Alteration of the river regime downstream small hydropower schemes. Exploratory analysis of the effects on the vegetation of the river corridor

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Abstract: The study described in this paper aimed at characterizing the alterations induced in the river flow regime by small hydropower schemes (SHPs) as well as their effects in the aquatic and riparian vegetation. Twelve small hydropower schemes at the North of Portugal were selected as case studies and characterized. Information about the riparian and the aquatic vegetation in river stretches where the schemes are located was collected and summarized in the form of metrics. For each SHP the daily inflows in natural conditions (i.e., prior to the scheme construction) were established based on a transposition/regionalization model developed for mainland Portugal. By simulating the daily exploitation of each scheme the daily flows between the water intake and the turbine tailrace and downstream the turbine tailrace were computed. The flow regime alteration was quantified through indicators of hydrologic alteration. The statistical procedure Principal Component Analysis (PCA) was used to identify relationships between the calculated indicators at the various case studies. It was concluded that there is significant alteration in the flow regime, namely in the river reach between the SHP water intake and the turbine tailrace. On the other hand, little or no change was observed between the flow regimes downstream the turbine tail race and upstream of the water intake. Based on the results of the vegetation metrics for the monitoring locations, we observed a small decrease in the ecological quality of the interfered and modified river stretches, when compared with natural ones.

Keywords - Small hydropower schemes; natural, interfered and modified flow regimes; indicators of hydrologic alteration; river flow modelling; aquatic and riparian vegetation.

1. INTRODUCTION

The temporal irregularity of the flow regime and the increasing water demands promote the construction of dams for multiple purposes, including hydropower generation, domestic and industrial consumption, flood control and irrigation. The river regime, in its different perspectives (quality, quantity and temporal variability), is the most important factor for aquatic and riverside vegetation communities. In this sense, river fragmentation through implementation of dams produces an important impact on those communities.

Most studies addressing hydrologic alterations in Iberian rivers were focused in large dams (e.g.: Cardoso, 2013; Martins, 2012), as well as research on impacts in aquatic and riparian vegetation (Bejarano *et al.*, 2012; Belmar et al., 2013). Small hydropower schemes (SHPs) defined as schemes with an installed

capacity up to 10 MW and minor environmental impact, have been understudied, although there are some works with unquestionable value about the issue (Monterroso, 2005; Harris, 1987).
The present study intended to characterize the alterations in the river flow regime due to SHPs and their effects on the riparian and aquatic vegetation.
To achieve this goal, a number of steps are taken for each one of the eleven SHPs and adopted as case studies: (i) characterization of the scheme with regard to the energy production conditions; (ii) compilation of vegetation data; (iii) establishment of the natural daily inflows (e.i., prior to the scheme construction), based on a flow regionalization model; (iv) establishment of the river flows downstream the water intake based on a daily exploitation simulation model; (v) assessment of the river regime alteration through the use of indicators of hydrologic alteration, IHA; (vi) analysis of the results based on statistical tools.
Besides this brief presentation, this paper includes the following additional sections: II – Case studies and base data; III – Establishment of river flow regimes, on a daily time step; IV – Analysis of results; and V – Conclusions.

2. CASE STUDIES AND BASE DATA

2.1. Case studies

The selection of the case studies took into account the availability of vegetation data. The general location of the river reaches where the SHPs are located is shown in Figure 1. Each circle may represent one or more SHP.

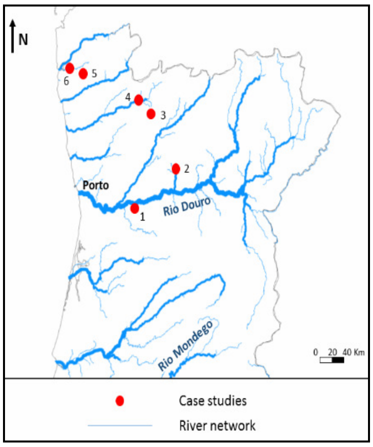


Figure 1 – Location of the case studies. 1. Cabrum River (Ovadas, Freigil and Aregos SHPs); Corgo and Sordo Rivers (Terragido and Sordo SHPs, respectively); Ouro River (Cefra SHP; Ave River: Guilhofrei, Ponte da Esperança and Andorinhas SHPs); Mestre River (Labruja SHP; Coura River: France SHPs).

