorded using a multi-parameter sensor and habitat characteristics were described, including the type of substrates, depth, presence of macrophyta and level of solar exposure. We also recorded the aquatic state of the section (i.e. flowing or pools) and when flow was present, discharge between pools was measured.

2.2.2. Dry-wet year comparison of the fish communities and refugia characterization

The number of sampled individuals were corrected by their capturability (p) for each species in this region, obtained from ACA (2006). In 2016, as the pools were very small, we considered that the fish had no opportunity to hide or escape, so the p was considered equal to 1. The density of each fish species was calculated for each sample dividing the number of individuals by the sampled area, but was not used for the comparison as the results are influenced by the variation of the wet area between samples. Lastly, the body length measures were used to calculate the size-diversity index, using the Shannon-Wiener formula, and to construct the size distribution graphics of each population, using only the individuals that were captured (no correction by the capturability).

The stream width and depth measures were used to create a digital elevation model (DEM) with the Geographical Information System software ArcMap 10.6 (ESRI, Redlands, California, USA) that allowed us to represent the streams morphology and to calculate the water volume and surface area contained in the study area in each sampling. The physicochemical and habitat conditions were also compared between years. The values from the year 2016 were taken in each pool present in the section, except for the Nespres stream, where only one value was available. Only one measure was taken in the year 2018's sample because as the stream was flowing, it was considered homogeneous for the measured variables.

For the characterization of the fish refugia during drought events, pools within the sampled sections were classified by their size (<10, 1-100, >100 m^2), depth (1-15, 15-50, >50 cm), the solar exposure (shadow, partial, exposed), the type of substrate present (bedrock, rocks, gravel, silt), the presence of macrophytes or algae, and the number of fish species present.

3. Results

3.1. Effects of the flow regime on total fish density, species richness and body length.

The random forest model results showed that for the total density of fish, the predictors used in the model explained the 45.78% of the variance. The top important variables were the days the river stood dried during that year (dry2), the number of days it was formed by disconnected pools before the sample (pools), the dissolved oxygen percentage and the total number of days with zero flow (Table A1.7 and Figure A1.2). The marginal effect plots (Figure 3) show that the variables dry2, pools, zero flow days and the altitude indicate a similar pattern, with fish density being stable until a threshold value was reached. Fish density did not vary with the number of impacts and Mp, but clearly decreased with the dry state persistence variables (Md, dry).

For the density of autochthonous fish species, the model explained the 60.21% of the variance, being the days without flowing (Zero flow days), the allochthonous species abundance (CPUEaloc) and the dry state variables Md and dry2 the top predictors (Table A1.7 and Figure A1.3). The fish density decreased quickly with the variable Zero flow days, with the abundance of allochthonous species and with the Md (Figure A1.5). The predictor number of impacts and pools did not show a clear effect while the response variable increased with altitude and reached a plateau. Finally, the Mp did not show great variations, except for a smooth decrease at intermediate values. The same results were observed for the density of autochthonous cyprinid species (Figure A1.6), with the exception that models showed a higher explained variance (72.37 %) and also pointed the altitude (Alt_m) as a relevant predictor (Table A1.7 and Figure A1.4).

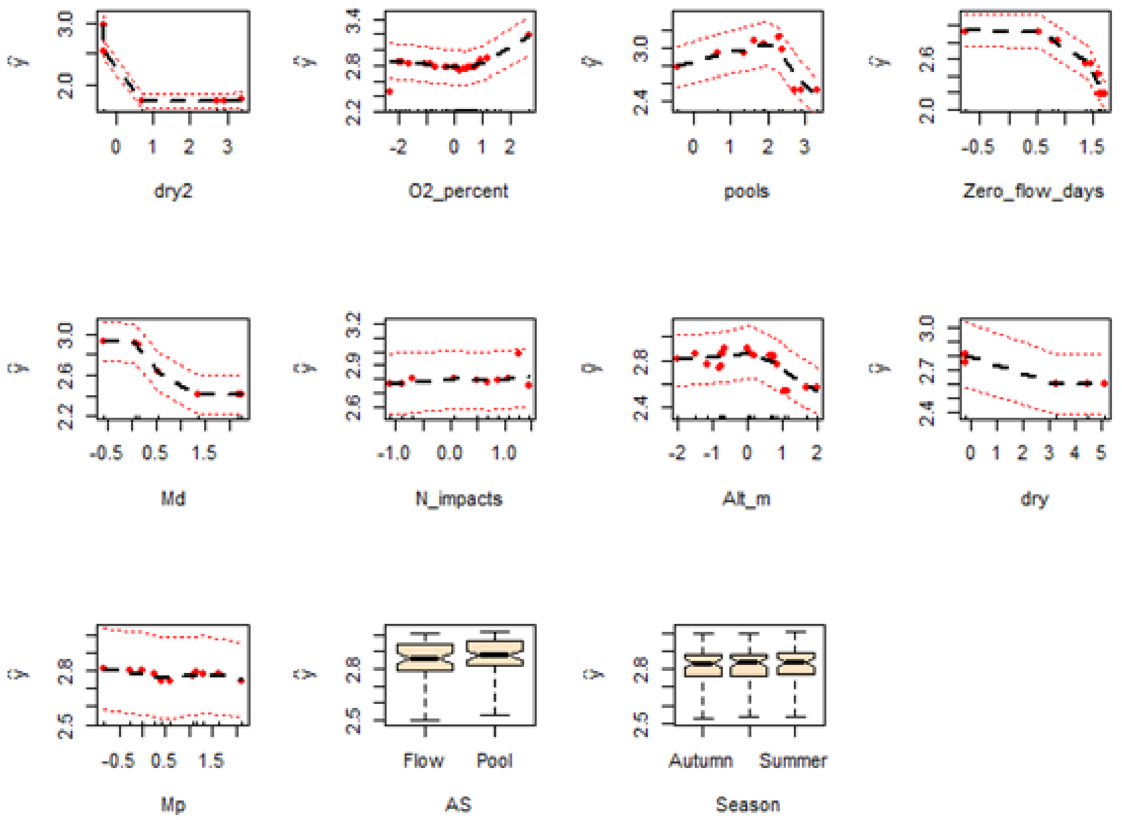

Figure 3. Marginal response plots of the total fish density to the different predictors included in the RF.

For species richness, the RF models results showed that the predictors explained a high percentage of the variance (57.29% for total, 61.16 % for autochthonous and 72.82 for autochthonous cyprinids) (Table A1.8). In the case of the total richness and autochthonous species richness, the most important variables were the zero flow days and the dry-state persistence (Md) (Figures A1.7 and A1.8). The first one was also important for the richness of cyprinids, together with altitude (Figure A1.9). These similarities between the models also were shown in the marginal effect plots from RF (Figure 4, A1.10 and A1.11). In the three cases, the richness steeply decreased with the zero flow days and with the Md. The response tended to increase with the altitude and then decreased again at higher values, more smoothly for the cyprinids. The impacts and the days the river was in pool-state before the sample (pools) did not show a clear effect, whereas Mp seemed to increase the richness, showing a tipping point at intermediate values. For the autochthonous and the cyprinids, the presence of allochthonous fish in low densities did not provoke any effect in the response, but it decreased quickly at a threshold value of the predictor.

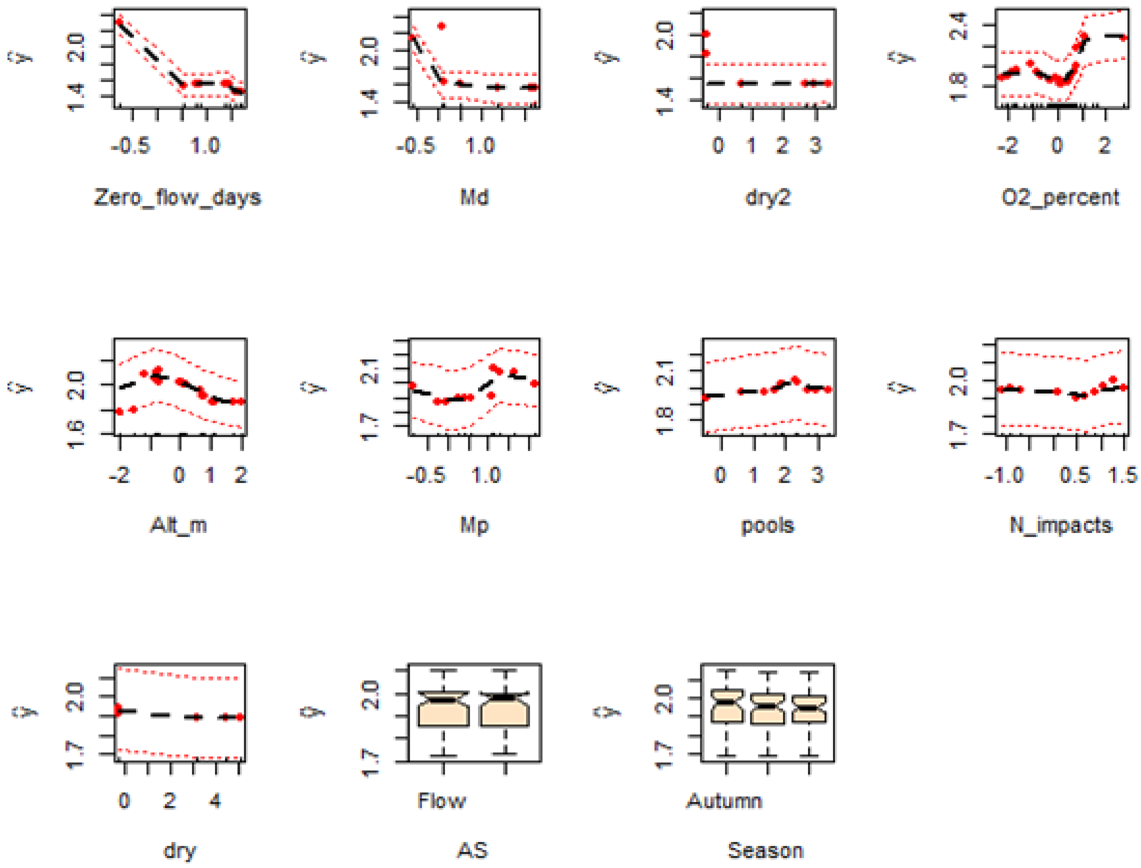

Figure 4. Marginal response plots of the total richness to the different predictors included in the RF.

For body length, the explained variance was 32.05% when considering the entire fish community and 12.63% for the autochthonous species. In this two cases, altitude, Mp and Md were the most important predictors (Table A1.9 and Figures A1.12, A1.13). The variance explained when considering the mean body length of autochthonous cyprinids was 16.34%, being altitude and the Md the top variables (Table A1.9 and Figure A1.14). The marginal effect plots for the total species (Figure 5) showed that the mean BL of the community increased with the altitude, but it was the opposite when only considering the autochthonous and cyprinid species (Figure A1.15 and A1.16). The increase on the Mp value of the site provoked a reduction of the BL of the total species until a threshold value, when it increased steeply. Contrarily, for the autochthonous and cyprinids, the Mp did not show clear patterns. The number of impacts had a negative effect on the mean BL of the community and mean BL of cyprinids but no clear patterns were observed for the BL of autochthonous. For the total, autochthonous and cyprinids, the richness did not vary with the pools and dry2 and decreased with the Md values, especially after a threshold value was exceeded.

Finally, the presence of allochthonous species (CPUEaloc) caused a steep increase on the autochthonous and cyprinids mean body length, although it decreased when the predictor reached higher values.

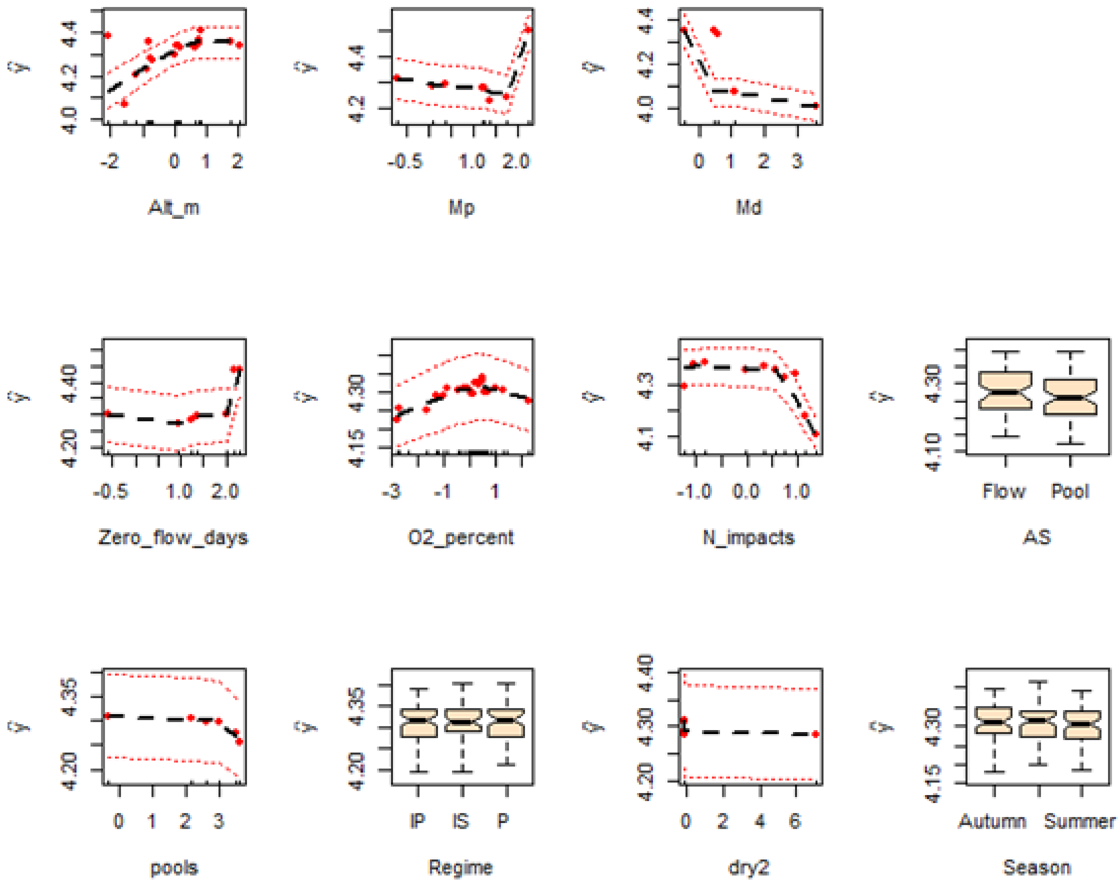

Figure 5. Marginal response plots of the total mean BL to the different predictors included in the RF.

The resulting averaged model for the total species density (Table 1) when using linear mixed modeling showed that the variables zero flow days and Md had a significant negative effect on the response variable and that the level pools from the Aquatic State had a positive effect (R^2m=0.59 and R^2c= 0.62). The tested interactions between the altitude and the zero flow days and the zero flow days with the number of impacts were not significant. Furthermore, for the autochthonous species, the predictors zero flow days and Md were found significant, both provoking a negative effect on the response variable. The Mp, which had a positive effect on the density, was also found statistically relevant. The model showed a higher goodness of fit (R^2m =0.69 and R^2c=0.79) than the model for the total species density. The interaction between the zero flow days and the impacts was significant, whose coefficient indicated that the relation between these two predictors was synergistic. Finally, for the autochthonous cyprinids, the significant predictors were Md and zero flow days, with negative effect on the fish density, and Mp and the Aquatic State, with a positive effect. The interaction between the zero flow days and the number of impacts was also significant and indicated a synergistic relation between them.

The models for richness indicated that the two considered interactions were significant for the three of them. The interaction concerning the zero flow days and the number of impacts described a synergistic relation between the predictors, whereas the interaction between the zero flow days and the altitude indicated an antagonistic effect for the total and autochthonous and an opposing effect for the richness of cyprinids. In addition, the total richness model indicated that the significant predictors were the Md, the zero flow days and the number of impacts, with a negative effect on the response, and Mp, with a positive sign (R^2m= 0.75 and R2c=0.75). Regarding the autochthonous richness model, Mp, Md, zero flow days and the number of impacts were significant (R^2m= 0.76 R^2c=0.87). All these had a negative effect on the richness value, except for the Mp. For the richness of autochthonous cyprinids, the significant predictors were the same the model for the autochthonous species but with higher goodness of fit (R^2m = 0.81, R^2c of 0.95).

The results of the linear models for the BL indicated that for the total species and cyprinids no predictor was statistically relevant. For the autochthonous species length, the altitude, with a negative effect, and the interaction between the impacts and the zero flow days, which was synergistic, were significant although the interaction p-value slightly exceeded the significance level of 0.05 (R^2m =0.43 and R^2c= 0.55).

Table 1. Resulting averaged linear mixed models coefficients. p-values: *** between 0 and 0.001. ** between 0.001 and 0.01. * between 0.01 and 0.05. + between 0.05 and 0.1. – Predictors not included in the global model for this response variable. ^ Predictors that were considered in the global model but were not selected by the model average function because of low significance (the coefficients were not calculated). R^2m represents the R^2 of the fixed effects. R^2c represents the R^2 of the model. The type of interaction is indicated as: ANT (Antagonistic) and SYN (Synergetic) and OP (Opposing).

	Int.	Md	ZFD	N Imp	Alt_m	Mp	CPUE aloc	AS (Pool)	ZFD*N Imp	ZFD*Alt	R^2m	R^2c
Rich Total	2.0	-0.9***	-1.14***	-0.38**	-0.16	0.86***	-	-0.07	-0.36** SYN	0.39** ANT	0.75	0.75
Rich aut	1.55	-1.01***	-0.91***	-0.39*	-0.02	0.99***	-0.01	-0.05	-0.52*** SYN	0.41** ANT	0.76	0.87
Rich Cyp aut	1.01	-0.47***	-0.55***	-0.2*	0.06	0.44***	-0.004	0.006	-0.18* SYN	0.25** OP	0.81	0.95
Density Total	2.65	-0.73***	-0.54**	0.08	-0.08	0.09	-	1.08**	0.005	0.03	0.59	0.62
Density aut	2.3	-0.99***	-1.09***	-0.29	0.33	0.85**	-0.1	0.45	-0.47* SYN	0.05	0.69	0.79
Density Cyp aut	2.24	-0.94***	-1.1***	-0.26	0.4	0.6*	-0.02	0.55**	-0.46* SYN	0.29	0.77	0.93
BL total	4.32	-0.26	0.005	-0.02	-0.0005	0.05	-	^	^	^	0.17	0.72
BL aut	4.45	-0.18	0.16	0.013	-0.33**	-0.11	0.05	-0.17	0.22 + SYN	0.001	0.43	0.55
BL Cyp aut	81.27	-5.14	3.03	-1.1	-0.09	1.02	1.89	-12.9	^	^	0.12	0.56

3.2. A case study of Mediterranean fish populations from intermittent streams in protected areas: wet-dry year comparison and identification of potential refugia

The results showed that the fish abundances were higher in the wet year than in the dry one, although the relative abundance of each species in each stream changed. In Talamanca and Castelló the autochthonous species expanded, while in Nespres the two native fish decreased their abundances.

