The authors are very grateful for the comments of the anonymous reviewer 1 and reviewer 2 – Maurits Ertsen. The concerns of the reviewers are pertinent and their suggestions much appreciated. The authors believe that such constructive criticism certainly improved the quality of the paper. An extensive revision was made with clarification of the issues raised by the editor and referees. Particularly, we improved the methods section and included a figure summarizing the methodology, we provided a detailed examination about our option for considering a static geomorphology during modeling, and we deposited all data in a reliable public repository. We believe that this revised version is much improved and we hope that that it now satisfies the concerns of the referees and handling editor. Bellow you will find detailed responses to the reviewers comments (in blue), stating exactly the changes performed into the revised manuscript. Thank you for allowing us the opportunity to revise this manuscript and contribute to Hydrology and Earth System Sciences Journal. Please do not hesitate to contact me if you have any questions.

Reviewer 1

Main concerns:

1. The methodological section should include some clarifications about the structure of...

The authors agree that a figure with a methodology scheme would improve the understanding of the modeling procedures. Such figure was included in the manuscript. Furthermore, the methodological section was improved by adding further details to ensure reproducibility of the results. In detail, the data transference from one model to another goes like this: the CASiMiR-vegetation model provides the riparian landscape scenarios resulting from each flow regime; these landscape scenarios, discriminated by succession phases, are transformed into roughness maps that are inputted into the River2D model and will characterize the channel roughness of each scenario during the hydrodynamic modeling for the corresponding flow regime. This explanation can be found in page 6, from line 22 to 29 but was strengthened by the methodology scheme and by the added details into the methods section. Also, an additional paragraph stating strengths and limitations of the models was included in the methods section (now in P7, L5-9; P8, L22-25).

About the aquatic zone, this is a misinterpretation resulting from different aquatic zone concepts and the authors realize now that such a simple explanation as the one presented in page 6, line 38, may go unnoticed or be misunderstood by a reader unfamiliar with CASiMiR-vegetation model. By aquatic zone, the authors were not talking about the channel wetted area, which is variable throughout the year. The aquatic zone in the sense of CASiMiR-vegetation model is the permanently inundated area by the river during the hydrologic year, this is, the area flooded by the absolute minimum discharge of the river. The concept underlying the definition of this zone is that herein riparian vegetation is not capable of establishing and develop because it is always under water and riparian vegetation needs grounds that are at least in some parts of the hydrological year out of water. This is only a concept that is incorporated in the modeling of the ecological succession of riparian vegetation by CASiMiR-vegetation in order to save computational resources that would be used in modeling areas that you know will never have riparian vegetation (as long as this area is permanently inundated). When using the hydrolynamic model River2D, all the river stretch is considered and the channel roughness is set according to the succession phases of each riparian landscape scenario as well as by the river

bed substrate where riparian vegetation is determined to be inexistent (this is, the aquatic zone *sensu* CASiMiR-vegetation).

The riparian vegetation landscape resulting from the CASiMiR-vegetation model will interact with river flow because the discharges in the considered flow regimes are always greater than the minimum discharge considered for the aquatic zone defined in the CASiMiR-vegetation model. Accordingly, all the area submerged by river flow in addition to this aquatic zone in the context of CASiMiR-vegetation will directly run through some succession phase of riparian vegetation. Furthermore, the interaction between river flow and riparian vegetation in the margins will influence the overall hydraulics, due to flow deflection or water retention in the margins, for instance, and thus, also the hydraulic parameters in the area without riparian vegetation will be affected. A better explanation about the definition of aquatic zone considered in the CASiMiR-vegetation model was also included in the text (now in P9, L13-16).

2. About flow regime definition (section 2.3) authors mentioned that...

The environmental flow regimes considered in this study were created in Ferreira et al. (2014) and used here. The proposal for an environmental flow regime created in Ferreira et al. (2014) considered two different flow regime components: a monthly flow regime addressing fish requirements and a multiannual flow regime composed by floods with different recurrence intervals addressing riparian vegetation requirements. The first component of this environmental flow regime, i.e., the flow regime addressing fish requirements (named Eflow in the manuscript) was determined according to the Instream Flow Incremental Methodology. The second component of this environmental flow regime to Rivaes et al. (2015). The environmental flow regimes used in this study were considered as an adaptation from Ferreira et al. (2014) because the authors used just the fish-addressing component as the standard procedure of an environmental flow regime considering only fish requirements (Eflow) and another environmental flow regime addressing fish and riparian requirements (named Eflow&Flush in the manuscript) composed by both components of the environmental flow regime proposed in Ferreira et al. (2014). Sentences were rewritten for a better understanding.