The general layout of most of the schemes includes a small weir/dam, a diversion circuit comprising a channel/tunnel, a penstock and the powerhouse. Some of the main characteristics of the case studies are mentioned in the following sections.
In order to analyse the alteration induced by each SHP in the flow regime and consequently in the aquatic and riparian vegetation, three river reaches with different flow regimes were considered: (i) the natural regime reach, or simply, **natural regime**; (ii) the interfered regime reach or **interfered regime**; and (iii) the modified regime reach or **modified regime**.
For each SHP, the natural regime refers to the flow regime that would occur in the absence of the disturbance induced by the scheme. The interfered regime refers to the flow regime between the water intake and the powerhouse of the SHP and is the regime which is expected to showcase the most significant

alteration from the natural regime. The modified regime refers to the flow regime downstream the powerhouse. The larger the reservoir, the wider becomes the span between natural and modified regimes, which means that in the case of run-of-river SHP the natural and the modified regimes are identical. The storage capacity of the reservoirs of the case studies and their design discharges are summarized in Table 1.

2.2. Base data

The data collected for each case study was organized into three groups: (1) technical attributes; (2) samples of daily flows at neighbour river gage stations; (3) vegetation data extracted from EDP's monitoring points.
The data of group (1) was collected from APREN, 2013 and EDP, 2011, and included the following attributes: water intake and powerhouse location coordinates; watershed area; reservoir capacity; channel/tunnel length; number and type of turbines; gross head; design discharge; ecological discharge, installed capacity and annual energy production.
For group (2), river gages stations were selected based on their proximity to the case studies and on the similarity of the mean annual flow depths in the corresponding watersheds. For those stations the daily flow samples were acquired via the SNIRH data basis. Table 2 specifies the river gages stations that were analysed aiming at establishing the daily flow regime at the case studies. Group (3) consists of vegetation information data sampled for EDP, SA. Surveys were made during the main vegetation period, at late spring-early summer of 2011, 2012 and 2013, by zigzagging across the channel or by walking along banks. The information was arranged into the form of vegetation metrics which, admittedly, display variation when there is an alteration of the flow regime. Vegetation data included aquatic and riparian vegetation collected at the submersed channel and at the riparian zone. Species were recorded in a 100-m section of the river channel, including the in-stream part of the channel that may be exposed temporarily under conditions of dry-water flow due to the Mediterranean climate characteristics.

3. ESTABLISHMENT OF RIVER FLOW REGIMES, ON A DAILY TIME STEP

3.1. Natural river flow regime

To characterize the natural regime of the inflows at each case study a transposition procedure was applied to the flow data acquired in one or more river gage stations. For that purpose the regional model developed by Portela & Quintela, 2006, and widely tested for mainland Portugal was adopted, according to the following steps:

1. Estimation of the mean annual flow depth under natural conditions in the watershed of the case study, H_2, and computation of the respective modulus, $Qmod_2$.
2. Identification of a river gage station also in natural conditions, with a watershed as close as possible to the one of the case study, presumably with identical geological conditions and with a mean annual flow depth, H_1, similar to H_2; computation of the modulus at the river gage section, $Qmod_1$.
3. Transposition of the daily flow records measured at the river gage station to the case study by applying the equation:

$$Q^{2}_{i,j} = Q^{1}_{i,j}\,\frac{Q_{mod\,2}}{Q_{mod\,1}} \qquad (1)$$

where theindexes 1 and 2 refer to the river gage station and to the case study, respectively, $Q_{i,j}$ is the daily flow in day i of month j and Q_{mod} represents the modulus.
In step (1) different estimates of H_2 were obtained based on: (a) the map with the contour lines of the mean annual flow depth in mainland Portugal obtained by Quintela, 1996; (b) the Turc formula applied to the mean annual values of the precipitation and air temperature Shaw, 1994, p, 269; and (c) a graphical relationship established by Quintela, 1996, for mainland Portugal that provides the mean annual flow depth

in a watershed as a function of the mean annual values of the precipitation and of the air temperature over the watershed and of the group of soil in the same. The estimation of the mean annual values of the precipitation and air temperature utilized maps of contour lines available for mainland Portugal.
The values of H_1 and Q_{mod1} in step (2) were obtained from the daily flow records at the river gage station. From the river gage stations presented in Table 2, three were not utilized in step (3), namely, Castro Daire (because its watershed is much bigger than those of other case studies) and Ponte Cavez and Quinta das Gregossas (both for having values of H_1 quite dissimilar from the corresponding values of H_2).
Table 1 shows the mean annual flow depths and modulus at each case study and at the corresponding river gages stations utilized in the flow transposition method.