Concretely, in Talamanca stream the only species detected in both sampling periods was the Iberian Redfin Barbel *Barbus haasi* (Table A2.2 and Figure 6). In the dry year, only two individuals were captured, both situated in the only persistent pool. In the wet year, the estimation indicated that 204 of them were present all along the section. In addition, the captured individuals size distribution increased drastically in the 2018 (Figure 6), with higher values of the size-diversity index, the mean, the minimum and the maximum size. In the dry year, Castelló stream was home to populations of the Mediterranean Barbel (*B. meridionalis)* and the invasive Common Sunfish (*Lepomis gibbosus)* and Eastern Mosquitofish (*Gambussia holbrooki)*, with 52, 16 and 2 captured individuals, respectively. In the wet year, only the Barbel was present in this section of the stream. The number of its individuals captured increased compared to the dry year although, as it could also be seen in the size-distribution graphics (Figure 6), the population seemed to be formed by smaller individuals (lower mean and minimum size) and to be more homogenous in respect of the body length (lower size-diversity index). In Nespres stream, we found individuals from *B. haasi, the Catalan chub (Squalius laietanus)* and the invasive *minnow (Phoxinus sp)* in the dry year*.* The most abundant species was the Mediterranean barbel, with 23 individuals captured, followed by the minnow (5 individuals) and the Catalan chub, with only two individuals. The latter species was not captured in the wet year, whereas the number of *B. haasi* dropped from 23 individuals to 8 and *Phoxinus sp.* multiplied its numbers by almost 24 (from 5 individuals to 118). The size distribution of the captured individuals also changed between the wet and dry year (Figure 6), as the size of the minnows increased (higher mean, minimum and maximum size) and all the remaining Mediterranean barbels were adults (above 102 cm long).

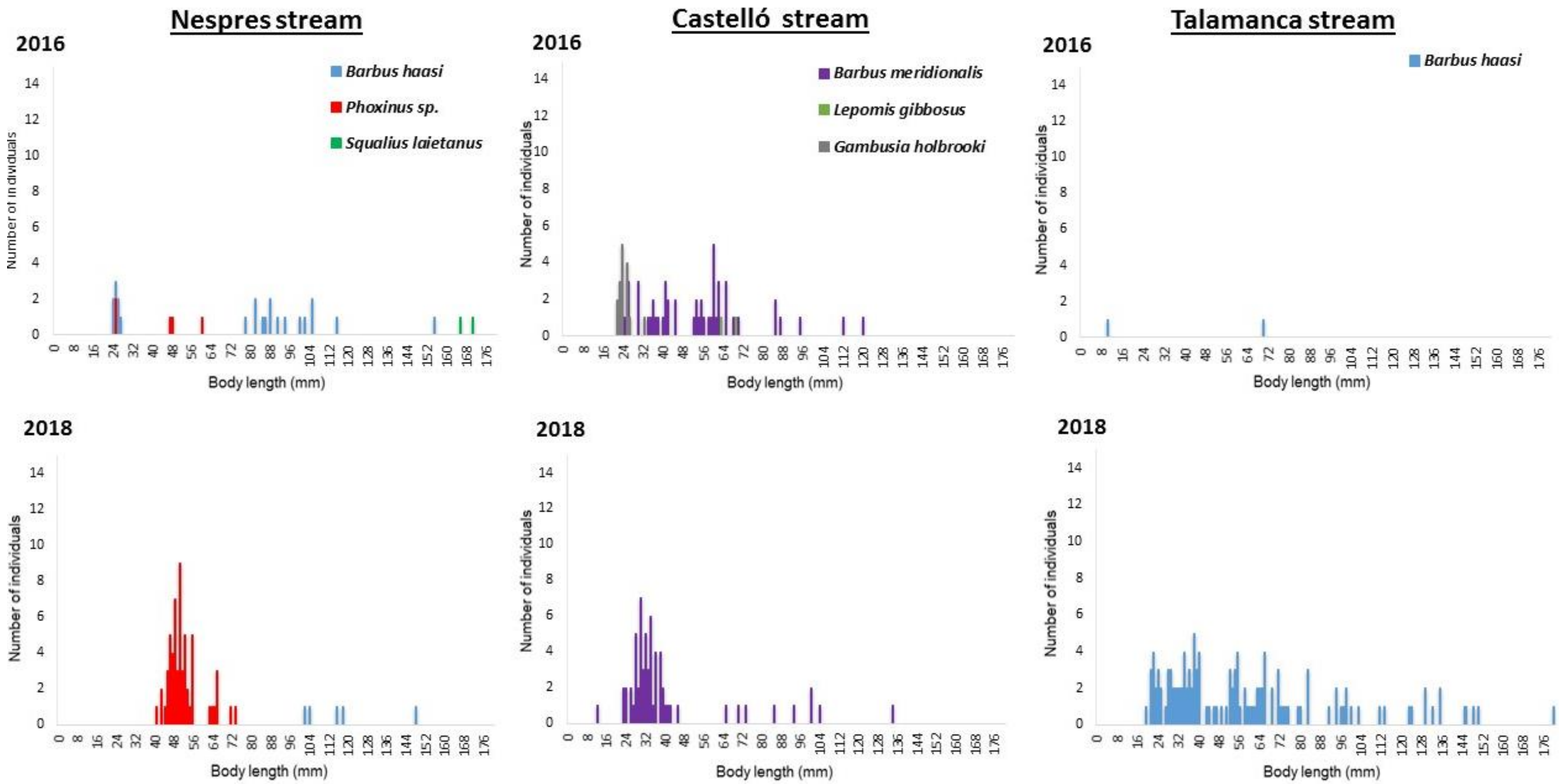

Figure 6. Size-distribution graphics of the captured fish individuals of each stream in a dry year (2016) and a wet year (2018).

The results of the habitat characterization showed a great habitat expansion from the dry year (i.e. 2016) to the wet year (i.e. 2018) and the transition from a pool-state stream to a flowing one (Table A2.1 and Figure A2.3). The reduction of the temperature and the increase of the dissolved oxygen were observed: the temperature values ranged from 18.3 to 22.8 ºC in the disconnected pools from 2016 and from 10.6 to 18.8 ºC in 2018 when all habitats were connected. In the case of the oxygen, the values ranged from 1.98 to 8.39 mg/L in 2016 and from 7.02 to 8.99 mg/L in 2018.

In the summer of 2016, four pools were found in Castelló. These all were small sized (<10 m^2) and were similar in respect to the type of substrates present (Table 2). Regarding the depth, two of them had values above 50 cm, one between 15 and 50 and one between 1 and 15 cm. This last one was also the only that had no type of cover to avoid the insolation, had presence of macrophyta and also was the only one to present allochthonous species. In Nespres, three pools were sampled, which were deep (>50 cm), with absence of macrophyta and small-sized (<10 m^2). The predominant substrate in these pools was bedrock. The solar exposure grade did not separate the pools with invasive species from the ones without as it happened in Castelló stream. Finally, in Talamanca the only sampled pool was characterized by high depth (>50 cm), small area (<10), the presence of bedrock, rocks and gravels and to be partially covered against the solar radiation. In this case, algae presence was also described. In general, pools maintaining native species during the dry year were those with elevated depth (>50 cm), partial solar exposure and with of presence bedrock.

Table 2. Characteristics of the sampled pools during the summer of 2016. Substrates: Bedrock (BR), rocks (R), gravel (G) and silt (S).

Pool ID	Area (m^2)	Substrate	Solar exposure	Macro-phyta	Depth (cm)	Fish species
Castelló						
B1	<10	BR+S	Partial	No	>50	*B.meridionalis*
B2	<10	BR+R+G+S	Partial	No	>50	*B.meridionalis*
B3	<10	BR+R+G+S	Partial	No	15-50	*B.meridionalis*
B4	<10	BR+R+G+S	Exposed	*Chara sp.*	1-15	*B.meridionalis* *L.gibbosus* *G. holbrooki*
Nespres						
B1	<10	BR+R+G	Exposed	No	>50	*B. haasi* *Phoxinus sp.*
B2	<10	BR+R+G	Partial	No	>50	*Phoxinus sp.* *S.laietanus*
B3	<10	BR+S	Partial	No	>50	*B.haasi*
Talamanca						
B1	<10	BR+R+G	Partial	Algae	>50	*B.haasi*

4. Discussion

4.1. Effects of the flow intermittence and anthropogenic disturbances in Mediterranean fish

Flow intermittence was the main factor influencing richness and fish density in our study. The effects flow intermittence on the fish community, represented by the zero flow days, were generally higher in stream affected by anthropogenic impacts, contrarily to our hypothesis, in which we expected that fish inhabiting intermittent streams would be more adapted to environmental stressors. In addition, the response of fish fauna to flow intermittence was not stronger at higher altitudes as we expected.

In agreement with other studies (Lake, 2003; Benejam *et al.,* 2010; Mas-Martí *et al.,* 2010), we observed that the stream's diversity and fish density greatly depends on the stream flow intermittence. We found that both variables related to the stream flow regime (Md and Mp) and to the hydrological conditions during the study year (i.e. zero flow days) were the most relevant. For instance, species richness and density decreased when the frequency of drying (Md) was high (Magoulick and Kobza, 2003). The effects of increased Md were critical at a certain threshold, indicating that there is a drying frequency where the capacity of recolonization and re-establishment of fish communities is no longer possible (Davey and Kelley, 2007). Notwithstanding, we found that pool persistence (Mp) is crucial to maintain autochthonous fish species populations. This agrees with Lake (2003) and Beesley *et al.,* (2010), which demonstrated that those streams that do not dry completely and some pools persist during the drought, may be able to maintain the fish populations during this period. Thus, the reduction in richness and fish density observed with increased number of zero flow days, which includes the days the stream stood dried or in disconnected pools, could be related to the fish disappearance that occur when the stream dries out (Magoulick and Kobza, 2003) or to the reduced fish survival due to the gradual deterioration of the persistent pools environmental conditions as the time since disconnection increases (Pires *et al.,* 2010; Woefle-Erskine *et al.,* 2017). Lastly, concerning the body length, it did not seem to be related to flow intermittence predictors, in disagreement with other studies conducted in Mediterranean streams (Merciai *et al.,* 2017).

Regarding altitude, although we did not observe a single effect in the reduction of richness and fish density, we observed an interaction with flow intermittence, having effects on species richness. On the one hand, an antagonistic effect was observed for the total and autochthonous richness, meaning that the negative effects of the flow intermittence on the richness are weaker at higher altitudes. This could be explained by the fact that the number of species in headwaters is generally already lower compared to downstream parts (Meyer *et al.,* 2007; Richardson and Danehy, 2007). On the other hand, for the cyprinids, the interaction between altitude and zero flow days had an opposing effect, indicating that the flow intermittence had a negative effect on the cyprinid richness at low altitude but a positive effect at the headwaters. This could be partially caused by a bias in our data, as the majority of studied streams situated at low altitudes did not present autochthonous cyprinid species, and also because a higher degree of flow intermittence was observed at higher altitudes. Regarding the fish mean body size for the autochthonous species, we observed a decrease with higher altitude. As found by Parra *et al.,* (2009) for brown trout (*Salmo trutta),* smaller body length values could be related with lower water temperatures which, even in disconnected pools, are lower at higher altitude. This reduction of the mean body size of the fish community with the altitude could also be related to the presence of large-sized species in the study sites with lower altitude. For instance, *Anguilla anguilla*, which was the bigger species sampled, is usually only found at downstream zones because of its catadromous behavior (spawns in the sea and grows up in freshwater streams) and the abundant presence of barriers that may cause its upstream migration failure (Feunteun, 2002).

Anthropogenic impacts were an important factor negatively affecting fish species richness in Mediterranean streams, showing a synergistic effect with flow intermittence on fish population's richness and autochthonous density. In agreement with Bogan *et al.,* (2017) and Merciai (2016), this can be related to the lower resistance and resilience capacity of the fish species when they are already under physiological stress. We observed the same pattern for body length but only for the autochthonous species, which could be explained by the increased mortality rates in the impacted intermittent streams and the consequent lower probabilities for the fish to reach large sizes (Merciai *et al.,* 2017).

Finally, the presence of allochthonous species was a leading factor negatively affecting the autochthonous species richness and density in Mediterranean streams as had been stated in Hermoso *et al.,* (2011). Nevertheless, our study indicated that the mean body length of the autochthonous populations increased with the presence of these species. One possible explanation to this pattern could be that the competence between the native and the allochthonous species can cause recruitment failures or higher mortality in juveniles, resulting in native populations mainly formed by adults (Ribeiro and Leunda, 2012; Mills *et al.,* 2004).

4.2. A case study of Mediterranean fish populations from intermittent streams in protected areas

Our results showed that the fish communities between a dry and a wet year differed in their composition, due to differential effect of the flow conditions on the different species (Bernardo *et al.,* 2003). For instance, in Castelló stream, we observed that in the wet year all the allochthonous species that were present during the dry year disappeared, whereas the native species *Barbus meridionalis* persisted. This agrees with Marchetti and Moyle (2001), which suggested that an increased peak flow during the floods season and the flow maintenance during the dry season favor the native species and may expel the allochthonous. In this case, this could be linked to the ecological requirements of the allochthonous species found in Castelló, i.e. *Gambusia holbrook*i and *Lepomis gibbosus*, which have a preference for stagnant waters with elevated temperature (Aparicio *et al.,* 2016), circumstances that are not met during the flow conditions. However, in Nespres stream, we observed an opposite pattern. The autochthonous chub disappeared and the *Barbus haasi* decreased its abundance. This could be a result of the continued water scarcity conditions that took place within the drought period, which produce great negative effects in their survival and recruitment (Merciai *et al.,* 2017; Magalhães *et al.,* 2007). In addition, the increased connectivity between the pools caused by the flow resumption (Fausch *et al.,* 2009) could have favored the expansion of the invasive *Phoxinus sp*., which has high recolonization potential (Aparicio *et al.,* 2016).

In Talamanca stream, populations of *Barbus haasi* seemed to have recovered from the drought, deducted from the great increase in number of captured individuals and the high abundance of small-sized individuals. This is consistent with the results from Magalhães *et al.,* (2007), who stated that the endemic Mediterranean fish species have adaptations to recover quickly from the drought once the conditions improve. In addition, the recolonization of the upstream rewetted section above the refugia was observed, which, according to Arthington and Balcombe (2011) and Pires *et al.,* (2014), responds to the objective of enhancing the probabilities of finding new high quality habitats and/or permitting the avoidance of predators and other stressors. The great difference in the fish abundance between years could also be related to sampling aspects (e.g. differences in capturability) or to the presence of other potential refugia not considered in the present study. For example, despite the existing physical barriers, fish could have moved upstream from an artificial pool located downstream our sampling site.

The dry season refugia for fish fauna in intermittent streams and rivers are known to be deep, large, with low degree of solar exposure and with impermeable substrate or possible water influx from groundwater (Labbe and Fausch 2000; Goulding, 1980). These characteristics allow the pools to persist and to keep adequate conditions for the fish fauna during the dry period and, in this way, constitute one essential element for the fish fauna resilience (Magoulick and Kobza, 2003; Bond *et al.,* 2015). All these characteristics were met in the dry year pools except for the groundwater influx, which was not evaluated. In any case, the sampled pools were able to maintain fish populations until the end of the drought, and therefore, acted as fish refugia. However, the concept of refugia is taxon-specific and varies over the time (Sheldon *et al.,* 2010), which may led to increased mortality rates in some species if their requirements are not met in these pools (Woefle-Erskine *et al.,* 2017). This was the case of the Catalan chub in Nespres stream, which was not found in the wet year after a prolonged period of drought. Moreover, the physiological stress that occurs in the refugia may not affect with the same intensity all the life-stages and, therefore, size-dependent mortality events can occur (Merciai *et al.,* 2017). This, together with a possible recruitment failure (Aparicio *et al.,* 2000), could explain why in Nespres only *B. haasi* adult individuals were captured after the drought period. In addition, in this same stream, we observed that the invasive species also persisted, probably due to the refugia, whose lentic characteristics usually favor the allochthonous species (Vila-Gispert *et al.,* 2005). Therefore, in order to protect the endemic fish fauna, it seems necessary to carry out complementary measures apart from the identification and protection of these refugia (Hermoso *et al.,* 2011).

Studies incorporating data on hydrology and local conditions across several years are important for the biodiversity management of intermittent rivers. On the one hand, they provide information on the species-specific responses to extreme environmental and biological conditions, and, on the other hand, inform us on how to adapt current conservation practices in these highly variable ecosystems (Hermoso *et al.,* 2013). This is crucial for the conservation of the autochthonous fish species in front of the flow regime changes that the Mediterranean streams are expected to suffer due to the climate change effects (Labbe and Fausch, 2000; Markovic *et al.,* 2014). Although this study was mainly limited to 2 years, we were able to detect the main patterns in an extremely dry summer and after a wet year. Nevertheless, the time gap between the dry and wet year samples could have masked some other underlying processes in the population's patterns (e.g. recruitment failures, mortality events, migration from upstream), together with the fact that the fish populations may take years to recover from multi-year droughts (Bêche *et al.,* 2009). Another limitation is the possible existence of hiding places inside the pools (e.g. cracks, holes) that may allow the fishes to avoid being captured through electrofishing (Mazzoni *et al.,* 2000).

5. Conclusions and perspectives for future work

The richness and density of fish in Mediterranean streams were strongly affected by the flow intermittence whereas the body length did not respond clearly to these variables. Flow intermittence consequences on the fish metrics were not increased at headwater streams but they were especially strong when the stream was impacted by human activities. This has implications for conservation management, as the mitigation of the anthropogenic alterations may be crucial for the survival of the fish communities in front of the increased flow variability that is expected to happen in the Mediterranean area under the climate change effects.