3. Regarding environmental flows considering riparian vegetation...

In this study, the sediment transport originated by the environmental flow regimes was not considered. The authors chose this approach based on their expert knowledge in previous studies, (namely, in Rivaes et al., 2015), where the sediment transport caused by dam flood discharges were modeled in two case studies and where results demonstrated, in both cases, that such flood discharges were not relevant for river bed degradation. Furthermore, in rivers with a bed substrate of much smaller sizes (pebbles and sand). As requested by the reviewer, a paragraph was included discussing this approach in the discussion section (now P13, L30-34).

4. Regarding vegetation modelling, CASiMiR model lacks of a crucial process such as the morphological evolution of the river...

The CASiMiR-vegetation model does not uses a fixed topography. CASiMiR-vegetation is not a hydraulic model but topography can be updated on a yearly basis during the input data upload into the dynamic module (see figure 21 of the CASiMiR-vegetation manual, page 35) of the model. Therefore, a comparison between modeling runs using fixed and variable topographies is possible using the CASiMiR-vegetation model. Nevertheless, the authors totally agree with the reviewer and are well aware of this interaction between river morphodynamics and riparian

vegetation with bi-directional influences, which is particularly important in very morphodynamic rivers. Although, the references provided by the reviewer are not good examples as those only refer to gravel riverbeds, which is not the case of our study sites. In fact, as mentioned by Corenblit et al. (2011), research on the temporal scales of geomorphic and ecological processes is still scarce, even more for such coarse substrate rivers. Every case must be analyzed with a critical thinking. In this case, using a fixed topography may be considered a flaw when modeling riparian vegetation but the authors made it intentionally. By using a fixed topography, the authors were able to isolate and better analyze the effect of riparian landscape degradation on river hydraulics. Furthermore, one may not forget that the authors already tested such flow regimes in other study sites with greater morphodynamics and showed that these flow regimes will not change topography in more than a few centimeters in a decade (see Rivaes et al., 2015). Also, incorporating topography changes in the modeling runs would not allow to address the results to a solely factor. The reasons that lead the authors to consider a fixed topography during this 10 year period were: 1- the typical substrate of both study sites is armored and very coarse (boulders, large boulders and bedrock), as mentioned; 2- no significant differences were found during the substrate analysis of the different succession phases regarding the data collected in the field survey that could allow the authors to infer substrate and topographic changes according to the succession phase, and therefore authors agreed not to forecast morphological changes in observed fairly stable topographies; 3- previous studies of the authors regarding this matter show that the considered floods do not bring substantial changes to river geomorphology; 4- flow velocities and water depths experienced in the study sites for monthly discharges are not expected to induce erosion in the existing river bed; 5- the study sites are located in a fairly steep valley in which the river is not allowed to meander considerably during such a short time scale; 6- this work is on a first part focused on the modeling of riparian vegetation dynamics in a representative proportion of the existing river landscape features and although the position of these features can eventually change over time, their overall proportion is expected to remain constant (Stanford et al., 2005) and posing no noteworthy effects on the analysis of vegetation dynamics. In fact, this last reason was the basis of the modeling methodology used by Politti et al. (2014) in which they verified that only from 25 years onwards the difference in the results of riparian vegetation landscapes using a fixed topography became notable in some parts of the study site. This was possible to observe because different topographies of the study site were available. Indeed, this study was conducted for the purpose of analyzing the effects of climate change on the riparian vegetation in an Alpine river exposed to a greater morphodynamics but provides support for the decision of the authors in disregarding morphodynamics in a minor time period and for a much more stable river. Furthermore, one must not forget that in this particular case, the model calibration and validation results while using the same methodology exhibited a good agreement with the observed riparian landscape. Thus, considering the previous premises, the authors are confident that the disregard of the river morphodynamics in this case does not bring a tangible shortcoming to this research. Notwithstanding, in order to clarify the reasoning for using a fixed topography, the authors included a paragraph in the methods chapter to explain better the use of this approach and another in the discussion section debating this option in the analysis (now in P8, L1-13 and P13, L21-30).