Table 1 – Mean annual runoffs and modular flows of each case study and corresponding hydrometric stations.

Hydropower scheme	Watershed area (km^2)	Stoarge capacity of the reservoir (dam^3)	Design discharge (m^3/s)	Mean annual flow depth, H_2 (mm)	Modulus, $Qmod_2$ (m^3/s)	River gage station	Watershed area (km^2)	Mean annual flow depth, H_1 (mm)	Modulus, $Qmod_1$ (m^3/s)
Ovadas	27.1	90	2.15	961	0.83	Cabriz	17	776	0.42
Freigil	54.0	130	4.00	790	1.35	Cabriz	17	776	0.42
Aregos	54.0	0	2.92	790	1.35	Cabriz	17	776	0.42
Cefra	101.0	100	3.30	1088	3.49	Cunhas	294	878	8.83
Sordo	48.0	280	3.60	620	0.94	Ermida Corgo	337	825	2.77
Terragido	243.2	115	10.03	700	5.40	Ermida Corgo	294	878	36.15
Guilhofrei	122.0	17100	15.60	1200	4.64	Garfe	193	1236	8.83
						Cunhas	337	825	32.12
Ponte da Esperança	122.0	0	12.00	918	3.55	Garfe	193	1236	8.19
						Cunhas	337	825	0.17
Andorinhas	148.0	1200	19.70	1139	5.35	Garfe	193	1236	8.19
						Cunhas	337	825	0.17
Labruja	8.9	0	0.80	1454	0.41	Aspra	68	1275	8.83
						Forno da Cal	2143	532	7.55
						Cunhas	337	825	8.83
France	176.0	140	12.00	1289	7.19	Aspra	68	1275	7.55
						Forno da Cal	2143	532	8.83
						Cunhas	337	825	7.55

3.2. *Interfered and modified river flow regimes*

Based on the estimates of the mean daily flows in natural conditions in each case study, the assessment of the corresponding interfered and modified flow regimes utilized the daily simulation of the exploitation of the SHP. For that purpose a mathematical simulation algorithm based on the mass equation was developed and applied at a daily level.
The input data required by the algorithm included, besides the series of mean daily inflows to the SHP, the design discharge of the powerhouse (m^3/s), the reservoir capacity (m^3) and the design ecological discharge (m^3/s). Only for the SHP of Terragido, Sordo and Labruja it was possible to have the design values of the ecological discharge (237.0, 100.0 and 17.5 l/s, respectively). For the rest of the case studies, the ecological discharges were set equal to 5% of the modulus. For each day, the algorithm returns the ecological discharge effectively released downstream (m^3/s), the turbinated discharge (m^3/s), the discharge through the spillway when the reservoir is full (m^3/s), and the current volume of water stored in the reservoir (m^3).
The interfered regime flow in each day was set equal to the sum of the ecological discharge plus the release through the spillway, and the modified regime flow to the sum of the interfered regime flow plus the turbinated discharge.
The daily simulation algorithm utilized the following exploitation rules:

1. The ecological discharge has priority regarding all the other discharges which means all the inflows smaller than the design ecological discharge are automatically release downstream, feeding the interfered river reach; when the inflows are equal or greater than the previous ones, at least the design ecological discharge is ensured along that reach.
2. If the inflow exceeds the design ecological discharge, the surplus is turbinated until its maximum value that is, until the design discharge of the powerhouse.

3. If the previous surplus is smaller than the design discharge of the powerhouse and if there is water stored in the reservoir, then the turbinated discharge is increased as much as possible (provided it is kept below its design value) by emptying the reservoir.
4. The inflows that exceed the sum of the design values of the ecological discharge and of the powerhouse are stored in the reservoir and release through the spillway when the reservoir attains is full capacity, contributing to the flows in the interfered river reach.

At the beginning of the application of the simulation algorithm the reservoir was considered empty (boundary condition). As mentioned, the algorithm provides the daily flow series of the interfered and modified river regimes. When applied to a case study downstream another case study having a reservoir with storage capacity, the inflows at the downstream scheme were given by the modified flows resulting from the upstream scheme.