The year-to-year flow variability also caused differences in the fish community's composition and density. The existence of refugia was crucial in the persistence of most of the native populations, proving that the identification and protection of the refugia is essential to avoid biodiversity loss in Mediterranean intermittent streams. However, some allochthonous species may persist during drought or recolonize after flow resumption, which may affect the autochthonous species survival and recruitment and thus, the recovery of the native populations. Therefore, the eradication of allochthonous species in dry season refugia is an important aspect in management practices.

Further investigation including other fish fauna metrics should be carried out in order to increase the knowledge about the impacts of the flow intermittence on the fish communities and their response to these effects. In this same direction, studying the effects of the local hydromorphological and physicochemical conditions of the refugia, together with fish movement and recruitment is crucial for the freshwater biodiversity management at the local scale (i.e. in a protected area). In this sense, in 2018 we started a pilot study using mark and recapture methods with the objective of assessing the movement patterns during the wet season and the survival rates in the pools during the drought, together with the study of physicochemical critical survival thresholds (e.g. dissolved oxygen, temperature).

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Annex 1

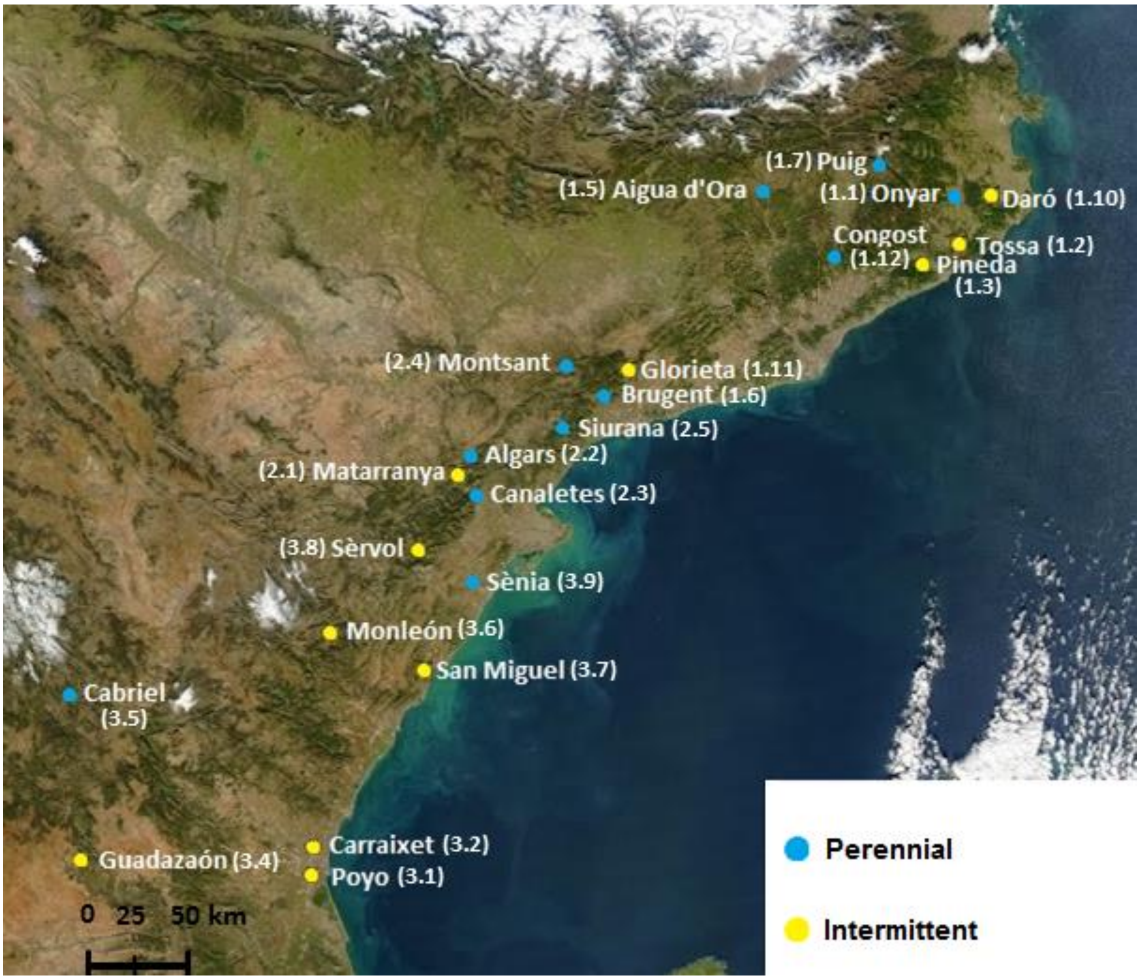

Figure A1.1 Location of the streams and rivers sampled during the LIFE+ TRivers project included to the statistical models. The color of the dot indicates their hydrological regime. The code site is indicated in parenthesis.

Table A1.1. Data matrix of the predictors and richness and density response variables obtained during the sampling and the following data management.

CODE SITE	Season	Q (L/s)	Cond (µS/cm)	O_2 %	O_2 mgl	Ta (ºC)	pH	Alt_m (m)	QBR	N_Imp	Reg	Pools (day)	Dry (day)	Pools2 (day)	Dry2 (day)	ZFD (day)	AS	Mf	Mp	Md	CPUE Aloc (ind/ha)	Dens. Tot (ind/ha)	Dens Autoc (ind/ha)	Dens cypAut (ind/ha)	Rich Tot	Rich Autoc	Rich Cyp Aut
TR 1.1	Spr	31	426.4	88.2	9.19	13.5	7.2	512	75	6	P	0	0	0	0	0	F	1	0	0	0	1878.5	1878.5	1878.5	2	2	2
TR 1.1	Sum	0.8	552	50.4	4.26	23.7	7.7	512	75	6	P	0	0	0	0	0	F	1	0	0	0	3399.4	3399.4	2942.1	3	3	2
TR 1.1	Aut.	4.3	386	56	6.97	6.7	7.6	512	75	6	P	0	0	0	0	0	F	1	0	0	0	1554.2	1554.2	1457.5	3	3	2
TR 1.10	Spr	3.9	581	98.1	9.55	16.5	6.6	80	70	1	IP	0	0	99	0	99	F	0.5	0.5	0	0	892.4	892.4	231.1	3	3	2
TR 1.10	Sum	0	635	29	2.36	26.2	7.6	80	70	1	IP	38	0	99	0	99	P	0.5	0.5	0	0	95152.5	95152.5	5389.5	3	3	2
TR 1.10	Aut.	6.2	251.1	90.7	10.92	7.5	7.6	80	70	1	IP	0	0	99	0	99	F	0.5	0.5	0	0	116.7	116.7	64.5	3	3	1
TR 1.11	Spr	43	1393	94.5	9.28	15.9	8.1	345	90	2	IP	0	0	30	0	30	F	0.67	0.22	0.11	0	3568.6	3568.6	3568.6	1	1	1
TR 1.11	Sum	1.4	806	42.6	3.68	21.5	7.4	345	90	2	IP	21	0	30	0	30	P	0.67	0.22	0.11	0	2264.2	2264.2	2264.2	1	1	1
TR 1.11	Aut.	3.2	556	94.9	11.31	7.8	8.1	345	90	2	IP	0	0	30	0	30	F	0.67	0.22	0.11	0	576.8	576.8	576.8	1	1	1
TR 1.12	Spr	43	1098	94.5	9.28	15.9	8.1	334	50	11	P	0	0	0	0	0	F	1	0	0	182.9	3952.7	3769.8	3769.8	3	2	2
TR 1.12	Sum	24.8	1704	60.8	5.12	23.8	8.1	334	50	11	P	0	0	0	0	0	F	1	0	0	0	2625.5	2625.5	2625.5	2	2	2
TR 1.12	Aut.	27.4	994	121.9	14.28	8.2	8.1	334	50	11	P	0	0	0	0	0	F	1	0	0	249.7	3237.1	2987.4	2987.4	3	2	2
TR 1.2	Spr	23	153.3	113	11	16.7	6.6	6	50	8	IP	0	0	135	0	135	F	0.4	0.6	0	0	1615.6	1615.6	0	1	1	0
TR 1.2	Sum	0	608	23.1	2.04	21.4	6.9	6	50	8	IP	9	0	135	0	135	P	0.4	0.6	0	0	3650.5	3650.5	0	1	1	0
TR 1.2	Aut.	0	589	14.2	1.48	12.9	7.1	6	50	8	IP	135	0	135	0	135	P	0.4	0.6	0	0	0	0	0	0	0	0
TR 1.3	Spr	23	554	91.9	9.49	13.8	6.7	142	100	1	IS	0	0	73	78	151	F	0.59	0.12	0.29	0	0	0	0	0	0	0
TR 1.3	Sum	1.6	613	26.8	2.95	12	8.1	142	100	1	IS	78	73	73	78	151	F	0.59	0.12	0.29	0	0	0	0	0	0	0
TR 1.5	Spr	320	382.1	80.1	8.08	15	8.1	544	100	0	P	0	0	0	0	0	F	1	0	0	0	1989.6	1989.6	1989.6	2	2	2
TR 1.5	Sum	301	523	84.6	7.14	23.7	8.3	544	100	0	P	0	0	0	0	0	F	1	0	0	0	2000.7	2000.7	2000.7	2	2	2
TR 1.5	Aut.	280.7	293.8	93.1	11.98	4.7	8.4	544	100	0	P	0	0	0	0	0	F	1	0	0	0	627.4	627.4	627.4	2	2	2
TR 1.6	Spr	53	478.1	97.4	9.97	14.1	7.7	583	90	1	P	0	0	0	0	0	F	1	0	0	373.8	676	302.2	302.2	3	1	1
TR 1.6	Sum	10.3	651	80.1	7.39	20.3	7.9	583	90	1	P	0	0	0	0	0	F	1	0	0	603.1	2204.8	1601.7	1601.7	2	1	1

CODE SITE	Season	Q (L/s)	Cond (µS/cm)	O_2 %	O_2 mgl	Ta (ºC)	pH	Alt_m (m)	QBR	N_Imp	Reg	Pools (day)	Dry (day)	Pools2 (day)	Dry2 (day)	ZFD (day)	AS	Mf	Mp	Md	CPUE Aloc (ind/ha)	Dens. Tot (ind/ha)	Dens Autoc (ind/ha)	Dens cypAut (ind/ha)	Rich Tot	Rich Autoc	Rich Cyp Aut
TR 1.6	Aut.	66.1	404.3	89.1	9.82	10.9	8.0	583	90	1	P	0	0	0	0	0	F	1	0	0	124.9	732.8	607.9	607.9	2	1	1
TR 1.7	Spr	125	478.1	97.4	9.97	14.1	7.7	140	30	11	P	0	0	0	0	0	F	1	0	0	42.4	188.7	146.4	43.7	3	2	1
TR 1.7	Sum	65.6	1052	71.1	6.82	17.3	7.3	140	30	11	P	0	0	0	0	0	F	1	0	0	0	684.8	684.8	684.8	1	1	1
TR 1.7	Aut.	129.2	979	52.2	5.48	12.9	7.9	140	30	11	P	0	0	0	0	0	F	1	0	0	418.9	766.7	347.8	250	4	2	1
TR 2.1	Spr	344	830	128.2	11.2	22.7	8.2	154	60	12	IP	0	0	37	0	0	F	0.5	0.4	0.1	0	917	917	917	4	4	4
TR 2.1	Sum	0	1437	114.2	9.3	25.5	8.0	154	60	12	IP	34	0	37	0	0	P	0.5	0.4	0.1	151.2	22629.6	22478.4	22478.4	5	4	4
TR 2.1	Aut.	269.2	595	103.6	11.93	9	8.5	154	60	12	IP	0	0	37	0	0	F	0.5	0.4	0.1	0	1103.2	1103.2	1103.2	4	4	4
TR 2.2	Spr	38	492.3	102.8	9.53	18.9	7.9	554	100	0	P	0	0	0	0	0	F	1	0	0	0	2455.7	2455.7	2455.7	2	2	2
TR 2.2	Sum	19.9	598	96.6	7.79	25.5	7.9	554	100	0	P	0	0	0	0	0	F	1	0	0	0	2517.6	2517.6	2517.6	2	2	2
TR 2.2	Aut.	25.3	374	89.1	1029	8.5	8.2	554	100	0	P	0	0	0	0	0	F	1	0	0	0	2392.1	2392.1	2392.1	2	2	2
TR 2.3	Spr	31.5	420.7	102.9	10.27	15.8	8.3	370	100	0	P	0	0	0	0	0	F	1	0	0	443.3	3624.1	3180.7	3180.7	4	3	3
TR 2.3	Sum	16.4	457.3	83.1	7.58	19.9	7.8	370	100	0	P	0	0	0	0	0	F	1	0	0	840.7	3554.7	2714	2714	3	2	2
TR 2.3	Aut.	12.6	313.9	95.9	11.55	7.3	8.5	370	100	0	P	0	0	0	0	0	F	1	0	0	103.9	2631.7	2527.9	2527.9	3	2	2
TR 2.4	Spr	76.4	486.5	96.2	9.96	14.3	7.8	550	100	2	P	0	0	0	0	0	F	1	0	0	1937.1	4509.3	2572.2	2572.2	2	1	1
TR 2.4	Sum	4.4	507	60.7	5.71	18	7.5	550	100	2	P	0	0	0	0	0	F	1	0	0	473.7	1557.4	1083.7	1083.7	3	2	2
TR 2.4	Aut.	40.9	561	80.6	8.99	10.4	7.9	550	100	2	P	0	0	0	0	0	F	1	0	0	183.3	2397.6	2214.3	2214.3	3	2	2
TR 2.5	Spr	67.2	846	84.8	7.99	18.1	7.8	370	80	9	P	0	0	0	0	0	F	1	0	0	0	2764.1	2764.1	2296.5	2	2	1
TR 2.5	Sum	63.7	593	86.4	8.33	17	8,0	370	80	9	P	0	0	0	0	0	F	1	0	0	0	126.6	126.6	126.6	1	1	1
TR 2.5	Aut.	54.9	608	83.3	10.33	6	8.0	370	80	9	P	0	0	0	0	0	F	1	0	0	0	1489.3	1489.3	1489.3	3	3	3
TR 3.1	Spr	8	2415	68.4	6.49	17.6	8.0	132	25	13	IP	0	0	24	0	24	F	0.44	0.39	0.17	0	0	0	0	0	0	0
TR 3.1	Sum	10.9	2970	22	1.76	26.2	8.9	132	25	13	IP	0	0	24	0	24	F	0.44	0.39	0.17	5319.1	5319.1	0	0	1	0	0
TR 3.1	Aut.	11.2	2195	43	4.66	11.3	8.1	132	25	13	IP	0	0	24	0	24	F	0.44	0.39	0.17	5065.9	5065.9	0	0	1	0	0
TR 3.2	Spr	3	1763	93.9	8.13	21.8	7.9	41	20	12	IP	0	0	14	0	14	F	0.83	0.17	0	9443.5	9443.5	0	0	1	0	0
TR 3.2	Sum	0.3	2152	158.6	11.01	34.7	8.2	41	20	12	IP	14	0	14	0	14	P	0.83	0.17	0	562838.3	562838.3	0	0	1	0	0

CODE SITE	Season	Q (L/s)	Cond (µS/cm)	O_2 %	O_2 mgl	Ta (ºC)	pH	Alt_m (m)	QBR	N_Imp	Reg	Pools (day)	Dry (day)	Pools2 (day)	Dry2 (day)	ZFD (day)	AS	Mf	Mp	Md	CPUE Aloc (ind/ha)	Dens. Tot (ind/ha)	Dens Autoc (ind/ha)	Dens cypAut (ind/ha)	Rich Tot	Rich Autoc	Rich Cyp Aut
TR 3.2	Aut.	15.3	1488	94.7	9.4	15.5	8.2	41	20	12	IP	0	0	14	0	14	F	0.83	0.17	0	1241.1	1241.1	0	0	1	0	0
TR 3.4	Spr	15	498.4	98.5	9.8	15.5	8.1	960	55	11	IS	0	0	18	150	168	F	0.44	0.39	0.17	0	61.3	61.3	61.3	1	1	1
TR 3.5	Spr	226	377.7	100	9.82	16.1	8.2	1100	100	1	P	0	0	0	0	0	F	1	0	0	26.6	744.4	717.8	717.8	2	1	1
TR 3.5	Sum	87.9	373.1	84.6	7.6	20.8	8.2	1100	100	1	P	0	0	0	0	0	F	1	0	0	123.9	926.7	802.8	802.8	2	1	1
TR 3.5	Aut.	60.3	225.6	85	11.39	3.2	8.4	1100	100	1	P	0	0	0	0	0	F	1	0	0	46	492.9	446.9	446.9	2	1	1
TR 3.6	Spr	395	329.5	102.6	10.81	13	8.1	715	100	0	IS	0	0	41	59	82	F	0.29	0.29	0.43	0	0	0	0	0	0	0
TR 3.6	Sum	0	420.1	19.5	1.71	21.7	7.8	715	100	0	IS	19	0	41	59	82	P	0.29	0.29	0.43	0	0	0	0	0	0	0
TR 3.6	Aut.	0	302.7	33.5	4.02	7.2	7.5	715	100	0	IS	59	23	41	59	82	F	0.29	0.29	0.43	0	0	0	0	0	0	0
TR 3.7	Spr	30	688	104.2	10.06	16.9	7.9	160	40	10	IP	0	0	0	0	0	P	0.14	0.43	0.43	0	1333.3	1333.3	1333.3	1	1	1
TR 3.7	Sum	12.8	943	72.4	5.91	25.6	7.9	160	40	10	IP	0	0	0	0	0	P	0.14	0.43	0.43	1950.4	4587	2636.6	2636.6	3	2	2
TR 3.7	Aut.	1.7	736	76.6	7.75	12.7	8.0	160	40	10	IP	0	0	0	0	0	P	0.14	0.43	0.43	1241.1	1407.8	166.7	166.7	2	1	1
TR 3.8	Spr	15	319.5	102.7	11.08	11.9	8.2	672	100	0	IS	0	0	134	3	137	F	0.33	0.25	0.42	0	0	0	0	0	0	0
TR 3.8	Aut.	1.3	333	73.2	8.69	7.9	8.0	672	100	0	IS	3	134	134	3	137	F	0.33	0.25	0.42	0	0	0	0	0	0	0
TR 3.9	Spr	1339	399.7	102.4	9.99	16.6	8.2	318	60	12	P	0	0	0	0	0	F	1	0	0	0	1475	1475	1475	2	2	2
TR 3.9	Sum	84.1	481.4	56.7	5.18	19.8	7.9	318	60	12	P	0	0	0	0	0	F	1	0	0	0	20033	20033	20033	2	2	2
TR 3.9	Aut.	33.6	427.4	107.4	11.23	12.9	8.4	318	60	12	P	0	0	0	0	0	F	1	0	0	57.4	15783.1	15725.7	15725.7	3	2	2
MIN		0	153,3	14,2	1,48	3,2	6,6	6	20	0		0	0	0	0	0		0,14	0	0	0	0	0	0	0	0	0
MAX		1339	2970	158,6	1029	34,7	8,9	1100	100	13		59	134	134	150	168		1	0,43	0,43	562838,3	562838,3	22478,4	22478,4	5	4	4
MEAN		80,7	743,5	81,4	24,6	15,9	7,9	380,8	72,2	5,6		6,61	3,71	25,4	7,89	30,6		0,75	0,16	0,09	9572,3	13222,2	3650	2086	1,92	1,5	1,3
STD		187,9	570,4	28,6	129,7	6,35	0,4	276,4	27,6	5,1		21,72	19,4	41,5	26,01	51,6		0,3	0,2	0,15	71432,8	72034,8	12515,7	4176,8	1,22	1,1	1,1

Table A1.2. Data matrix of the predictors and body length response variables obtained during the sampling and the following data management.