5. About results presentation, now this section is a bit confuse and I think it will benefit from...

The authors agree that one or two sentences can be included in the results section summarizing the main results. Although the authors provide the response to the research questions in the

manuscript, sentences were included to explicitly respond to those questions (now in P12, L4-6; P13, L1-6).

Specific comments:

Title: As your study encompass a decade, talk about "the long-term" is not very appropriate...

This "long-term" expression refers to the efficiency of environmental flows assessed by habitat modeling methods on the aquatic biota for which requirements it is said these flows are addressed to. The focus of this study is not on the effects of flow regulation on riparian vegetation but on the effects of environmental flows on aquatic fauna, surrogated by microhabitat metrics, in reaches for which environmental flow prescriptions are settle considering only aquatic fauna requirements. Accordingly, this research is more of a microhabitat analysis in which authors analyze the influence of the riparian landscape degradation on the hydraulic parameters water depth and flow velocity. Hence, for this spatial scale, the appropriate time scale would be, according to Frissell et al. (1986), of about 10⁻¹ to at most 10 years. The authors considered a time frame of a decade in order to obtain a notable response of the riparian landscape to flow regulation without the geomorphology constrains discussed previously, which in fact revealed to be appropriate to disclose a significant trend in the riparian landscape response, but the focus is still on the effects of microhabitat amendments for fishes, which clearly change gradually every year until the end of the decade. Indubitably, considering that dams are built to last a century or more, those amendments will certainly continue to happen until a metastable state equilibrium occurs over time. In this sense, we are talking about the influence of environmental flows obtained by habitat modeling methods over the long-term perspective of the aquatic microhabitat. The authors propose to change the title to: "Importance of considering riparian vegetation requirements for the long-term efficiency of environmental flows on aquatic microhabitat".

Introduction: Introduction section provides an appropriate "stat-of-the-art" about...

Done, the authors provided clearer answers to the research questions (now in P12, L5-6 and P13, L1-6).

Methods: Study site: Page 3 line 9: Authors use a very general reference...

Information about discharge data and return periods were included in the description of the study area (now P3, L35-37). Figure 1 was changed according to the reviewer comments.

Data collection: Please, give a brief description about field procedures like...

Although sent to literature to keep the manuscript not too long, additional descriptions about field procedures were included in the methods section (now in P4, L36 until P5, L2 and P5, L25-35).

Riparian vegetation modelling Page 5 lines 36-39: "the hydrological regime is inputted...

Yes, the hydric stress imposed by the duration of extreme low flows is also accounted by CASiMiR-vegetation model. The magnitude and duration of extreme low flows are reflected in the mean annual discharge of the river, which is a model input used as a reference for the general habitat conditions that determine the expected riparian landscape according to the thresholds of riparian succession phases. This information was slightly approached in the text (page 6, lines 1-2) but an additional paragraph was included for a better explanation regarding this issue (now P7, L17-22).

Page 6 Line 8: Authors have included many supplementary material which is very appreciate...

Done according to the reviewer suggestions.

Page 6 Lines 12-13: "The resulting riparian... hereafter named natural, Eflow and Eflow&Flush...

The authors changed the word "habitats" by "landscape" (throughout the text, e.g. P1, L16). Landscape ecology is the science that studies the interactions between biotic and abiotic structures, functions, and their spatial organization (Zonneveld, 1990). The riparian landscape is therefore a term used in the scope of this science and stands for the specific spatial patterns of riparian vegetation resulting from ecological, geomorphological and hydrological processes. The elements that compose riparian landscapes can be defined as the patches with different vegetation types and succession phases, like the ones that compose our vegetation maps. Thus, riparian landscapes should not be understood here like the river corridor as a landscape, but as the riparian zone functionally dominant feature that contains and connects the elements (Malanson, 1993). Accordingly, we think this term suits well the meaning of what we want to define by riparian landscapes, which is the riparian patch mosaic that derives from a specific flow regime. The explanation of what is a riparian landscape was also included in the text (now in P3, L15-17).

Table S5: in supplementary material contains some of the vegetation model parameters...