3.3. Global assessment of the performance of the regionalization model

To conclude about the consistency of the estimates of the daily flows at the case studies the mean annual values of the energy production presented by EDP, 2011, and resulting from the daily simulation algorithm were compared. The computation of the mean annual energy, *E*(GWh), produced in each case study was done according to:

$$E = \frac{9.8\, h\, V\, \eta}{3600} \quad (2)$$

where h is the net head (m) obtained by multiplying the gross head presented in EDP, 2011, (Table 2) by a head factor that combines all the head losses taking into account the layout of the diversion circuit (often around 2.5%, but obviously depending on this layout); V is the mean annual turbinated volume (hm^3) resulting from the simulation algorithm and η is an average efficiency of the powerhouse (circa 88%).

Because the values of the head factor and of efficiency η were not made available by EDP, in the simulation algorithm they were allowed to vary, within reasonable limits fixed according to the experience of the authors, so that the energy production resulting from the algorithm would be as close as possible to the one presented in EDP, 2011. Table 2 displays the results achieved, including the mean annual energies provided by EDP, 2011, and resulting from the simulation algorithm.

For the five last case studies the table presents results from more than one river gage. Despite the similarity among mean annual energies presented in EDP, 2011, and given by the simulation algorithm, the stations of Garfe, Aspra and Forno da Cal were excluded from the remaining analysis because their counterpart – Cunhas station – also ensured good approximations and has a larger recording period, making it more statistically representative.

Results at Table 2 clearly show that, with two exceptions, the mean annual energy productions according to EDP, 2011 and given by the daily simulation algorithm are remarkably similar. This circumstance confirms the suitability of the implemented approach, with emphasis to the daily flow transposition model, but also to the simulation model and respective assumptions. The only exceptions were Aregos and Sordo case studies where the models did not perform so well, at least, within the range of acceptable values of the head factor and of the powerhouse efficiency. However, as the results are still acceptable those two case studies were included in the following analyses.

4. ANALYSIS OF THE RESULTS

4.1. Pardé-coefficients

The comparison, at the daily level and for each case study, between the natural flow regime and the interfered and modified flow regimes utilized the Pardé-coefficients (Matos *et al.* 2010). For each day, *d*, the

Pardé-coefficient, PC_d, is defined as the ratio between the average of the flow in that day, Q_d, and the average daily flow over the recording period, i.e., the modulus, Q_{mod}. PC_d is therefore a dimensionless daily flow given by:

$$PC_d = Q_d / Q_{mod} \tag{3}$$

Table 2 – Comparison between mean annual energy presented by EDP, 2011, and given by the daily simulation algorithm. Names of gage stations and recording periods are given

Hydropower scheme	River gage station	Recording period	Mean annual energy production according to EDP, 2011 (GWh)	Conditions and results from the daily simulation algorithm				
				Head (m)		Average efficiency of the powerhouse (-)	Mean annual turbinated volume (m^3)	Mean annual energy production (GWh)
				Gross	Net			
Ovadas	Cabriz	1966/67-1996/97	14.2	334	307	0.88	19.24	14.17
Freigil	Cabriz	1966/67-1996/97	10.3	127	124	0.88	32.60	9.67
Aregos	Cabriz	1966/67-1996/97	9.8	124	121	0.88	29.03	8.41
Cefra	Cunhas	1949/50-2005/06	5.2	54	49	0.84	49.53	5.50
Sordo	Ermida Corgo	1956/57-2005/06	21.3	321	313	0.88	22.54	16.90
Terragido	Ermida Corgo	1956/57-2005/06	31.7	127	124	0.88	105.58	31.32
Guilhofrei	Garfe *	1982/83-1991/92	11.0	35.6	35	0.88	131.43	10.93
	Cunhas	1949/50-2005/06			35	0.88	128.89	10.72
Ponte da Esperança	Garfe *	1982/83-1991/92	8.0	29	28	0.88	119.84	8.12
	Cunhas	1949/50-2005/06			28	0.88	112.85	7.64
Andorinhas	Garfe *	1982/83-1991/92	19.0	53	52	0.89	152.16	19.05
	Cunhas	1949/50-2005/06			52	0.90	149.24	18.89
Labruja	Aspra *	1980/81-1989/90	2.9	148	138	0.88	9.07	2.99
	Forno da Cal *	1979/80-1987/88			144	0.88	8.36	2.89
	Cunhas	1949/50-2005/06			144	0.88	8.15	2.82
France	Aspra *	1980/81-1989/90	25.7	76	72	0.88	149.38	25.84
	Forno da Cal *	1979/80-1987/88			74	0.88	137.66	24.44
	Cunhas	1949/50-2005/06			74	0.94	134.58	25.52

* River gage station not adopted in the development of the analysis.