CODE SITE	Season	Q (L/s)	Cond (µS/cm	O_2 %	O_2 mgl	pH	Ta (ºC)	Alt_m (m)	QBR	N_imp	Reg	Pools (days)	Dry (days)	Pools2 (days)	Dry2 (days)	ZFD (days)	AS	Mf	Mp	Md	CPUE Aloc (Ind/ha)	BL Tot (mm)	BL Aut (mm)	BL Cyp Aut (mm)
TR 1.1	Spr	31.0	426.4	88.2	9.2	7.2	13.5	512	75	6	P	0	0	0	0	0	F	1	0	0	0.0	68.4	68.4	68.4
TR 1.1	Sum	0.8	552.0	50.4	4.3	7.7	23.7	512	75	6	P	0	0	0	0	0	F	1	0	0	0.0	88.8	88.8	67.1
TR 1.1	Aut.	4.3	386.0	56.0	7.0	7.6	6.7	512	75	6	P	0	0	0	0	0	F	1	0	0	0.0	93.8	93.8	87.9
TR 1.10	Spr	3.9	581.0	98.1	9.6	6.6	16.5	80	70	1	IP	0	0	99	0	99	F	0.5	0.5	0	0.0	64.5	64.5	126.1
TR 1.10	Sum	0.0	635.0	29.0	2.4	7.6	26.2	80	70	1	IP	38	0	99	0	99	P	0.5	0.5	0	0.0	31.6	31.6	63.4
TR 1.10	Aut.	6.2	251.1	90.7	10.9	7.6	7.5	80	70	1	IP	0	0	99	0	99	F	0.5	0.5	0	0.0	136.5	136.5	94.7
TR 1.11	Spr	43.0	1393.0	94.5	9.3	8.1	15.9	345	90	2	IP	0	0	30	0	30	F	0.67	0.22	0.11	0.0	98.1	98.1	98.1
TR 1.11	Sum	1.4	806.0	42.6	3.7	7.4	21.5	345	90	2	IP	21	0	30	0	30	P	0.67	0.22	0.11	0.0	104.8	104.8	104.8
TR 1.11	Aut.	3.2	556.0	94.9	11.3	8.1	7.8	345	90	2	IP	0	0	30	0	30	F	0.67	0.22	0.11	0.0	113.7	113.7	113.7
TR 1.12	Spr	43.0	1098.0	94.5	9.3	8.1	15.9	334	50	11	P	0	0	0	0	0	F	1	0	0	182.9	95.9	96.8	96.8
TR 1.12	Sum	24.8	1704.0	60.8	5.1	8.1	23.8	334	50	11	P	0	0	0	0	0	F	1	0	0	0.0	99.6	99.6	99.6
TR 1.12	Aut.	27.4	994.0	121.9	14.3	8.1	8.2	334	50	11	P	0	0	0	0	0	F	1	0	0	249.7	71.2	72.8	72.8
TR 1.2	Spr	23.0	153.3	113.0	11.0	6.6	16.7	6	50	8	IP	0	0	135	0	135	F	0.4	0.6	0	0.0	317.3	317.3	NA
TR 1.2	Sum	0.0	608.0	23.1	2.0	6.9	21.4	6	50	8	IP	9	0	135	0	135	P	0.4	0.6	0	0.0	319.9	319.9	NA
TR 1.5	Spr	320.0	382.1	80.1	8.1	8.1	15.0	544	100	0	P	0	0	0	0	0	F	1	0	0	0.0	69.8	69.8	69.8
TR 1.5	Sum	301.0	523.0	84.6	7.1	8.3	23.7	544	100	0	P	0	0	0	0	0	F	1	0	0	0.0	78.4	78.4	78.4
TR 1.5	Aut.	280.7	293.8	93.1	12.0	8.4	4.7	544	100	0	P	0	0	0	0	0	F	1	0	0	0.0	72.1	72.1	72.1
TR 1.6	Spr	53.0	478.1	97.4	10.0	7.7	14.1	583	90	1	P	0	0	0	0	0	F	1	0	0	373.8	119.1	79.7	79.7
TR 1.6	Sum	10.3	651.0	80.1	7.4	7.9	20.3	583	90	1	P	0	0	0	0	0	F	1	0	0	603.1	187.5	171.4	171.4
TR 1.6	Aut.	66.1	404.3	89.1	9.8	8.0	10.9	583	90	1	P	0	0	0	0	0	F	1	0	0	124.9	166.2	163.8	163.8
TR 1.7	Spr	125.0	478.1	97.4	10.0	7.7	14.1	140	30	11	P	0	0	0	0	0	F	1	0	0	42.4	366.0	428.7	80.0
TR 1.7	Sum	65.6	1052.0	71.1	6.8	7.3	17.3	140	30	11	P	0	0	0	0	0	F	1	0	0	0.0	61.2	61.2	61.2
TR 1.7	Aut.	129.2	979.0	52.2	5.5	7.9	12.9	140	30	11	P	0	0	0	0	0	F	1	0	0	418.9	77.9	109.3	92.3

CODE SITE	Season	Q (L/s)	Cond (µS/cm	O_2 %	O_2 mgl	pH	Ta (ºC)	Alt_m (m)	QBR	N_imp	Reg	Pools (days)	Dry (days)	Pools2 (days)	Dry2 (days)	ZFD (days)	AS	Mf	Mp	Md	CPUE Aloc (Ind/ha)	BL Tot (mm)	BL Aut (mm)	BL Cyp Aut (mm)
TR 2.1	Spr	344.0	830.0	128.2	11.2	8.2	22.7	154	60	12	IP	0	0	37	0	0	F	0.5	0.4	0.1	0.0	100.1	100.1	100.1
TR 2.1	Sum	0.0	1437.0	114.2	9.3	8.0	25.5	154	60	12	IP	34	0	37	0	0	P	0.5	0.4	0.1	151.2	79.5	79.8	79.8
TR 2.1	Aut.	269.2	595.0	103.6	11.9	8.5	9.0	154	60	12	IP	0	0	37	0	0	F	0.5	0.4	0.1	0.0	68.5	68.5	68.5
TR 2.2	Spr	38.0	492.3	102.8	9.5	7.9	18.9	554	100	0	P	0	0	0	0	0	F	1	0	0	0.0	62.6	62.6	62.6
TR 2.2	Sum	19.9	598.0	96.6	7.8	7.9	25.5	554	100	0	P	0	0	0	0	0	F	1	0	0	0.0	52.4	52.4	52.4
TR 2.2	Aut.	25.3	374.0	89.1	1029.0	8.2	8.5	554	100	0	P	0	0	0	0	0	F	1	0	0	0.0	52.9	52.9	52.9
TR 2.3	Spr	31.5	420.7	102.9	10.3	8.3	15.8	370	100	0	P	0	0	0	0	0	F	1	0	0	443.3	78.9	78.4	78.4
TR 2.3	Sum	16.4	457.3	83.1	7.6	7.8	19.9	370	100	0	P	0	0	0	0	0	F	1	0	0	840.7	73.8	69.6	69.6
TR 2.3	Aut.	12.6	313.9	95.9	11.6	8.5	7.3	370	100	0	P	0	0	0	0	0	F	1	0	0	103.9	67.6	67.7	67.7
TR 2.4	Spr	76.4	486.5	96.2	10.0	7.8	14.3	550	100	2	P	0	0	0	0	0	F	1	0	0	1937.1	154.7	124.0	124.0
TR 2.4	Sum	4.4	507.0	60.7	5.7	7.5	18.0	550	100	2	P	0	0	0	0	0	F	1	0	0	473.7	130.3	126.9	126.9
TR 2.4	Aut.	40.9	561.0	80.6	9.0	7.9	10.4	550	100	2	P	0	0	0	0	0	F	1	0	0	183.3	108.0	103.4	103.4
TR 2.5	Spr	67.2	846.0	84.8	8.0	7.8	18.1	370	80	9	P	0	0	0	0	0	F	1	0	0	0.0	88.0	88.0	56.5
TR 2.5	Sum	63.7	593.0	86.4	8.3	8.0	17.0	370	80	9	P	0	0	0	0	0	F	1	0	0	0.0	60.0	60.0	60.0
TR 2.5	Aut.	54.9	608.0	83.3	10.3	8.0	6.0	370	80	9	P	0	0	0	0	0	F	1	0	0	0.0	93.6	93.6	93.6
TR 3.1	Sum	10.9	2970.0	22.0	1.8	8.9	26.2	132	25	13	IP	0	0	24	0	24	F	0.44	0.39	0.17	5319.1	19.0	NA	NA
TR 3.1	Aut.	11.2	2195.0	43.0	4.7	8.1	11.3	132	25	13	IP	0	0	24	0	24	F	0.44	0.39	0.17	5065.9	23.5	NA	NA
TR 3.2	Spr	3.0	1763.0	93.9	8.1	7.9	21.8	41	20	12	IP	0	0	14	0	14	F	0.83	0.17	0	9443.5	33.1	NA	NA
TR 3.2	Sum	0.3	2152.0	158.6	11.0	8.2	34.7	41	20	12	IP	14	0	14	0	14	P	0.83	0.17	0	562838.3	25.1	NA	NA
TR 3.2	Aut.	15.3	1488.0	94.7	9.4	8.2	15.5	41	20	12	IP	0	0	14	0	14	F	0.83	0.17	0	1241.1	25.0	NA	NA
TR 3.4	Spr	15.0	498.4	98.5	9.8	8.1	15.5	960	55	11	IS	0	0	18	150	168	F	0.44	0.39	0.17	0.0	76.5	76.5	76.5
TR 3.5	Spr	226.0	377.7	100.0	9.8	8.2	16.1	1100	100	1	P	0	0	0	0	0	F	1	0	0	26.6	72.2	68.7	68.7
TR 3.5	Sum	87.9	373.1	84.6	7.6	8.2	20.8	1100	100	1	P	0	0	0	0	0	F	1	0	0	123.9	41.7	27.6	27.6
TR 3.5	Aut.	60.3	225.6	85.0	11.4	8.4	3.2	1100	100	1	P	0	0	0	0	0	F	1	0	0	46.0	64.8	51.4	51.4
TR 3.7	Spr	30.0	688.0	104.2	10.1	7.9	16.9	160	40	10	IP	0	0	0	0	0	P	0.14	0.43	0.43	0.0	27.5	27.5	27.5

CODE SITE	Season	Q (L/s)	Cond (µS/cm	O_2 %	O_2 mgl	pH	Ta (ºC)	Alt_m (m)	QBR	N_imp	Reg	Pools (days)	Dry (days)	Pools2 (days)	Dry2 (days)	ZFD (days)	AS	Mf	Mp	Md	CPUE Aloc (Ind/ha)	BL Tot (mm)	BL Aut (mm)	BL Cyp Aut (mm)
TR 3.7	Sum	12.8	943.0	72.4	5.9	7.9	25.6	160	40	10	IP	0	0	0	0	0	P	0.14	0.43	0.43	1950.4	34.6	35.7	35.7
TR 3.7	Aut.	1.7	736.0	76.6	7.8	8.0	12.7	160	40	10	IP	0	0	0	0	0	P	0.14	0.43	0.43	1241.1	31.5	35.0	35.0
TR 3.9	Spr	1339.0	399.7	102.4	10.0	8.2	16.6	318	60	12	P	0	0	0	0	0	F	1	0	0	0.0	75.9	75.9	75.9
TR 3.9	Sum	84.1	481.4	56.7	5.2	7.9	19.8	318	60	12	P	0	0	0	0	0	F	1	0	0	0.0	40.6	40.6	40.6
TR 3.9	Aut.	33.6	427.4	107.4	11.2	8.4	12.9	318	60	12	P	0	0	0	0	0	F	1	0	0	57.4	57.4	57.4	57.4
MIN		0.0	153.3	22.0	1.8	6.6	3.2	6.0	20.0	0.0		0.0		0.0	0.0	0.0		0.1	0.0	0.0	0.0	19.0	27.5	27.5
MAX		1339.0	2970.0	158.6	1029.0	8.9	34.7	1100.0	100.0	13.0		38.0		135.0	150.0	168.0		1.0	0.6	0.4	562838.3	366.0	428.7	171.4
MEAN		86.0	758.9	85.1	27.7	7.9	16.3	371.7	69.8	6.1		2.2		16.5	2.8	17.3		0.8	0.1	0.0	11197.8	91.0	97.2	79.5
STD		196.58	557.25	25.71	140.21	0.43	6.54	271.50	27.09	5.05		7.68		34.04	20.60	39.88		0.27	0.20	0.11	77247.98	70.37	75.44	30.83

Table A1.3 Density of each species (ind/ha) captured in the study sites. In red, allochthonous species and in black, autochthonous. The captured species were *Achondrostoma arcasii* (A_arcasii), *Alburnus alburnus* (A_albur), *Anguilla Anguilla* (A_ang), *Barbus haasi* (B_haasi), *Barbus meriodionalis* (B_meri), *Cyprinus carpio* (C_carpio), *Gambusia holbrooki*(G_holbr), *Gasterosteus gymnurus* (G_gym), *Gobio lozanoi* (G_lozanoi), *Luciobarbus graellsi* (L_graell), *Onchorynchus* mykiss (O_mykiss), *Parachondrostoma miegii* (P_miegii), *Phoxinus sp.* (P_phoxi), *Salmo trutta* (S_trutta), *Squalius laietanus* (S_laiet), *Squalius pyrenaicus* (S_pyr) and *Squalius valentinus* (S_valen).

CODE SITE	Season	A_arcasii	A_albur	A_ang	B_haasi	B_meri	C_carpio	G_holbr	G_gym	G_lozanoi	L_graell	O_mykiss	P_miegii	P_phoxi	S_trutta	S_laiet	S_pyr	S_valen
TR 1.1	Spring	0.00	0.00	0.00	0.00	1790.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	88.16	0.00	0.00
TR 1.1	Summer	0.00	0.00	457.32	0.00	2743.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	198.17	0.00	0.00
TR 1.1	Autumn	0.00	0.00	96.73	0.00	619.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	838.36	0.00	0.00
TR 1.10	Spring	0.00	0.00	0.00	0.00	127.51	0.00	0.00	661.26	0.00	0.00	0.00	0.00	0.00	0.00	103.60	0.00	0.00
TR 1.10	Summer	0.00	0.00	0.00	0.00	2415.98	0.00	0.00	89763.05	0.00	0.00	0.00	0.00	0.00	0.00	2973.52	0.00	0.00
TR 1.10	Autumn	0.00	0.00	24.80	0.00	0.00	0.00	0.00	27.44	0.00	0.00	0.00	0.00	0.00	0.00	64.47	0.00	0.00
TR 1.11	Spring	0.00	0.00	0.00	3568.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TR 1.11	Summer	0.00	0.00	0.00	2264.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TR 1.11	Autumn	0.00	0.00	0.00	576.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TR 1.12	Spring	0.00	0.00	0.00	0.00	3693.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	182.92	0.00	76.22	0.00	0.00
TR 1.12	Summer	0.00	0.00	0.00	0.00	2566.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	59.15	0.00	0.00
TR 1.12	Autumn	0.00	0.00	0.00	0.00	2432.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	249.66	0.00	554.81	0.00	0.00
TR 1.2	Spring	0.00	0.00	1615.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TR 1.2	Summer	0.00	0.00	3650.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TR 1.2	Autumn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TR 1.3	Spring	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TR 1.3	Summer	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TR 1.5	Spring	0.00	0.00	0.00	1503.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	485.83	0.00	0.00	0.00	0.00	0.00
TR 1.5	Summer	0.00	0.00	0.00	811.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1188.71	0.00	0.00	0.00	0.00	0.00
TR 1.5	Autumn	0.00	0.00	0.00	82.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	544.51	0.00	0.00	0.00	0.00	0.00
TR 1.6	Spring	0.00	0.00	0.00	302.17	0.00	0.00	0.00	0.00	0.00	0.00	146.29	0.00	0.00	227.56	0.00	0.00	0.00
TR 1.6	Summer	0.00	0.00	0.00	1601.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	603.10	0.00	0.00	0.00
TR 1.6	Autumn	0.00	0.00	0.00	607.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	124.86	0.00	0.00	0.00
TR 1.7	Spring	0.00	0.00	102.64	43.75	0.00	42.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TR 1.7	Summer	0.00	0.00	0.00	684.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TR 1.7	Autumn	0.00	0.00	97.76	250.01	0.00	40.35	378.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TR 2.1	Spring	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25.46	119.55	0.00	359.56	0.00	0.00	412.44	0.00	0.00
TR 2.1	Summer	0.00	0.00	0.00	0.00	0.00	0.00	151.20	0.00	725.50	823.96	0.00	12161.08	0.00	0.00	8767.84	0.00	0.00
TR 2.1	Autumn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	203.77	22.78	0.00	798.05	0.00	0.00	78.60	0.00	0.00
TR 2.2	Spring	0.00	0.00	0.00	1659.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	796.59	0.00	0.00	0.00	0.00	0.00
TR 2.2	Summer	0.00	0.00	0.00	1879.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	638.00	0.00	0.00	0.00	0.00	0.00
TR 2.2	Autumn	0.00	0.00	0.00	729.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1662.64	0.00	0.00	0.00	0.00	0.00