The authors can only speculate about the reasons for this discrepancy as no in-depth research was conducted to ascertain this issue. The resistance thresholds of riparian vegetation to shear stress deeply rely on the river geomorphology and ecophysiological traits of the riparian species. Differences between Politti et al. (2014) and these case studies are found in river type, flow regime, geomorphology, hydraulics and riparian species. The Austrian case study is located in an Alpine river of much greater dimension than the considered Mediterranean case, with greater catchment area, higher and longer maximum discharges, longer flood durations and with a phenomenon known as glacial milk, which confers much more sediment load to the flowing water. Furthermore, the higher discharges in this Alpine river occur during summer, when vegetation is in its vegetative period and consequently more vulnerable to these stresses. On the other hand, Mediterranean species are well adapted to the flow regimes flashiness, characterized by very short flood durations, mostly occurring out of its vegetative period. These are all differences in the river systems that can explain the different calibration parameterization of riparian vegetation resistance thresholds in these two river systems. For instance, if you look to the Spanish case study presented by García-Arias et al. (2013), in a river stretch much more similar to our case studies, you can see a model parameterization much closer to ours.

Hydrodynamic modeling Page 6 Lines 29-31 31. "The hydraulic characteristics of each habitat...

Yes, at this stage the hydraulic parameter values were considered all together regardless from succession phases. As mentioned in the manuscript research questions (page 2 lines 30 to 38), one of the objectives of this research was to question the capacity of fish-addressed environmental flows in maintaining fish habitat availability in the long-term. The used ecohydraulic approach was successful in this task, as the considered hydraulic parameters water depth and flow velocity were significantly different between scenarios. One may not forget that we are assessing fish habitat availability in the light of fish preference for water depth and flow velocity and that we are focused on the influence of riparian landscapes in the river flow patterns. An analysis of these hydraulic parameters by succession phase is feasible but would not bring (in this case) substantial increase of information as the main succession phase

interacting with river flow is Early Succession Woodland phase. This is due to the low discharges considered in the Eflow. Besides, one may not forget that the water depth and flow velocity in a certain microhabitat do not result only from the existing local conditions, but also from surrounding conditions. Furthermore, this kind of analysis would require data that the authors do not have, such as, fish preference curves for each type of vegetation indicator of each succession phase or the preference of fish species for hanging vegetation, for instance. For these reasons the authors think that analyzing the use of fish by each succession phase is quite out of the scope of the paper.

Results: In general, this section could be better structured with some sub-sections...

The authors agree and sub-sections were included in the text.

Page 7 Line 19: Here authors use "habitat" in a different context...

The authors agree and proceeded as proposed to the previous comment regarding this matter.

Page 7 Line 36: "The changes undertaken by the riparian vegetation facing different flow regimes are able...

The roughness values refer to the entire study site areas in each scenario while the values of water depth and flow velocity only refer to the areas inundated by the considered discharges as only there one can find water depth and flow velocity estimates. Once again, the authors are not analyzing the habitat suitability according with fish preference for the type of vegetation, but according to the preference of fish for water depth, flow velocity and substrate. The habitat suitability regarding these parameters can be computed independently from the type of vegetation. Although, the type of vegetation interfere in these parameters due to different characteristic roughness, which were considered during the hydrodynamic modeling.

Page 8 Lines 3-6: Comments about ks, it is not clear which comment refers to figure 4...

Figure 4 (now Figure 5) shows the distribution of the values regarding the considered hydraulic parameters for each study site. The tests presented in the supplementary material are a complement to the figure. The analysis on the differences in roughness, depth and flow velocity can be done by looking only to Figure 4 (now Figure 5). Due to the great amount of data, differences between landscapes are not very noticeable in some cases, namely in water depths and flow velocities. Nevertheless, there are statistically significant different groups that are characterized by the different letters in the figure. Consequently, the authors decided to include in the supplementary material the tests results that support the figure construction and the author statements regarding the significant differences in the hydraulic characteristics of each riparian landscape. But these test do not show the exact same information as the figure. When we stated that those differences were statistically significant, we felt obliged to present the statistical tests that support our statements. Additional clarifications were included in the text.

Figure 5: It is not indicated to which reach refer each set of graphics...

This information was added to the figure caption which was changed according comments.

Page 8 Line 34: "The Eflow habitat consistently provides less habitat suitability during autumn...

This is an error. You should read "... nase juveniles and adults...". Text was corrected (now P12, L25).

Discussion: As I mentioned before, the modelling techniques that authors used have...

Limitations of the used techniques were discussed in the discussion section. The used terms were homogenized and the paragraph rewritten. P10, L19 was also rearranged (now P15, L3-7).

Reviewer 2

Introduction

If I understand the argument correctly, the claim is that environmental flows for fish are...