Because the inflows at any of the case are indistinguishable from the flows of the modified regime (or even equal to these last flows), only the comparison based on the Pardé-coefficients applied to the natural and interfered regimes is relevant. Figure 2 exemplifies such comparison for the Ovadas SHP, clearly denoting the dissimilarity between regimes due to the scheme.

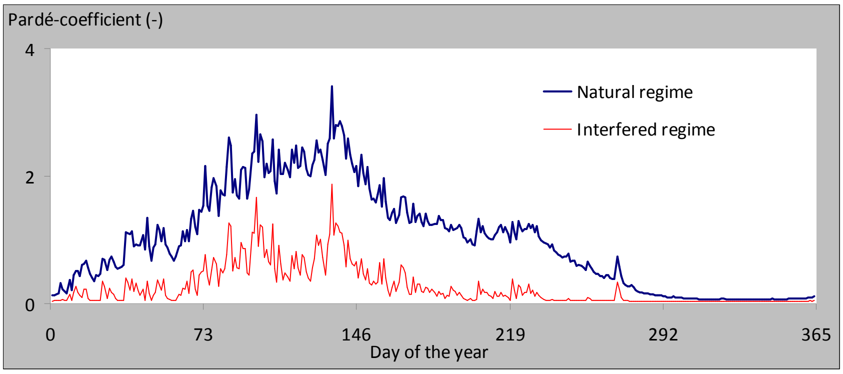


Figure 2 – Pardé-coefficients on a daily scale for the Ovadas case study.

4.2. *Hydrologic alterations*

To properly analyse the obtained daily flow data, a set of hydrologic metrics which have been largely applied in eco-hydrological studies were used – the indicators of hydrologic alteration, IHA (Richter et al. 1996). These indicators are a suite of statistics that characterize the inter annual and intra annual variation of the stream flow regime and are estimated using daily flow series of records (Table 3). The calculation of the

IHA for the overall locations of the various case studies was performed using the IHA v7.1 software (The Nature Conservancy, 2006-2009). Median values of IHA were used in the present study.

Table 3 – Indicators of Hydrologic Alteration, IHA (adapted from Richter et al., 1996)