CODE SITE	Season	A_arcasii	A_albur	A_ang	B_haasi	B_meri	C_carpio	G_holbr	G_gym	G_lozanoi	L_graell	O_mykiss	P_miegii	P_phoxi	S_trutta	S_laiet	S_pyr	S_valen
TR 2.3	Spring	0.00	0.00	0.00	2634.48	0.00	0.00	0.00	0.00	205.24	0.00	0.00	341.02	0.00	0.00	0.00	443.32	0.00
TR 2.3	Summer	0.00	0.00	0.00	2170.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	543.24	0.00	0.00	0.00	840.73	0.00
TR 2.3	Autumn	0.00	0.00	0.00	2128.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	399.48	0.00	0.00	0.00	103.87	0.00
TR 2.4	Spring	0.00	0.00	0.00	2572.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1937.09	0.00	0.00	0.00
TR 2.4	Summer	0.00	0.00	0.00	559.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	524.67	0.00	473.66	0.00	0.00	0.00
TR 2.4	Autumn	0.00	0.00	0.00	2163.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.76	0.00	183.30	0.00	0.00	0.00
TR 2.5	Spring	0.00	0.00	467.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2296.52	0.00	0.00
TR 2.5	Summer	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	126.62	0.00	0.00	0.00	0.00	0.00
TR 2.5	Autumn	0.00	0.00	0.00	343.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	214.85	0.00	0.00	931.02	0.00	0.00
TR 3.1	Spring	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TR 3.1	Summer	0.00	0.00	0.00	0.00	0.00	0.00	5319.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TR 3.1	Autumn	0.00	0.00	0.00	0.00	0.00	0.00	5065.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TR 3.2	Spring	0.00	0.00	0.00	0.00	0.00	0.00	9443.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TR 3.2	Summer	0.00	0.00	0.00	0.00	0.00	0.00	562838.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TR 3.2	Autumn	0.00	0.00	0.00	0.00	0.00	0.00	1241.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TR 3.4	Spring	61.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TR 3.5	Spring	717.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	26.58	0.00	0.00	0.00
TR 3.5	Summer	802.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	123.89	0.00	0.00	0.00
TR 3.5	Autumn	446.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	45.98	0.00	0.00	0.00
TR 3.6	Spring	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TR 3.6	Summer	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TR 3.6	Autumn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TR 3.7	Spring	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1333.33
TR 3.7	Summer	0.00	0.00	0.00	136.61	0.00	0.00	1950.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2500.00
TR 3.7	Autumn	0.00	0.00	0.00	0.00	0.00	0.00	1241.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	166.67
TR 3.8	Spring	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TR 3.8	Autumn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TR 3.9	Spring	0.00	0.00	0.00	579.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	895.62	0.00	0.00	0.00	0.00	0.00
TR 3.9	Summer	0.00	0.00	0.00	2261.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	17771.88	0.00	0.00	0.00	0.00	0.00
TR 3.9	Autumn	0.00	57.44	0.00	2685.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13040.05	0.00	0.00	0.00	0.00	0.00

Table A1.4. Description and abbreviations of the predictors and variables used in the study.

	Abbreviation	Description
Predictors		
Sampling site	CODE SITE	Sampled point during the TRivers project in 2015.
Season	Season	Season the sample took place: Spring, Summer or Autumn.
Discharge (L/s)	Q	Discharge present in the site at the moment of sample
Conductivity (uS/cm)	Cond	Measured conductivity in the site at the moment of sample
Dissolved oxygen (mg/L)	O2 mgl	Measured dissolved oxygen in mg/L in the site at the moment of sample
Dissolved oxygen (%)	O2 %	Measured dissolved oxygen in percentage in the site at the moment of sample
Temperature (ºC)	Ta	Measured water temperature in the site at the moment of sample
pH	pH	Measured pH in the site at the moment of sample
Altitude (m)	Alt	Altitude above the sea level of the sampled site
Riparian forest quality index	QBR	Described in Munné *et al.,* (2002)
Number of impacts	N_imp	Described in Sánchez- Montoya *et al.,* (2009)
Flow regime	Reg	Perennial (P), Intermittent-pools (IP) and Intermittent-dry (IS)
Days in pools before sample	Pools	Number of days the stream was in pools during 2015 before sample
Days dried before sample	Dry	Number of days the stream was dried during 2015 before sample
Days in pools during the year	Pools2	Number of days the stream was in pools during 2015
Days dried during the year	Dry2	Number of days the stream was dried during 2015
Zero flow days	ZFD	Number of days the stream did not flow during 2015. Equals to Pools2+Dry2
Aquatic State	AS	Flow or Pools
Mf	Mf	Flow persistence over the years (*sensu* Gallart *et al.,* 2017)
Mp	Mp	Pools persistence over the years (*sensu* Gallart *et al.,* 2017)
Md	Md	Dry persistence over the years (*sensu* Gallart *et al.,* 2017)
Allochthonous fish density	CPUEaloc	Density of allochthonous fish species (ind/ha)
Response variables		
Autochthonous fish density	Dens aut	Density of autochthonous fish species (ind/ha)
Allochthonous cyprinid fish density	Dens cyp Aut	Density of autochthonous cyprinid species (ind/ha)

	Abbreviation	Description
Total fish density	Dens tot	Density of fish species (ind/ha)
Autochthonous fish richness	Rich aut	Number of autochthonous fish species present
Autochthonous cyprinid fish richness	Rich cyp aut	Number of autochthonous cyprinid fish species present
Total fish richness	Rich tot	Number fish species present
Autochthonous body length	BL aut	Mean body length of the autocthonous fish present in mm
Autochthonous cyprinid body length	Bl cyp aut	Mean body length of the autocthonous cyprinid fish present in mm
Total species body length	BL tot	Mean body length of the fish present in mm

Table A1.5. Pearson correlation values matrix for the response richness and fish density.

	Q	Cond	O_2 %	O_2 mgl	pH	Ta	Alt_m	QBR	N_Imp	pools	dry	pools2	dry2	ZFD	Mf	Mp	Md	CPUE aloc	Dens tot	Dens aut	Dens cypAut	Rich Tot	Rich Aut	Rich CypAut
Q	1.00	-0.19	0.44	0.51	0.34	-0.22	0.33	0.15	0.00	-0.67	-0.30	-0.49	-0.17	-0.53	0.44	-0.46	-0.25	-0.08	0.09	0.26	0.35	0.25	0.23	0.31
Cond	-0.19	1.00	-0.07	-0.26	0.25	0.47	-0.46	-0.69	0.64	0.03	-0.15	0.12	-0.21	0.04	-0.11	0.17	-0.01	0.43	0.28	-0.27	-0.19	-0.09	-0.20	-0.13
O2_%	0.44	-0.07	1.00	0.91	0.20	-0.02	0.09	0.00	0.07	-0.48	-0.27	-0.20	-0.19	-0.31	0.22	-0.20	-0.18	0.21	0.28	0.19	0.24	0.30	0.24	0.31
O2_mgl	0.51	-0.26	0.91	1.00	0.23	-0.40	0.20	0.13	-0.04	-0.55	-0.20	-0.21	-0.15	-0.29	0.24	-0.24	-0.15	0.09	0.13	0.18	0.24	0.29	0.25	0.31
pH	0.34	0.25	0.20	0.23	1.00	-0.03	0.36	0.02	0.11	-0.23	0.00	-0.31	-0.11	-0.37	0.18	-0.31	0.05	0.32	0.17	-0.03	0.19	0.16	0.03	0.21
Ta	-0.22	0.47	-0.02	-0.40	-0.03	1.00	-0.25	-0.28	0.23	0.18	-0.24	0.04	-0.14	-0.02	-0.05	0.14	-0.08	0.22	0.41	0.11	0.05	0.03	0.02	0.04
Alt_m	0.33	-0.46	0.09	0.20	0.36	-0.25	1.00	0.71	-0.54	-0.24	0.10	-0.44	0.24	-0.31	0.35	-0.57	0.08	-0.12	-0.18	0.13	0.32	0.00	-0.02	0.12
QBR	0.15	-0.69	0.00	0.13	0.02	-0.28	0.71	1.00	-0.89	0.03	0.23	-0.12	0.27	-0.06	0.24	-0.39	0.05	-0.34	-0.27	0.18	0.25	-0.02	0.08	0.15
N_imp	0.00	0.64	0.07	-0.04	0.11	0.23	-0.54	-0.89	1.00	-0.09	-0.23	-0.02	-0.24	-0.14	-0.12	0.23	-0.08	0.25	0.29	-0.05	-0.07	0.13	0.07	0.07
pools	-0.67	0.03	-0.48	-0.55	-0.23	0.18	-0.24	0.03	-0.09	1.00	0.45	0.52	0.33	0.48	-0.38	0.39	0.23	-0.12	-0.24	-0.25	-0.31	-0.28	-0.21	-0.22
dry	-0.30	-0.15	-0.27	-0.20	0.00	-0.24	0.10	0.23	-0.23	0.45	1.00	0.31	0.45	0.35	-0.25	0.05	0.44	-0.17	-0.48	-0.38	-0.35	-0.35	-0.30	-0.28
pools2	-0.49	0.12	-0.20	-0.21	-0.31	0.04	-0.44	-0.12	-0.02	0.52	0.31	1.00	0.41	0.91	-0.73	0.78	0.39	-0.27	-0.43	-0.52	-0.66	-0.45	-0.29	-0.39
dry2	-0.17	-0.21	-0.19	-0.15	-0.11	-0.14	0.24	0.27	-0.24	0.33	0.45	0.41	1.00	0.56	-0.41	0.15	0.62	-0.28	-0.69	-0.54	-0.49	-0.52	-0.42	-0.39
ZFD	-0.53	0.04	-0.31	-0.29	-0.37	-0.02	-0.31	-0.06	-0.14	0.48	0.35	0.91	0.56	1.00	-0.67	0.67	0.43	-0.27	-0.53	-0.61	-0.75	-0.66	-0.52	-0.64
Mf	0.44	-0.11	0.22	0.24	0.18	-0.05	0.35	0.24	-0.12	-0.38	-0.25	-0.73	-0.41	-0.67	1.00	-0.89	-0.79	0.18	0.43	0.45	0.54	0.41	0.30	0.34
Mp	-0.46	0.17	-0.20	-0.24	-0.31	0.14	-0.57	-0.39	0.23	0.39	0.05	0.78	0.15	0.67	-0.89	1.00	0.42	-0.16	-0.20	-0.27	-0.47	-0.24	-0.12	-0.23
Md	-0.25	-0.01	-0.18	-0.15	0.05	-0.08	0.08	0.05	-0.08	0.23	0.44	0.39	0.62	0.43	-0.79	0.42	1.00	-0.14	-0.59	-0.52	-0.45	-0.49	-0.44	-0.36
CPUEaloc	-0.08	0.43	0.21	0.09	0.32	0.22	-0.12	-0.34	0.25	-0.12	-0.17	-0.27	-0.28	-0.27	0.18	-0.16	-0.14	1.00	0.46	-0.12	-0.04	0.24	-0.17	-0.09
Dens tot	0.09	0.28	0.28	0.13	0.17	0.41	-0.18	-0.27	0.29	-0.24	-0.48	-0.43	-0.69	-0.53	0.43	-0.20	-0.59	0.46	1.00	0.66	0.60	0.60	0.48	0.48
Dens aut	0.26	-0.27	0.19	0.18	-0.03	0.11	0.13	0.18	-0.05	-0.25	-0.38	-0.52	-0.54	-0.61	0.45	-0.27	-0.52	-0.12	0.66	1.00	0.91	0.71	0.76	0.73
Dens cypAut	0.35	-0.19	0.24	0.24	0.19	0.05	0.32	0.25	-0.07	-0.31	-0.35	-0.66	-0.49	-0.75	0.54	-0.47	-0.45	-0.04	0.60	0.91	1.00	0.73	0.74	0.80
Rich Tot	0.25	-0.09	0.30	0.29	0.16	0.03	0.00	-0.02	0.13	-0.28	-0.35	-0.45	-0.52	-0.66	0.41	-0.24	-0.49	0.24	0.60	0.71	0.73	1.00	0.89	0.84
Rich Aut	0.23	-0.20	0.24	0.25	0.03	0.02	-0.02	0.08	0.07	-0.21	-0.30	-0.29	-0.42	-0.52	0.30	-0.12	-0.44	-0.17	0.48	0.76	0.74	0.89	1.00	0.92
Rich CypAut	0.31	-0.13	0.31	0.31	0.21	0.04	0.12	0.15	0.07	-0.22	-0.28	-0.39	-0.39	-0.64	0.34	-0.23	-0.36	-0.09	0.48	0.73	0.80	0.84	0.92	1.00

Table A1.6. Pearson correlation values matrix for the response variable body length.

	Q	Cond	O2_%	O2_mgl	pH	Ta	Alt	QBR	N_imp	Pools	Pools2	dry2	ZFD	Mf	Mp	Md	BLtot	BLaut	BLcypAut
Q	1.00	-0.20	0.40	0.38	0.44	-0.20	0.24	0.04	0.13	-0.53	-0.38	-0.06	-0.44	0.39	-0.42	-0.24	0.10	0.08	-0.07
Cond	-0.20	1.00	-0.09	-0.27	-0.08	0.45	-0.42	-0.50	0.49	0.28	0.18	-0.06	0.01	-0.26	0.21	0.27	-0.05	0.03	0.09
O2_percent	0.40	-0.09	1.00	0.88	0.33	-0.26	0.08	0.05	0.10	-0.37	0.00	0.09	-0.18	-0.04	0.03	0.06	0.14	0.10	0.01
O2_mgl	0.38	-0.27	0.88	1.00	0.37	-0.65	0.10	0.09	0.03	-0.39	0.03	0.07	-0.10	0.02	-0.01	-0.04	0.19	0.15	0.08
pH	0.44	-0.08	0.33	0.37	1.00	-0.19	0.32	0.14	0.10	-0.17	-0.25	0.07	-0.37	0.12	-0.22	0.06	-0.11	-0.12	-0.23
Ta	-0.20	0.45	-0.26	-0.65	-0.19	1.00	-0.14	-0.10	0.08	0.39	0.10	-0.01	0.01	-0.17	0.17	0.14	-0.22	-0.21	-0.16
Alt_m	0.24	-0.42	0.08	0.10	0.32	-0.14	1.00	0.65	-0.43	-0.28	-0.44	0.28	-0.22	0.51	-0.57	-0.30	0.11	-0.02	-0.01
QBR	0.04	-0.50	0.05	0.09	0.14	-0.10	0.65	1.00	-0.85	-0.03	-0.09	-0.13	-0.02	0.43	-0.37	-0.43	0.16	0.04	0.23
N_imp	0.13	0.49	0.10	0.03	0.10	0.08	-0.43	-0.85	1.00	-0.02	-0.03	0.17	-0.20	-0.25	0.17	0.32	-0.14	-0.04	-0.24
pools	-0.53	0.28	-0.37	-0.39	-0.17	0.39	-0.28	-0.03	-0.02	1.00	0.51	-0.04	0.35	-0.29	0.39	0.05	-0.13	-0.11	0.05
Pools2	-0.38	0.18	0.00	0.03	-0.25	0.10	-0.44	-0.09	-0.03	0.51	1.00	0.20	0.81	-0.59	0.79	0.12	0.02	0.04	0.26
dry2	-0.06	-0.06	0.09	0.07	0.07	-0.01	0.28	-0.13	0.17	-0.04	0.20	1.00	0.44	-0.23	0.23	0.17	-0.01	0.00	0.01
ZFD	-0.44	0.01	-0.18	-0.10	-0.37	0.01	-0.22	-0.02	-0.20	0.35	0.81	0.44	1.00	-0.46	0.62	0.08	0.01	0.03	0.24
Mf	0.39	-0.26	-0.04	0.02	0.12	-0.17	0.51	0.43	-0.25	-0.29	-0.59	-0.23	-0.46	1.00	-0.95	-0.85	0.40	0.35	0.28
Mp	-0.42	0.21	0.03	-0.01	-0.22	0.17	-0.57	-0.37	0.17	0.39	0.79	0.23	0.62	-0.95	1.00	0.63	-0.31	-0.27	-0.12
Md	-0.24	0.27	0.06	-0.04	0.06	0.14	-0.30	-0.43	0.32	0.05	0.12	0.17	0.08	-0.85	0.63	1.00	-0.46	-0.40	-0.46
BLtot	0.10	-0.05	0.14	0.19	-0.11	-0.22	0.11	0.16	-0.14	-0.13	0.02	-0.01	0.01	0.40	-0.31	-0.46	1.00	0.97	0.78
BLaut	0.08	0.03	0.10	0.15	-0.12	-0.21	-0.02	0.04	-0.04	-0.11	0.04	0.00	0.03	0.35	-0.27	-0.40	0.97	1.00	0.79
BLcypAut	-0.07	0.09	0.01	0.08	-0.23	-0.16	-0.01	0.23	-0.24	0.05	0.26	0.01	0.24	0.28	-0.12	-0.46	0.78	0.79	1.00

Random Forest models results

-Fish density

Table A1.7. Random forest results for the total, autochthonous and autochthonous cyprinids fish species density: explained variance by the model, predicted error and predictor's VIMP.