When the authors refer to species with longer lifecycles they are talking in general to mention that the usual approach on environmental flows only takes into consideration the intra-annual variability of the fluvial system but there is an inter-annual variation that can influence the life cycle of many organisms and which should be considered. In this case, the authors used riparian vegetation as the example for their case study. Riparian vegetation was then introduced in the next paragraph (page 2, lines 24 and 25), where the authors explain its connection to the flow regime and to the aquatic fauna when one mentions that riparian vegetation has a clear significance in the habitat improvement of aquatic systems, with references provided. Notwithstanding, riparian vegetation was mentioned in the text as example in the considered sentence (now P2, L20).

Assuming that the paper focusses on fish and vegetation, the introduction should clarify much...

Because of the manuscript length, particularly the introduction section, the authors did not find necessary to present a deep bibliographic review about the relations between riparian vegetation and aquatic fauna. The reason for this decision is that the main scope of the manuscript is on the efficiency of environmental flows when ignoring riparian requirements and fish species were used as a surrogate for the response of aquatic communities to the expected riparian landscape changes. This response was approached from an ecohydraulic point of view, in which the river hydraulics was the considered linkage between these two communities (page 2, lines 30-33). Even so, references were presented showing the influence of riparian communities on aquatic species assemblages in order to highlight the importance of restoring riparian vegetation not only for the improvement of these communities but also for the inherent improvements that such restoration can bring to aquatic species (page 2, line 26). Nevertheless, this paragraph was improved to better clarify how riparian vegetation and fish species relate to each other (now P2, L29-39).

The research questions are not defined in a way that allows any other answer than that...

If the authors understood correctly the concern of reviewer 2, the objective of this research is not to demonstrate that habitat modeling is the only good method for environmental flow assessment. In fact, the authors never make that statement throughout the manuscript. However, this study is based on habitat analysis and the authors needed to use habitat modeling to address their research questions. The term "overlook" of the second research question means the disregard that common approaches for environmental flows definition have for other biological communities. This comes from the bibliographic review in the introduction section where it is mentioned the need for environmental flows to address the ecological requirements of different biological communities rather than only a single biological group, which usually are always fish species. The question here is not if environmental flows disregarding riparian vegetation requirements allow for the degradation of these communities. We have already noticed that from previous studies. Based on the bibliographic review, the authors did not know the answer to question 1 but they raised their hypotheses. First, the authors question if the fish habitat would stay the same throughout the years facing the degradation of riparian vegetation due to flow regulation. If changes in habitat are noticeable, second question is: what is the extent of that change due to neglecting riparian requirements. Nonetheless, the authors understand the concern of the reviewer and this sentence was changed by a more consensual one (P3, L19-21).

What is the "structural response" of riparian vegetation?

Riparian vegetation is structured or arrayed in space and time along gradients in the three river dimensions: longitudinal, lateral and vertical. A response of riparian vegetation to a certain driver implying a change in this structure is denominated a structural response of riparian vegetation. This expression is widely used in vegetation science nomenclature (e.g. NRC, 2002; Naiman et al., 2005) and the authors provided such references on the text (now in P3, L23 and 24).

Detailed remarks:

Page 1, line 33: would avoid using words like "truly".

This word was changed by "Actually" (now P1, L33).

Page 1, line 36: why "Therefore"?

The authors mean that this is a consequence of the previous sentence. However, this was changed for a better understanding (now P1, L36).

Page 2, line 6: "It is now in agreement" with only one reference is not very strong.

The authors agree. More references were added, namely, Brisbane Declaration (2007); Arthington (2012); Poff et al. (1997); Acreman et al. (2014); Acreman and Ferguson (2010) and Davis and Hirji (2003). Now in P2, L8-10.

Page 2, lines 10-11: what does "holistic" mean?

There are different methodology types for environmental flow assessment. One of those types are named "holistic methodologies" (see Arthington et al., 2003; Dyson et al., 2003; Tharme, 2003; Arthington, 2012) also known as "function analysis" (see Dyson et al., 2003). Holistic methodologies are meant to address river systems as a whole. These methodologies emerged parallel in Australia and South Africa and share one same purpose: to protect or restore the flow-related biophysical components and ecological processes of the entire river system. An explanation and references were included in the text to support the context in which this term was mentioned (now in P2, L12-15).

Page 2, line 15: why "clearly"?