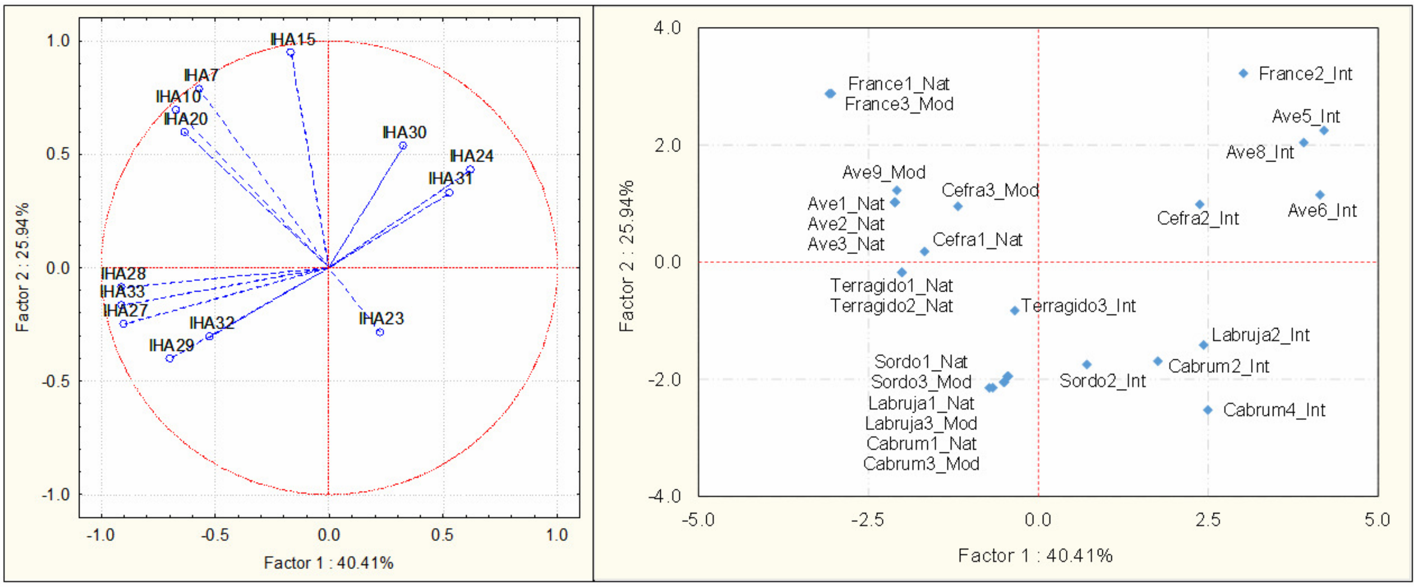
IHA Group	Flow regime characteristics	Indicators of Hydrologic Alteration, IHA		
1. Magnitude of monthly water conditions	Magnitude/ *timing*	IHA_1 a IHA_{12}	Median value for each calendar month	m^3/s
2. Magnitude and duration of annual extreme water conditions	Magnitude/ duration	IHA_{13}	Annual minima, 1-day median	
		IHA_{14}	Annual minima, 3-day median	
		IHA_{15}	Annual minima, 7-day median	
		IHA_{16}	Annual minima, 30-day median	
		IHA_{17}	Annual minima, 90-day median	
		IHA_{18}	Annual maxima, 1-day median	
		IHA_{19}	Annual maxima, 3-day median	
		IHA_{20}	Annual maxima, 7-day median	
		IHA_{21}	Annual maxima, 30-day median	
		IHA_{22}	Annual maxima, 90-day median	
		IHA_{23}	Number of zero-flow days	days
		IHA_{24}	Base flow index	-
3. Timing of annual extreme conditions	Timing	IHA_{25}	Julian date of each annual 1-day minimum	days
		IHA_{26}	Julian date of each annual 1-day maximum	
4.Frequency and duration of high/low pulses	Magnitude/ frequency/duration	IHA_{27}	Number of low pulses	-
		IHA_{28}	Median duration of low pulses	days
		IHA_{29}	Number of high pulses	-
		IHA_{30}	Mean duration of high pulses	days
5. Rate and frequency of water condition changes	Frequency/ rate of change	IHA_{31}	Rise rates	m^3/s
		IHA_{32}	Fall rates	
		IHA_{33}	Number of hydrologic reversals	-

A Principal Component Analysis, PCA (Jackson, 1991) was performed to relate the obtained IHA and the river reach regimes (natural, interfered, modified) of the various case studies. Analyses were done with the STATISTICA software, (StatSoft, Inc., 2007),

The PCA is a statistical procedure that uses an orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components. This transformation is defined in such a way that the first principal component has the largest possible variance (that is, accounts for as much of the variability in the data as possible), and each succeeding component in turn has the highest variance possible under the constraint that it is orthogonal to (i.e., uncorrelated with) the preceding components.

Since the number of IHA is far superior to the number of monitoring points, a correlation analysis between the hydrologic variables was undertaken in order to obtain a non-conditioned matrix. The following criteria were used to reduce the dimensionality of the data: i) exclude IHA that showcased values of correlation > 0.80 between each other; ii) keep, at least, one indicator from each of the IHA groups 1,2,4 and 5 displayed in Table 3, and iii) if possible, in case of doubt between two correlated indicators, the indicators mentioned in Belmar *et al.* (2013) should be kept – which are, according to these authors, the indicators which display the most significant relation to the river vegetation of iberian fluvial systems.

A matrix including the values of the selected indicators for each of the twenty six vegetation monitoring locations was used to perform the PCA. Figure 3 contains bi-dimensional graphs whose axes correspond to scores for the two principal components of greater variance (named factor 1 and factor 2, displaying variances of 40.41% and 25.94%, respectively).



a) b)

Figure 3 – Ordination biplots of the first and second axes, showing the eigenvectors of the IHA (a) and the monitoring reaches (b). Names of monitoring locations are related to the respective SHP, exception made to those of the Ave River. The _Nat (natural regime), _Int (interfered regime) and _Mod (modified regime) suffixes were added for ease of interpretation. Acronyms for IHA are given in Table 3.

By analysing the PCA biplots, some considerations can be done. Every river reach in interfered regime is located to the right side of the vertical axis, with the exception of the interfered location of Terragido case study. This result suggests that the river flow regime variability is similar in between interfered regime river reaches and in between natural and modified regimes.