	Total density		Autochthonous density		Autoc cyp. density	
Explained Variance (%)	47.78		60.21		72.37	
Error	0.94		0.84		0.6	
	Predictor	**VIMP**	**Predictor**	**VIMP**	**Predictor**	**VIMP**
	Dry2	1.25	Zero flow days	0.89	Zero flow days	1.31
	O2_percent	0.96	Dry2	0.79	Alt_m	1.09
	Pools	0.87	Md	0.77	Dry2	0.58
	Zero flow days	0.73	CPUEaloc	0.73	Md	0.44
	Md	0.53	Alt_m	0.54	Mp	0.43
	Dry	0.47	O2_percent	0.56	O2_percent	0.33
	Alt_m	0.35	N_impacts	0.46	N_impacts	0.32
	N_impacts	0.28	Pools	0.45	CPUEaloc	0.27
	Mp	0.19	Mp	0.31	Pools	0.13
	AS	0.08	Dry	0.09	Dry	0.06
	Season	0.05	As	0.05	AS	0.02
			Season	0.01	Season	-0.01

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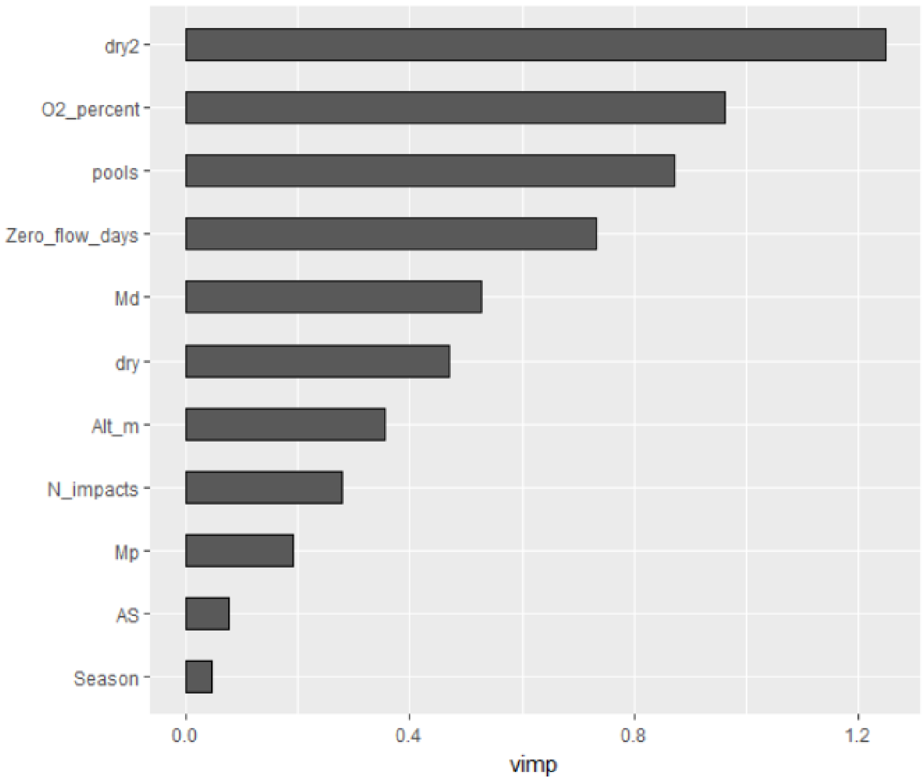


Figure A1.2. Predictor's VIMP value for the total species density RF model.

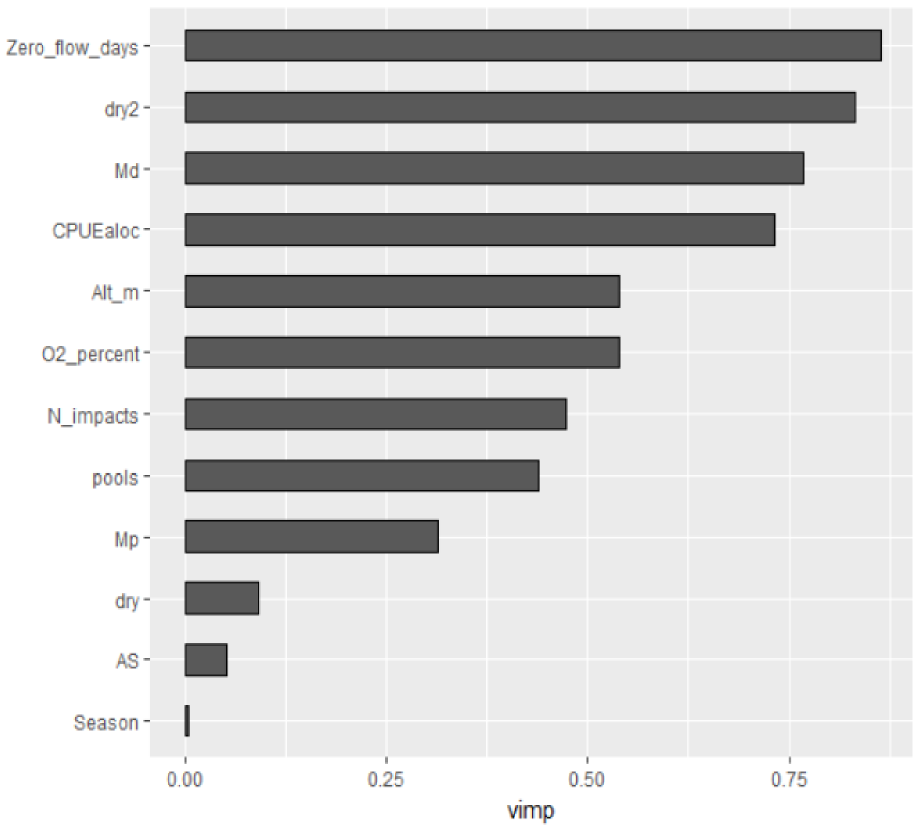


Figure A1.3. Predictor's VIMP value for the autochthonous species density RF model.

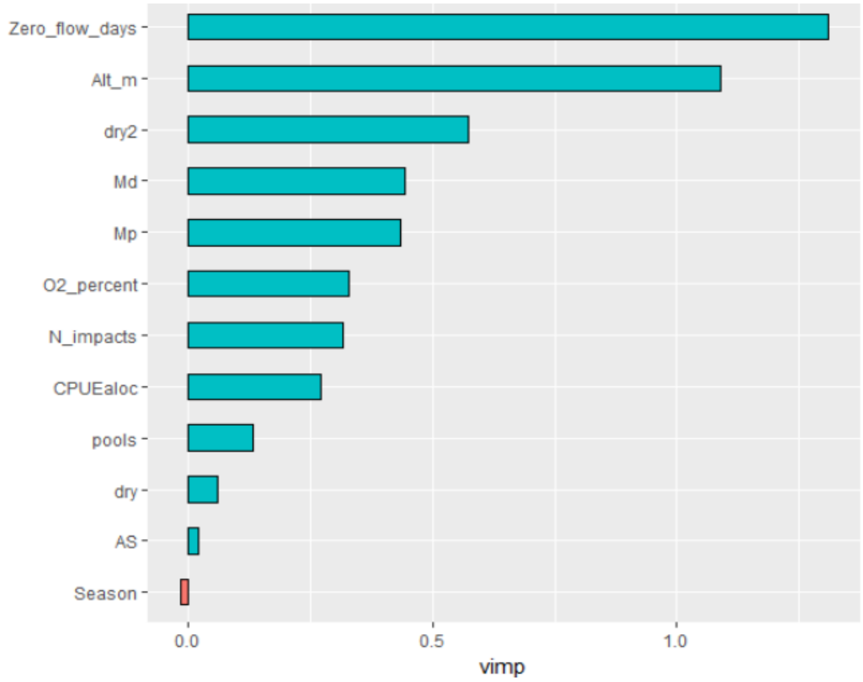


Figure A1.4. Predictor's VIMP value for the autochthonous cyprinids species density RF model.

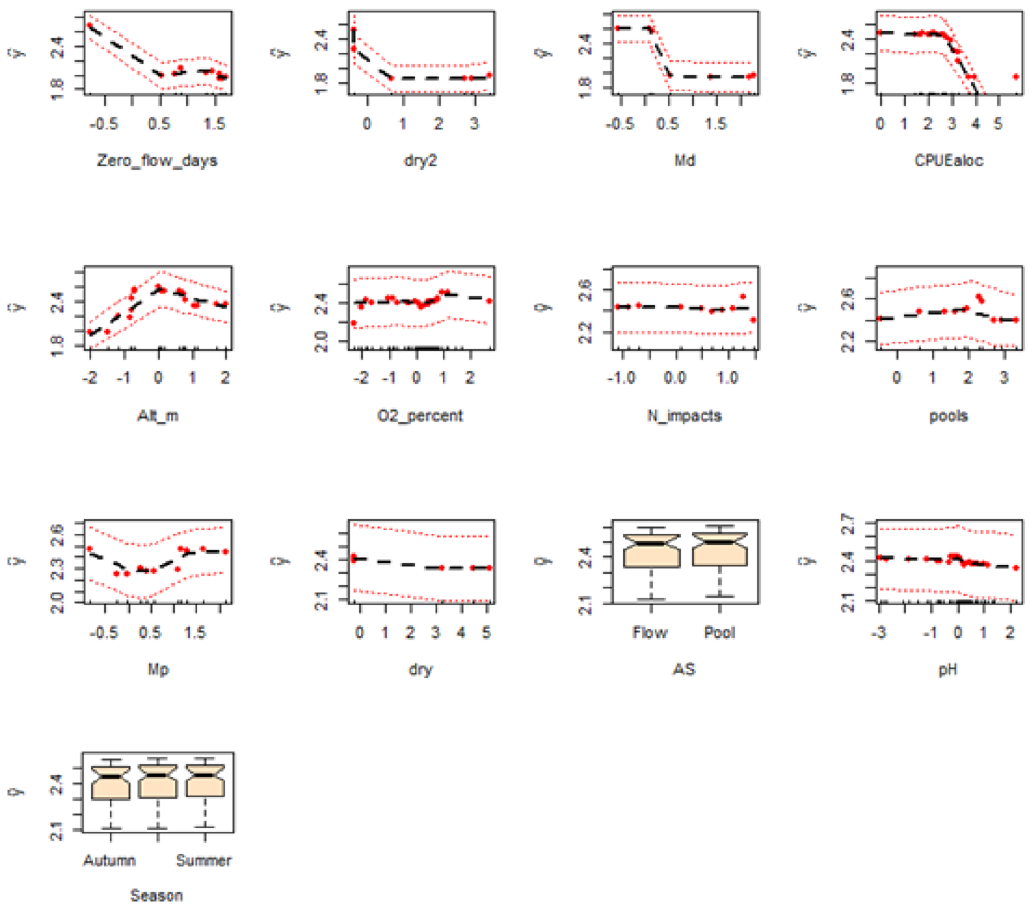


Figure A1.5. Marginal response plots of the autochthonous fish density to the different predictors included in the RF.

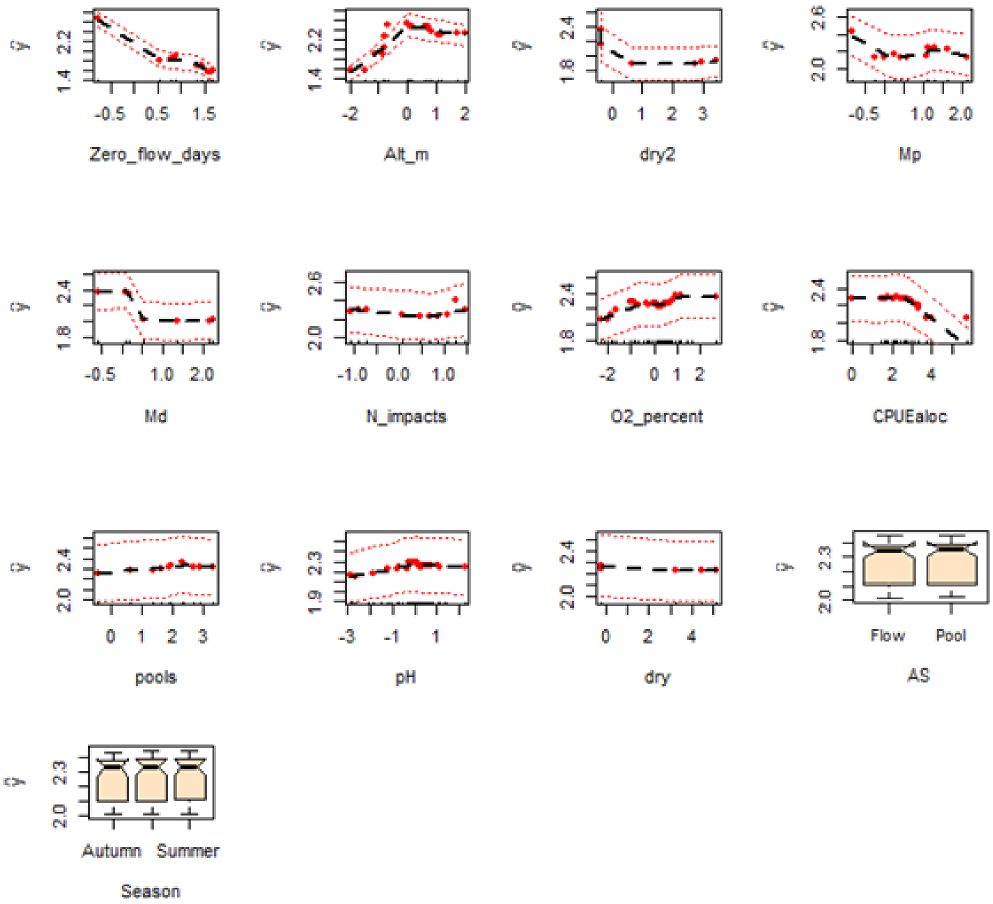


Figure A1.6. Marginal response plots of the autochthonous cyprinids fish density to the different predictors included in the RF.

-Richness

Table A1.8. Random forest results for the total, autochthonous and autochthonous cyprinids fish species richness: explained variance by the model, predicted error and predictor's VIMP.

	Total richness		Autochthonous richness		Autoc. Cyprinid richness	
Explained variance (%)	57.29		61.16		72.82	
Error	0.6		0.49		0.11	
	Predictor	**VIMP**	**Predictor**	**VIMP**	**Predictor**	**VIMP**
	Zero Flow days	0.82	Md	0.66	Zero flow days	0.26
	Md	0.69	Zero flow days	0.51	Alt_m	0.19
	Dry2	0.35	Alt_m	0.45	Md	0.09
	O2_percent	0.36	Mp	0.39	Dry2	0.09
	Alt_m	0.36	O2_percent	0.35	O2_percent	0.08
	Mp	0.29	CPUEaloc	0.22	Mp	0.07
	Pools	0.21	N_impacts	0.20	N_impacts	0.07
	N_impacts	0.18	Dry2	0.19	CPUEaloc	0.05
	Dry	0.04	Pools	0.1	Pools	0.02
	AS	0.02	AS	0.01	Dry	0.01
	Season	-0.001	dry	0.01	AS	0.003
			Season	-0.01	Season	-0.003

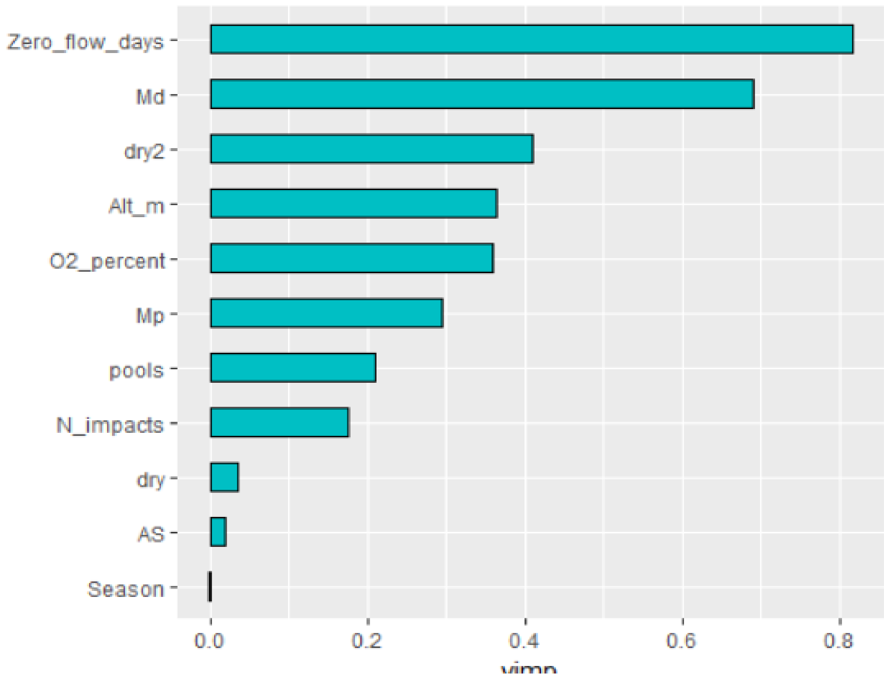


Figure A1.7. Predictor's VIMP value for the total species richness RF model.

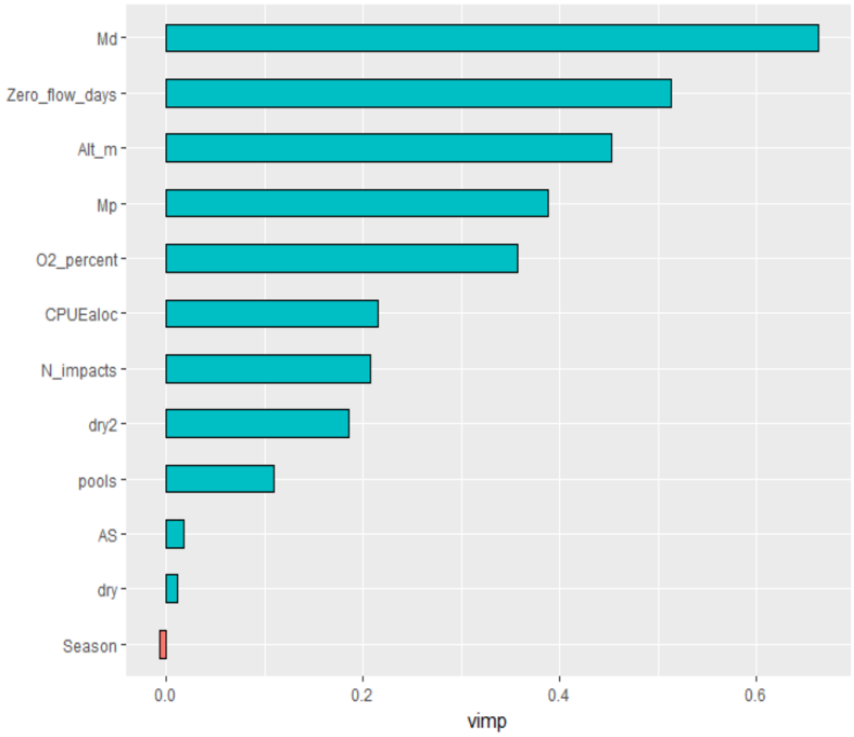


Figure A1.8. Predictor's VIMP value for the autochthonous species richness RF model.