The authors state "clearly" supported in the systematic synthesis of the global literature regarding environmental flows done by Gillespie et al. (2014), which realized that the majority of the studies reported to fish response and given the importance of all trophic levels in sustaining freshwater ecological integrity, the predisposition towards monitoring of this traditional indicator taxa is a concern. According to this author, also Olden et al. (2014) found this tendency and therefore verified a clear need for diversification of monitoring strategies to cover less typically monitored taxa in future studies. Notwithstanding, this word "clearly" was removed without changing the meaning of the phrase.

Page 2, line 16: do you need the word "biased"?

This comes in line with the previous question about whether environmental flow assessments are prone to fish response evaluation rather than other biological groups. This word was removed.

Page 2, line 35: "In what extent", does that exist?

The authors propose to change to "to what extent".

Methods

It is clear how the models link to the measurements. It is not clear at all how the models have...

Additional information about models calibration was included in the text (now in P7, L24-29 and P8, L26-30). The calibration and validation of the models were referred to existing literature in order to control the length of the manuscript (see page 6, lines 3-6 and 19-20). Since the scope of the manuscript is not to present a particular model, the exhaustive description of the calibration methodology was not deemed necessary as plenty published papers already describe thoroughly the validation methodology of these models. Notwithstanding, the authors referred the calibration methodology employed in this case and presented the result of such calibration, so the reader can verify the accuracy of the model in this specific case study. Cohen's Kappa statistic was the chosen measure to evaluate the calibration of the CASiMiR-vegetation model because this is considered a good measure to analyze this model's accuracy and the most often used measure of inter-rater agreement for categorical classifications. Furthermore, it has an advantage over sensitivity, since it corrects the overall accuracy of model predictions by compensating for random agreement. Considering the River2D model, the authors first estimated the bed roughness coefficient, the roughness height, in accordance with the observations of bed material and bedform size for the natural flow regime. The final values of roughness height were obtained by calibrating the water surface elevation measured in different cross-sections in the field and the model results. For the different scenarios (i.e. Eflow regime and Eflow&Flush regime) the roughness height values were changed according to the expected riparian vegetation maps. For the roughness heights of the different vegetation types the authors supported their choice on expert judgment and literature. In the end, the employed models are widely used and scientifically accepted tools that were calibrated for the study sites according to recognized methodologies. Calibration results were analyzed by comparison to observed data and achieved a good classification according to different categorizations of map classification agreement. All of these provide confidence to the authors that the model results are right and simulate correctly the considered fluvial system. Furthermore, model uncertainty due to parameter estimation uncertainty can be performed by means of sensitivity analysis (Uusitalo et al., 2015). This was already assessed for both models by the authors and in both cases the models showed to be fairly robust to parameter input uncertainty (see Rivaes et al., 2013 and Boavida et al., 2013). These uncertainty analyses support the confidence of the authors that the uncertainty of models outputs are relatively small. The authors included a paragraph discussing this topic (P15, L20-24).

Results

Detailed remarks:

Done. All these remarks were addressed (see P11, L19-23, L27-28, L30-31).

Discussion

Lines 23-26 on page 9 seem to be rather important. I would suggest that these could...

Lines 23-26 were stated in a more prominent way. The two-way relation (back from fish to vegetation) is not considered in this modeling work. The two models employed in this study do not consider the effect of fish on vegetation or morphodynamics. The authors do not think this is applicable considering the river particle dimensions. River bed was considered stable during modeling runs (please see the response to reviewer 1 regarding this matter). The topics mentioned for this section by the reviewer 2 are pertinent and were discussed in the discussion section (now P13, L21-30 and P13, L34-37).

Detailed remarks:

Page 9, line 16: what does "pushed through" mean?

This means that such approach puts forward an ecological modeling procedure that is more realistic than the actual paradigm in the assessment of environmental flows by means of fish habitat modeling. This expression were changed by "enables" (now P13, L14).

Page 9, line 36: why suddenly the term "substantially"?

This means that the habitat availability originated by the Eflow changes a lot when compared to the natural and Eflow&Flush flow regimes. This expression was removed.

Other remarks:

Please check the abstract. The second sentence is very difficult to understand...

The second sentence of the abstract was modified for a better understanding.

The numbers mentioned in the abstract were introduced in a way that the authors thought to be more comprehensive and appealing to the reader without reading the entire article. Nevertheless, these specific numbers were introduced in the results section for a direct relation with the abstract values (now in P11, L36).