It can be observed that, exception made to the Labruja case study, which is different from the remaining case studies for being associated to a far smaller watershed, the locations displayed in the first quadrant have a mean annual runoff in between 1090 and 1290 mm, or, simply, superior to 1000 mm, while, for the case studies displayed in the third quadrant, the mean annual runoff ranges between 620 and 960 mm, or simply, lower than 1000 mm. The mean annual runoff is a variable that characterize the temporal variability of river flow regime whether inter-annual or intra-annual variability, and it is expected that such variability is more apparent as the mean annual runoff diminishes. Therefore, the IHA were able to group SHPs with expectably similar river regimes.

It might also be interesting to note that, for the interfered regimes located in the second quadrant, the corresponding natural and modified regimes are displayed in the first quadrant, while the same relation can be observed between the fourth and third quadrants, except for the Terragido case study.

In the second quadrant, the interfered regime locations of France, Ave, Cefra, are displayed, which is related to the IHA_{30}, IHA_{24} and IHA_{31} indicators, while the fourth quadrant displays the interfered regime locations of Sordo, Cabrum and Labruja, which is related to IHA_{23} (‘number of days with no flow’).

On the other hand, the indicators displayed in the first quadrant – IHA_7, IHA_{10}, IHA_{15} and IHA_{20} – are all related to the minimum and maximum values of the median flows.

Ultimately, one of the main conclusions to be taken from this analysis is that there is a factual difference between the river reaches downstream and upstream of the water intake, and a similarity between river flow regimes upstream of the same structure and downstream of the power house.

4.3. Ecological response of plant communities to hydrologic alterations

Riparian forests of studied rivers were dominated by alders, ashes and willows. The shrubby strata included frequently the hawthorn, the dyer's buckthorn, and the tree heath. The floristic list of monitoring locations had more than 150 species, of which most of species were hygrophytes (associated with the river and wet environments). There were few strictly aquatic species (hydrophytes), ranging from no aquatic species to four species at the monitoring locations, as was reported in other studies in this region (Aguiar et al., 2009).
Prior to the analysis of the effects of hydrologic alterations in the plant communities, we explored the differences in climatic, geomorphological and habitat factors between monitoring locations by hierarchical classification, and using the software PRIMER (Clarke & Gorley, 2006). Though most of monitoring locations within case studies were similar, Rio Ouro and River Ave displayed differences between monitoring locations (natural and interfered/modified), which added some noise in data, and influenced the interpretation of the vegetation responses to stream flow alteration. Thus, in future studies, the amount of field data, i.e. number of floristic surveys and case studies should be sufficient to permit a more consistent analysis of the results.
Plant traits were assigned to each species and functional, compositional and structural metrics, with expected responses to flow alterations were obtained and compared between monitoring locations (natural, interfered and modified) and analysed, according to expected responses. This comparison indicates that, most of the metrics displayed expected responses to hydrologic alteration (Figure 4 and Table 4). However, given the small number of floristic surveys, the statistical significance of this variation was not performed, and variations were frequently small.

Table 4 – Expected and observed responses of vegetation metrics.

Vegetation metric		**Type of assessment; units**	**Expected response**	**Observed response**
Category	**Designation**			
Functional metric of the river regime	Hygrophytes	Richness; Number	↘	↘
	Proportion of hygrophytes	Proportion;%	↘	↘
	Helophytes	Richness; Number	↘	↘
	Hydrophytes	Richness; Number	↘	↘
Functional metric of disturbance	Ruderal species	Richness; Number	↘	↘
	Proportion of ruderal species	Proportion;%	↘	↘
	Endemic species	Richness; Number	↘	↘
	Proportion of endemic species	Proportion;%	↘	not concordant
	Acidophyllous species	Richness; Number	↘	↘(modified)
	Proportion of acidophyllous	Proportion;%	↘	↘
	Exotic species	Richness; Number	↘	↘
	Proportion of exotic species	Proportion;%	↘	↘
	Exotic species cover	Abundance;%	↘	↘
	Weighted woody cover	Abundance;%	↘	not concordant
	Perennial species	Richness; Number	↘	↘
	Proportion of perennial species	Proportion;%	↘	↘□ (modified)
Funcional metric of indicator species	Cover of *Carex elata* ssp. *reuteriana*	Abundance;%	↘	↘(modified)
	Cover of *Erica arborea* +*Frangula alnus*	Abundance;%	↘	↘
Vegetation indices	RVI, Riparian Vegetation Index	value; 10-50	↘	↘
	IBMR, Macrophyte Biological Index for Rivers	value; 0-20	↘	↘