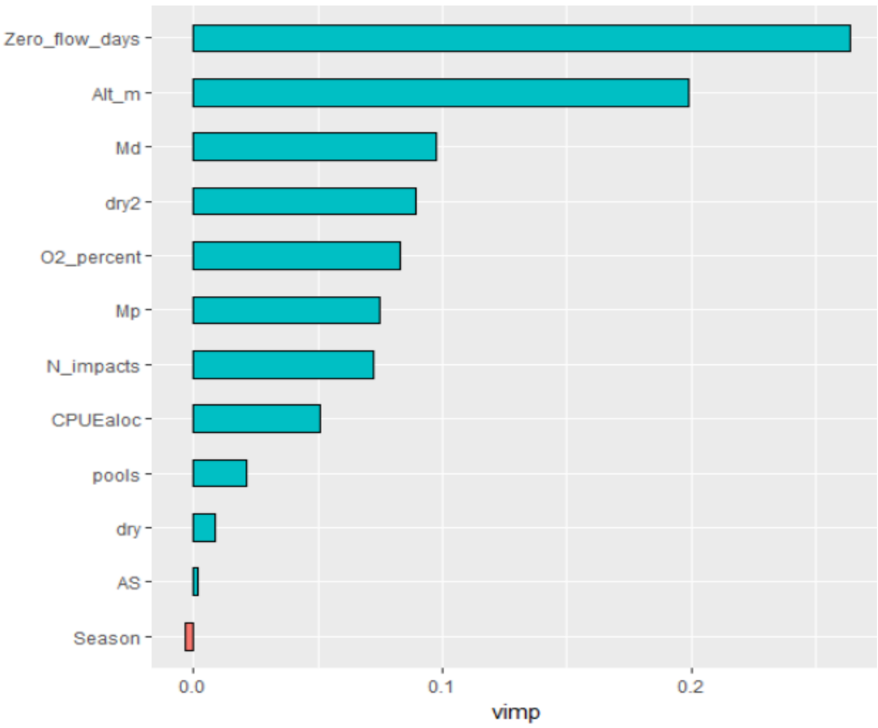


Figure A1.9. Predictor's VIMP value for the autochthonous cyprinids species richness RF model.

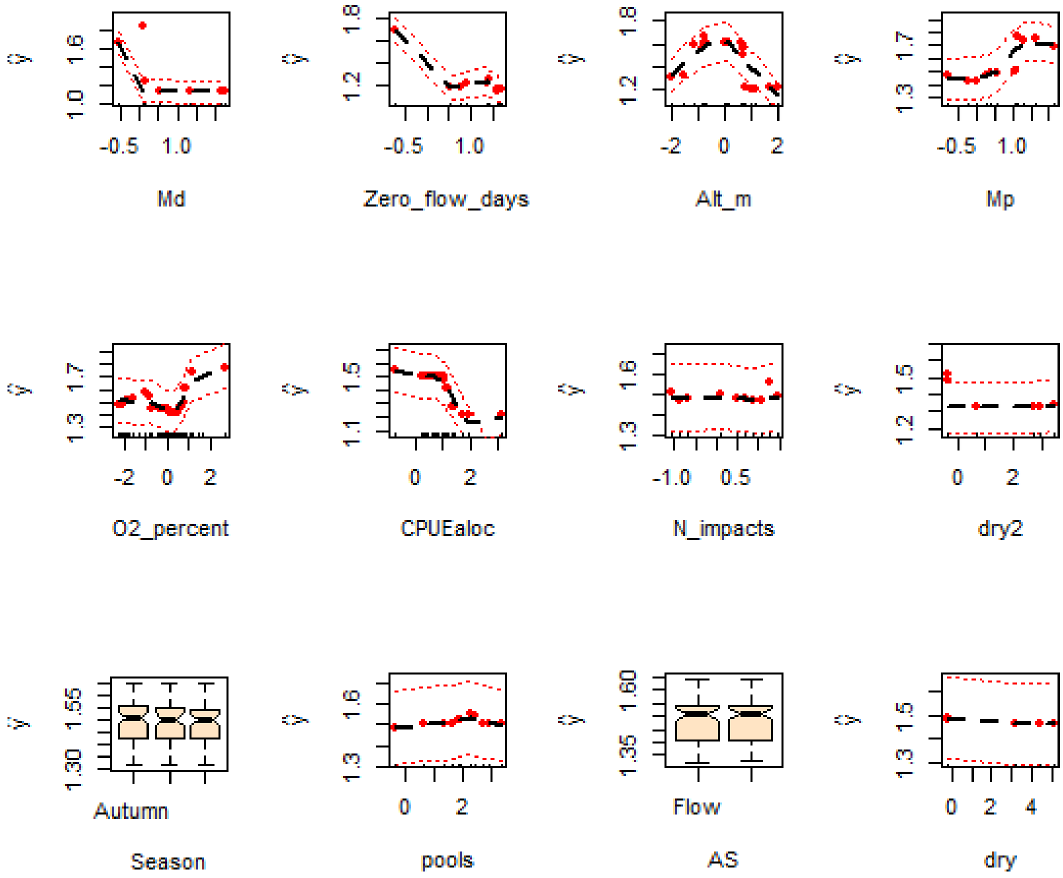


Figure A1.10. Marginal response plots of the autochthonous fish richness to the different predictors included in the RF.

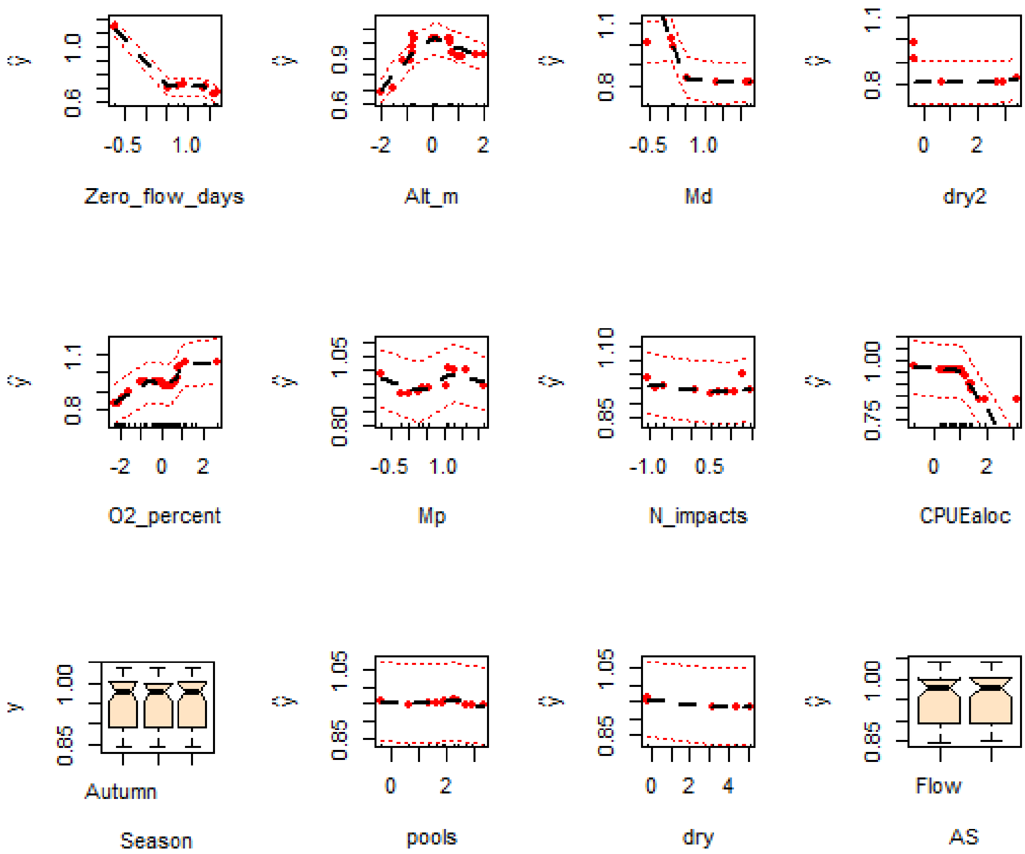


Figure A1.11. Marginal response plots of the autochthonous cyprinid fish richness to the different predictors included in the RF.

-Body length

Table A1.9. Random forest results for the total, autochthonous and autochthonous cyprinids fish species body length: explained variance by the model, predicted error and predictor's VIMP.

	Total BL		Autochthonous BL		Autoc. Cyprinid BL	
Explained variance (%)	32.05		12.63		16.34	
Error	0.28		0.28		0.13	
	Predictor	**VIMP**	**Predictor**	**VIMP**	**Predictor**	**VIMP**
	Alt_m	0.4	Alt_m	0.32	Md	0.14
	Mp	0.27	Mp	0.25	Alt_m	0.073
	Md	0.17	Md	0.14	CPUEaloc	0.054
	Zero flow days	0.14	O2_ percent	0.11	Mp	0.023
	O2_ percent	0.13	Zero flow days	0.08	AS	0.022
	N_impacts	0.12	CPUEaloc	0.05	N_impacts	0.007
	AS	0.03	Pools	0.045	O2_percent	0.0006
	Pools	0.03	AS	0.037	Zero flow days	0.0005
	Regime	0.01	N_impacts	0.006	Regime	0.0002
	Dry2	-0.0003	Dry2	-0.00008	Season	0.0005
	Season	-0.004	Season	-0.0003	Dry2	-0.00007
			Regime	-0.0004	pools	-0.0003

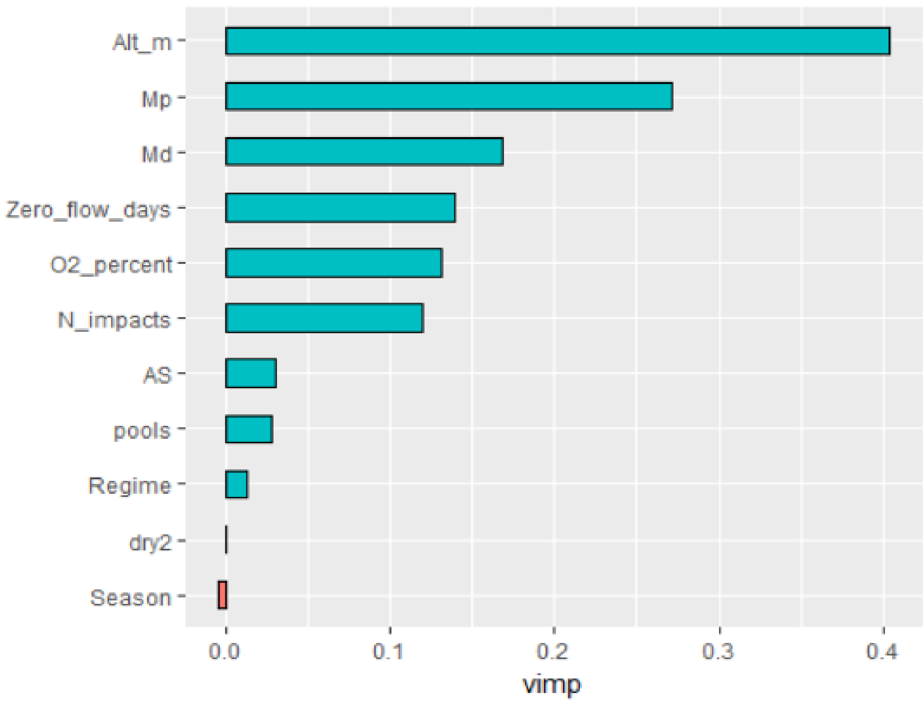


Figure A1.12. Predictor's VIMP value for the total species body length RF model.

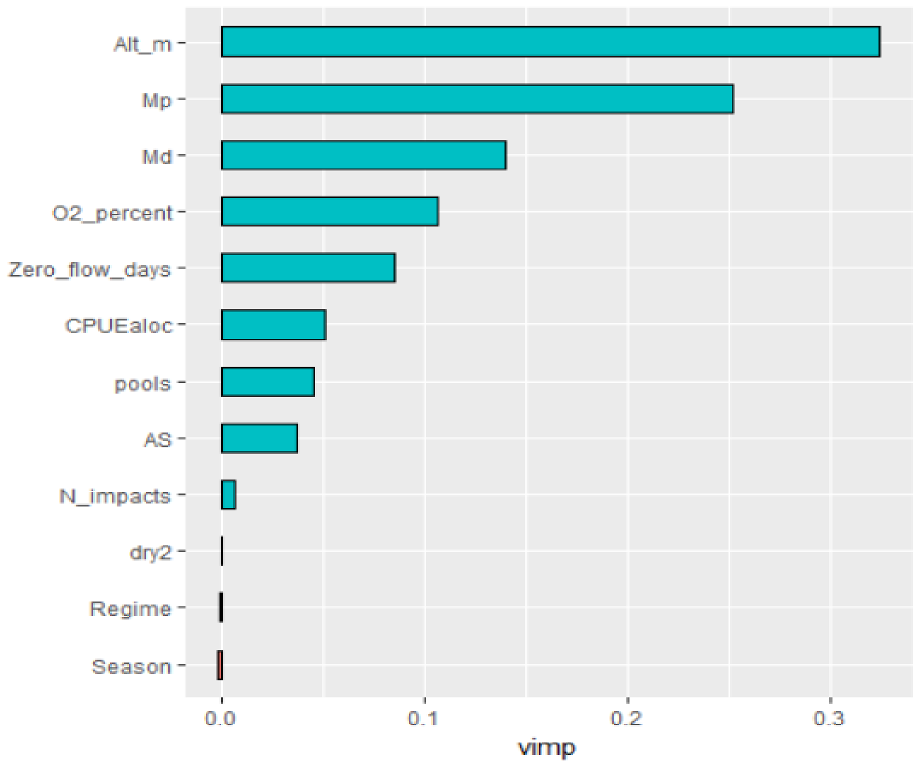


Figure A1.13. Predictor's VIMP value for the autochthonous species body length RF model.

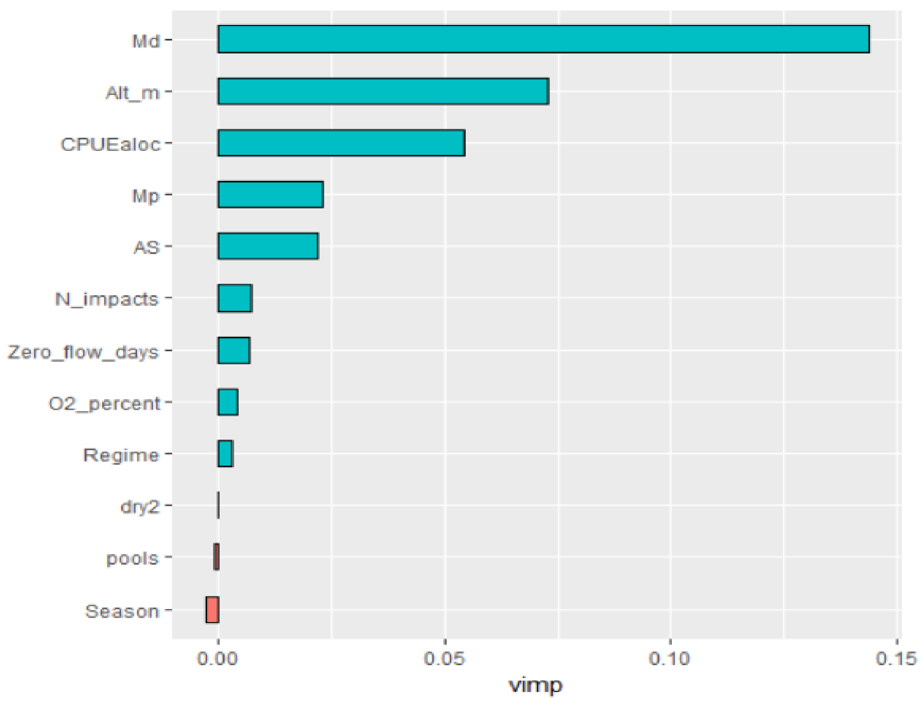


Figure A1.14. Predictor's VIMP value for the autochthonous cyprinids species body length RF model.

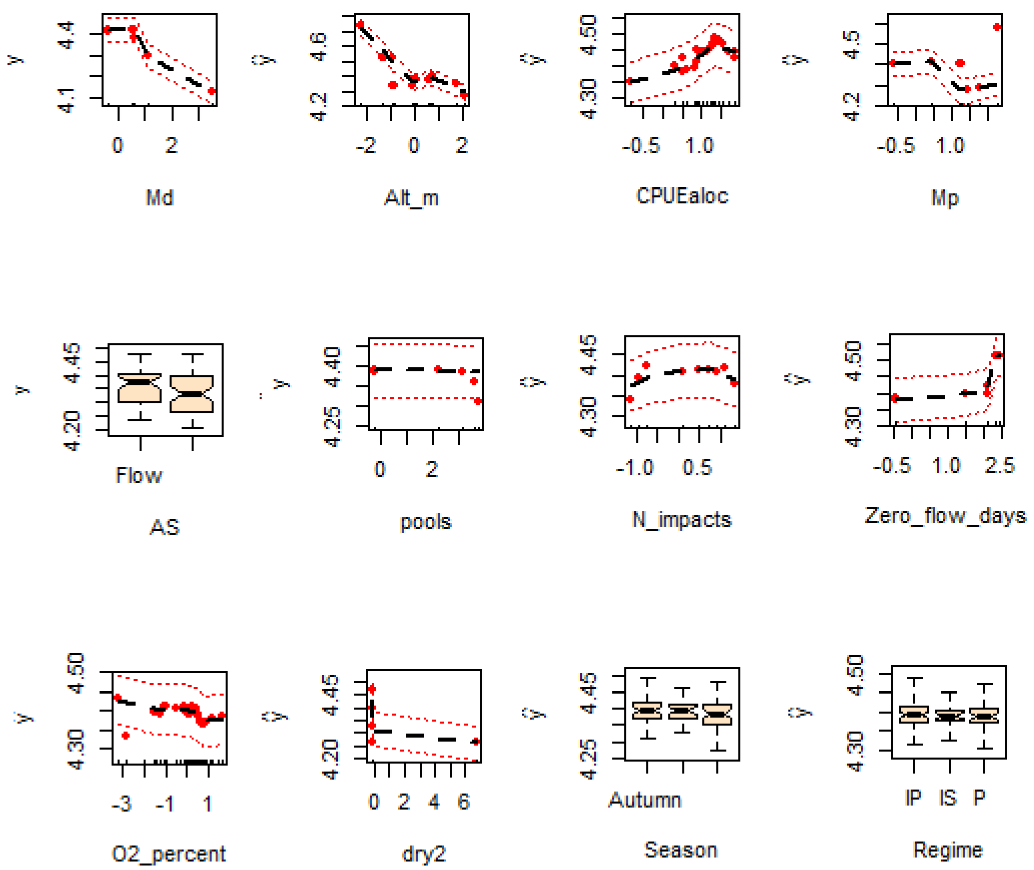


Figure A1.15. Marginal response plots of the autochthonous body length to the different predictors included in the RF.