The language needs to be improved. For example, several times the word "inputted" is...

The manuscript was English revised by Elsevier Language Editing Services prior to the submission to HESSD journal and holds a certificate from this institution. The word "inputted" is the past tense and past participle of the verb "input". This can be found in different English dictionaries, like the Cambridge dictionary (<u>http://dictionary.cambridge.org/dictionary/english/input</u>) or the Oxford dictionary (<u>https://en.oxforddictionaries.com/definition/input</u>). If the reviewers and/or the handling editor still require a more thorough proofreading, the authors can readdress this issue to the Elsevier Language Editing Services in order to meet the expectations of the reviewers and handling editor.

Reference list:

Acreman, M. C., and Ferguson, J. D.: Environmental flows and the European Water Framework Directive, Freshwater Biology, 55, 32-48, 10.1111/j.1365-2427.2009.02181.x, 2010.

Acreman, M. C., Overton, I. C., King, J., Wood, P. J., Cowx, I. G., Dunbar, M. J., Kendy, E., and Young, W. J.: The changing role of ecohydrological science in guiding environmental flows, Hydrological Sciences Journal, 59, 433-450, 10.1080/02626667.2014.886019, 2014.

Arthington, A.H.: *Environmental flows: saving rivers in the third millennium*. Univ of California Press, 2012

Arthington, A.H., Tharme, R.E., Brizga, S.O., Pusey, B.J., and Kennard, M.J.: "Environmental flow assessment with emphasis on holistic methodologies", in: *Second International Symposium on the Management of Large Rivers for Fisheries*), 37-66, 2013.

Boavida, I., Santos, J. M., Katopodis, C., Ferreira, M. T., and Pinheiro, A.: Uncertainty in predicting the fish-response to two-dimensional habitat modeling using field data, River Research and Applications, 29, 1164-1174, 10.1002/rra.2603, 2013.

Brisbane Declaration: The Brisbane Declaration. Environmental flows are essential for freshwater ecosystem health and human well-being, Declaration of the 10th International Riversymposium and International Environmental Flows Conference, Brisbane, AUS, 2007.

Corenblit, D., Baas, A.C.W., Bornette, G., Darrozes, J., Delmotte, S., Francis, R.A., et al.: Feedbacks between geomorphology and biota controlling Earth surface processes and landforms: A review of foundation concepts and current understandings. *Earth-Science Reviews* 106, 307-331. doi: http://dx.doi.org/10.1016/j.earscirev.2011.03.002, 2011.

Davis, R., and Hirji, R.: Environmental flows: concepts and methods. Water Resources and Environment Technical Note n^o C1, Environmental Flow Assessment series, World Bank, Washington, DC, 27 pp., 2003.

Dyson, M., Bergkamp, G., and Scanion, J. (eds.).: *Flow. The Essentials of Environmental Flows.* Gland, Switzerland and Cambridge, UK: IUCN, 2003.

Ferreira, M.T., Pinheiro, A.N., Santos, J.M., Boavida, I., Rivaes, R., and Branco, P.: "Determinação de um regime de caudais ecológicos a jusante do empreendimento de Alvito". (Lisboa: Instituto Superior de Agronomia, Universidade de Lisboa). Relatório Final. Estudo realizado pelo Instituto Superior de Agronomia para a ATKINS, no âmbito do Protocolo de Colaboração ATKINS – ISA-ADISA, de 19 de Junho de 2012 (URL: <u>http://hdl.handle.net/10400.5/13341</u>), 2014.

Frissell, C., Liss, W., Warren, C., and Hurley, M.: A hierarchical framework for stream habitat classification: Viewing streams in a watershed context. *Environmental Management* 10(2), 199-214, 1986.

García-Arias, A., Francés, F., Ferreira, T., Egger, G., Martínez-Capel, F., Garófano-Gómez, V., Andrés-Doménech, I., Politti, E., Rivaes, R., and Rodríguez-González, P. M.: Implementing a dynamic riparian vegetation model in three European river systems, *Ecohydrology*, 6, 635-651, 10.1002/eco.1331, 2013.

Gillespie, B.R., Desmet, S., Kay, P., Tillotson, M.R., and Brown, L.E.: A critical analysis of regulated river ecosystem responses to managed environmental flows from reservoirs. *Freshwater Biology* 60(2), 410-425. doi: 10.1111/fwb.12506, 2014.