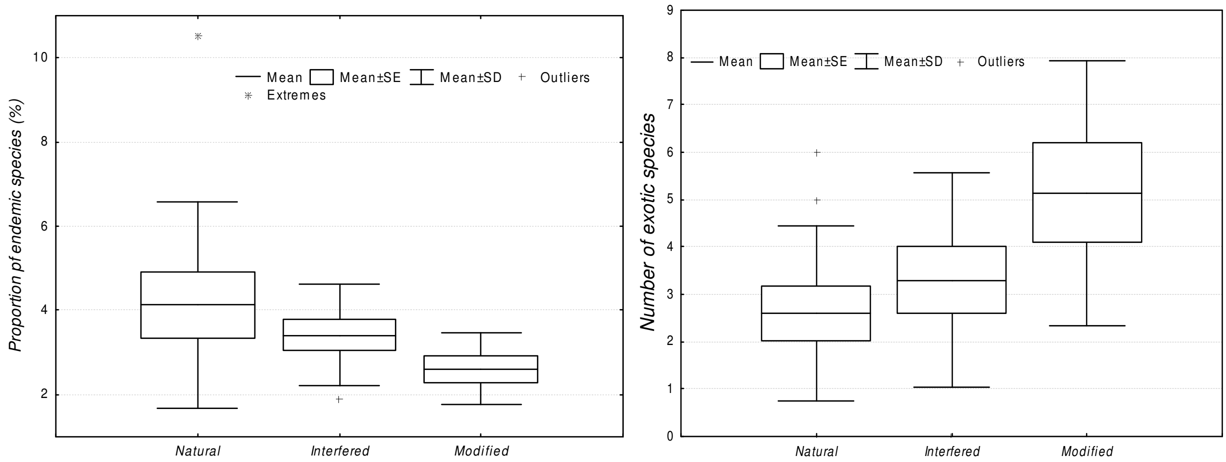


Figure 4 – Box-plots of vegetation metrics (examples for exotic and endemic species) at the studied locations.

The plant-based indices RVI (Aguiar *et al.*, 2009) and IBMR (Haury *et al.*, 2006), allow for an analysis of the ecological quality status of river systems for the overall river corridor and river channel, respectively. Eighty-five percent of the surveyed locations were classified as having Excellent and Good status of the overall river corridor, whereas concerning the aquatic environment, around seventy percent were classified as Excellent and Good. Both plant-based indices displayed a decrease from the natural to the interfered and modified locations, suggesting the need for further monitoring of these regulated river systems.
Modified flows were similar with the natural ones, but differences in flows during the day may be a cause for the decreasing of the ecological quality of the system. In addition, given the differences between hydropower schemes, the analyses should be done attending to these dissimilarities.

5. CONCLUSIONS

The present studied contributed to improve the knowledge of river regime alterations induced by small hydropower schemes in mainland Portugal and their effects in river plants. Admittedly, this approach may be used as a basis for similar studies. The main conclusions achieved are summarized as follows:

- The river flow transposition model of Portela & Quintela, 2006, as well as the algorithm developed to simulate SHPs, allowed for an accurate establishment of river flow regimes in each river reach – natural, interfered and modified;
- The river flow alterations are mostly relevant in the interfered regime (downstream of the water intake), and are mainly related with the frequency and duration of high/low pulses, and with the rate and frequency of water condition changes;
- The interfered regimes of Rivers Mestre, Cabrum, Sordo and Corgo are distinct from those of Rivers Ouro, Ave and Coura mostly due to the magnitude of monthly water conditions, and magnitude and duration of annual extreme water conditions;
- A decrease of the ecological quality is observed in reaches with interfered and modified river flow regimes, which might be indicative of the effects of hydrologic disturbance in the vegetation communities and in their lateral and longitudinal structure, making it deserving surveillance;
- Though responses of metrics were mostly concordant with what was expected under disturbance, the magnitude of changes was small, in comparison with the magnitude of alterations in the flow regime. Thus, further studies are needed to allow consistent conclusions;

- We observed similarities between the natural and modified regimes, but there might be significant hourly hydrologic variations, not quantifiable in this work, which are relevant to the structure and composition of vegetation downstream of power houses;
- The methodology applied to these case studies can be replicated for other small hydropower schemes, with the careful prior analysis of other environmental and habitat variables, so that the study of the disturbances due to river flow regime alterations is reliable.

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