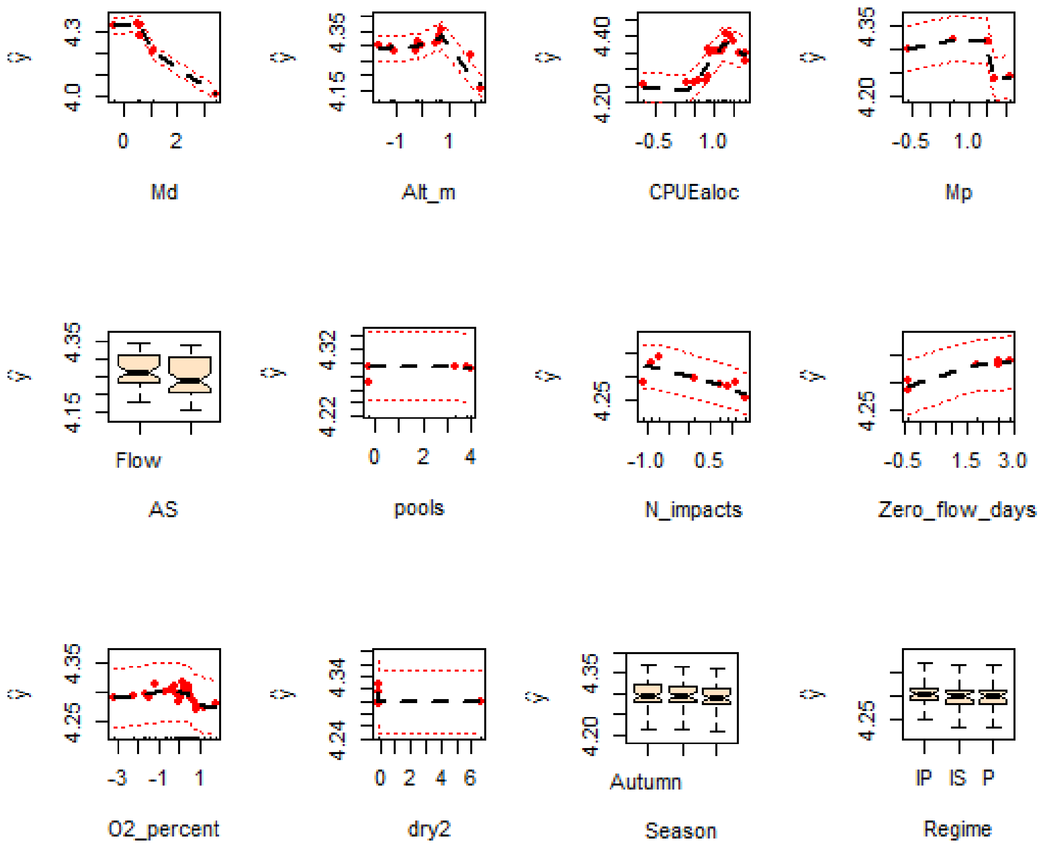
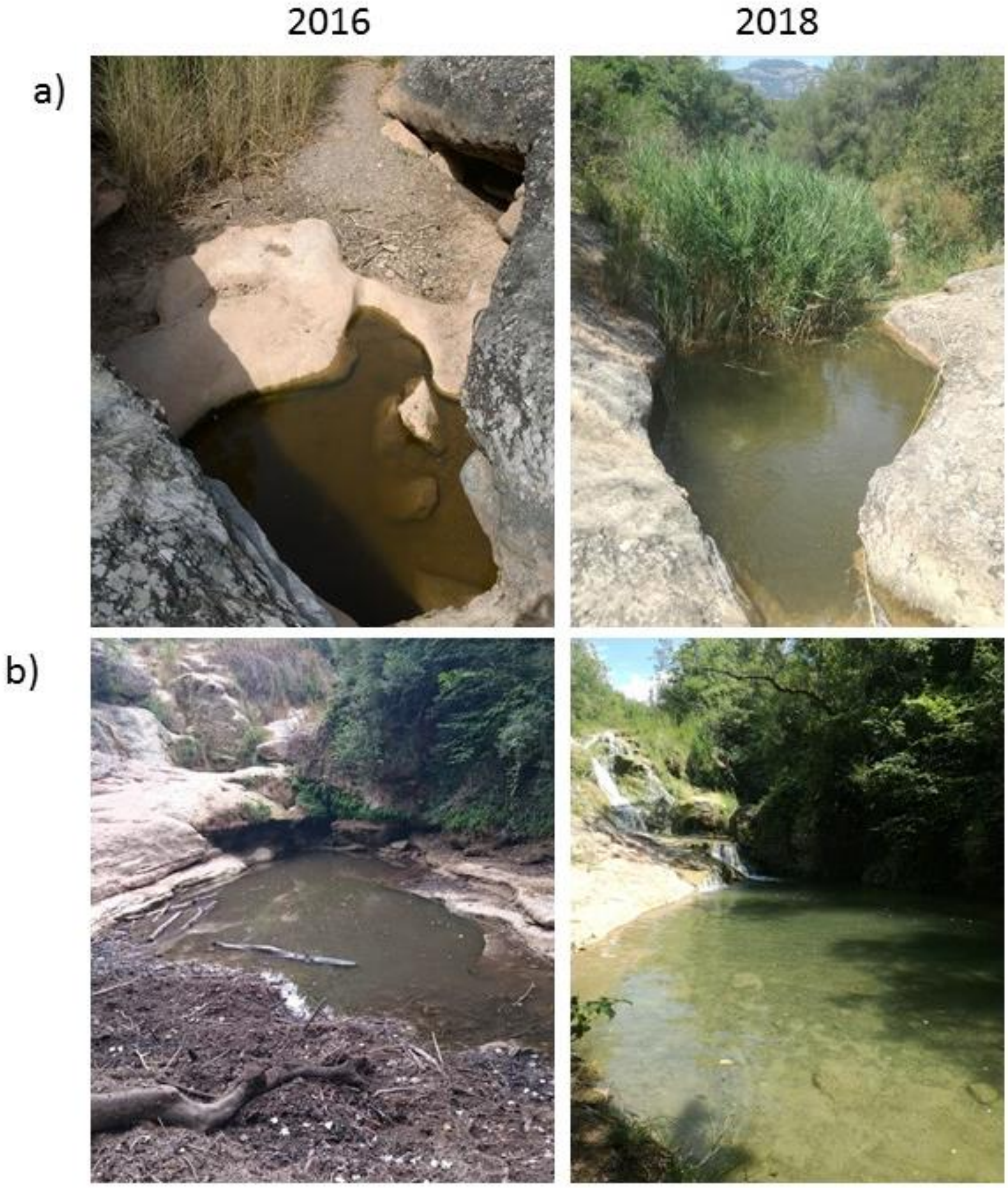


Figure A1.16. Marginal response plots of the autochthonous cyprinid body length to the different predictors included in the RF.

Annex 2

Figure A2.1. Aspect of the pools in July 2016 and July 2018. A) Pool B3 in Castelló stream. B) Gorg del Padre in Nespres stream (not sampled).



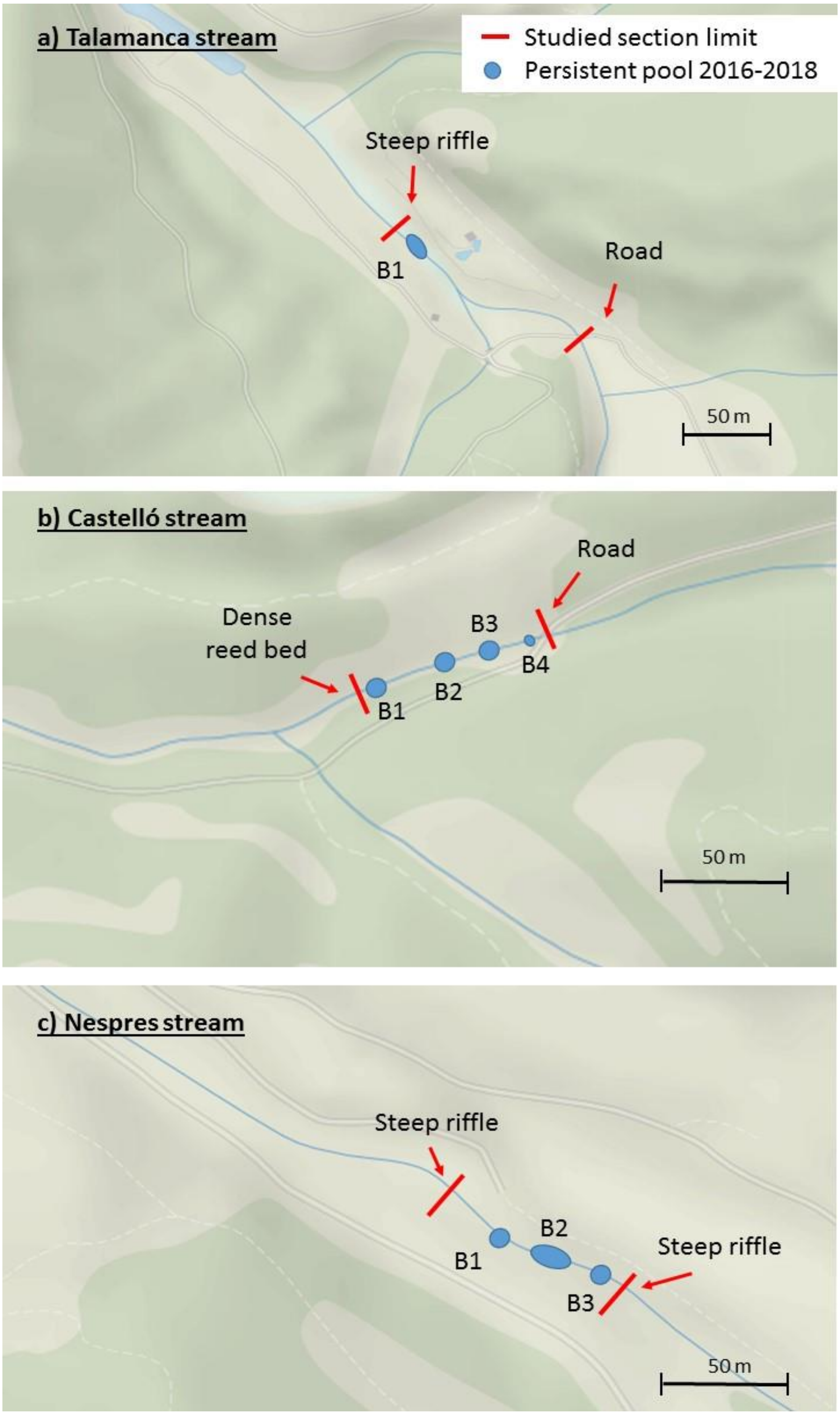


Figure A2.2. Morphology of the studied sections. a) Talamanca stream b) Castelló stream c) Nespres stream.

Table A2.1. Physicochemical characteristics of the sampled sites during the dry (2016) and wet year (2018).

	ID	Ta (ºC)	O_2 (%)	O_2 (mg/L)	Cond (uS /cm)	pH	AS	Dis-charge (L/s)	Wet area (m^2)	Water volume (m^3)
2016										
Tala-manca	B1	22.8	44	3.8	429	8.08	Pool	0	17.92	6.83
Castelló	B1	20.6	33.7	3.06	520	8.03	Pool	0	14.49	3.07
	B2	18.3	21.1	1.98	435	8.04	Pool	0		
	B3	20.6	47.9	4.29	463.1	8.36	Pool	0		
	B4	24.5	101.5	8.39	63 8	8.72	Pool	0		
Nespres	B3	22.6	65	5.61	586	8.41	Pool	0	23.62	8.59
	B4	22.6	65	5.61	586	8.41	Pool	0		
	B5	22.6	65	5.61	586	8.41	Pool	0		
2018										
Tala-manca	Section	18.8	83	7.02	602	7.78	Flow	0.88	151.56	18.31
Castelló	Section	10.6	99.3	8.92	550	-	Flow	4.42	193.99	29.54
Nespres	Section	14.3	87.65	8.99	484	8.18	Flow	31.54	201.06	27.46

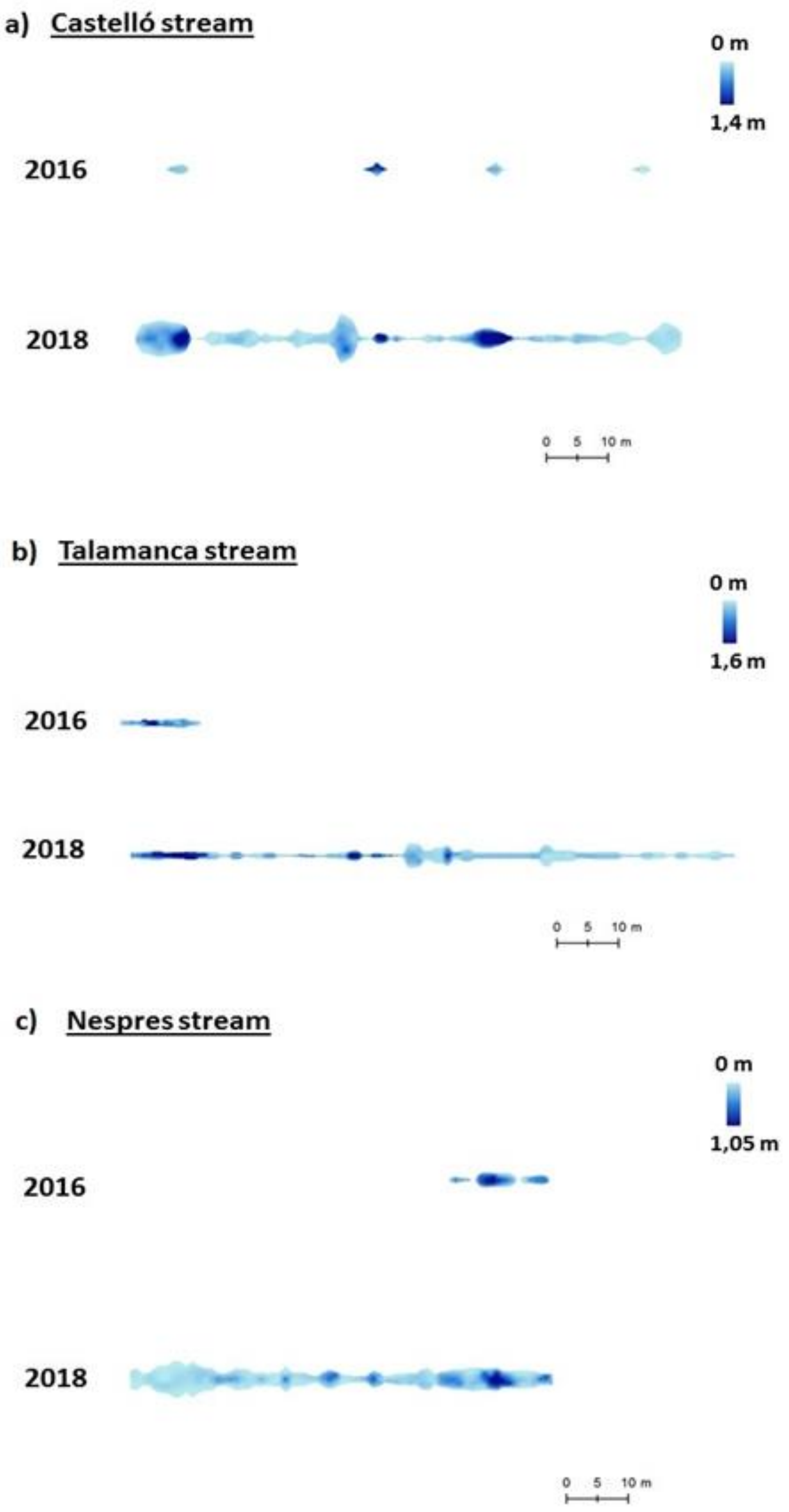


Figure A2.3. Digital elevation models (DEM) created using ArcMap 10.6 for the samples of 2016 and 2018. a) Castelló stream, b) Talamanca stream and c) Nespres stream.

Table A2.2. Summary of the fish density and size-related variables measured at each sample.

	Species	Mean BL	Std D BL	Min BL	Max BL	Size diversity	Nº ind	Nº ind corrected	Density (ind/ha)
2016									
Talamanca	*B. haasi*	40	42.43	10	70	0.30	2	2	1133.79
Castelló	*B.meridionalis*	53.81	21.17	24	120	1.44	52	52	43369.47
	G. holbrooki	23.81	2.66	21	32	0.71	16	16	13344.45
	L. gibbosus	66	4.24	63	69	0.30	2	2	1668.06
Nespres	*B. haasi*	72.09	38.17	24	155	1.17	23	23	10658.02
	Phoxinus sp.	41	15.48	25	60	0.58	5	5	2316.96
	S. laietanus	167.5	3.54	165	165	0.30	2	2	926.78
2018									
Talamanca	*B. haasi*	58.78	33.79	19	180	1.76	125	204	13520.59
Castelló	*B.meridionalis*	40.47	22.97	12	134	1.34	63	96.9	4996.29
	G. holbrooki	-	-	-	-	-	0	0	0
	L. gibbosus	-	-	-	-	-	0	0	0
Nespres	*B. haasi*	117.40	18.43	102	148	0.70	5	8.2	407.67
	Phoxinus sp.	51.36	6.84	40	73	1.2	59	118	5868.89
	S. laietanus	-	-	-	-	-	0	0	0