Malanson, G. P.: Riparian landscapes, 1993.

Naiman, R.J., Décamps, H., and McClain, M.E. (eds.): *Riparia - Ecology, conservation and management of streamside communities.* London, UK: Elsevier academic press, 2005.

NRC, N.R.C.: *Riparian Areas: Functions and Strategies for Management.* Washington, D.C., USA: The National Academies Press, 2002.

Olden, J.D., Konrad, C.P., Melis, T.S., Kennard, M.J., Freeman, M.C., Mims, M.C., et al.: Are largescale flow experiments informing the science and management of freshwater ecosystems? *Frontiers in Ecology and the Environment* 12(3), 176-185. doi: 10.1890/130076, 2014.

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

Rivaes, R., Rodríguez-González, P. M., Albuquerque, A., Pinheiro, A. N., Egger, G., and Ferreira, M. T.: Riparian vegetation responses to altered flow regimes driven by climate change in Mediterranean rivers, *Ecohydrology*, 6, 413-424, 10.1002/eco.1287, 2013.

Rivaes, R., Rodríguez-González, P.M., Albuquerque, A., Pinheiro, A.N., Egger, G., and Ferreira, M.T.: Reducing river regulation effects on riparian vegetation using flushing flow regimes. *Ecological Engineering* 81, 428-438. doi: 10.1016/j.ecoleng.2015.04.059, 2015.

Stanford, J.A., Lorang, M.S., and Hauer, F.R.: The shifting habitat mosaic of river ecosystems. *Verh. Internat. Verein. Limnol.* 29. doi: 0368-0770/05/1940-0013 \$ 2.00, 2005.

Tharme, R.E.: A global perspective on environmental flow assessment: emerging trends in the development and application of environmental flow methodologies for rivers. *River Research and Applications* 19(5-6), 397-441. doi: 10.1002/rra.736, 2003.

Uusitalo, L., Lehikoinen, A., Helle, I., and Myrberg, K.: An overview of methods to evaluate uncertainty of deterministic models in decision support, *Environmental Modelling & Software*, 63, 24-31, http://dx.doi.org/10.1016/j.envsoft.2014.09.017, 2015.

Zonneveld, I. S.: Scope and Concepts of Landscape Ecology as an Emerging Science, in: *Changing Landscapes: An Ecological Perspective*, edited by: Zonneveld, I. S., and Forman, R. T. T., Springer New York, 3-20, 1990.

Importance of considering riparian vegetation requirements for the long-term efficiency of environmental flows<u>on aquatic microhabitat</u>

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10 Abstract. Environmental flows remain biased toward the traditional biological group of fish species. AccordinglyConsequently, these flows ignore the inter-annual flow variability that rules species with longer life cycles and, thereby therefore -disregarding the long-term perspective of the riverine ecosystem. We analyzed the influence-importance of considering riparian requirements for the long-term efficiency of environmental flows. For that analysis, we modeled the riparian vegetation development for a decade facing

- 15 different environmental flows in two case studies. Next, we assessed the corresponding fish habitat availability of three common fish species in each of the resulting riparian landscapehabitat scenarios. Modeling results demonstrated that the environmental flows disregarding riparian vegetation requirements promoted riparian degradation, particularly vegetation encroachment. Such circumstance altered the hydraulic characteristics of the river channel where flow depths and velocities underwent local changes up to 10 cm and 40 cm s⁻¹, respectively. Accordingly, after a decade of this flow regime, the available habitat
- area for the considered fish species experienced modifications in absolute from 18.16% up to 11009.75% when compared to the natural habitat. In turn, environmental flows regarding riparian vegetation requirements were able to maintain riparian vegetation near natural standards, thereby preserving the hydraulic characteristics of the river channel and sustaining the fish habitat close to the natural condition.

As a result, fish habitat availability never changed more than $1\frac{76.17}{6}$ from the natural habitat.

1 Introduction

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Freshwater ecosystems provide vital services for human existence but are on top of the world's most threatened ecosystems (Dudgeon et al., 2006; Revenga et al., 2000), primarily due to river damming (Allan and Castillo, 2007). The ability to provide sufficient water to ensure the functioning of freshwater ecosystems is an important concern as its capacity to provide goods and services is sustained by water-

- dependent ecological processes (Acreman, 2001). The relevance of this subject compelled the scientific community to appeal to all governments and water-related institutions across the globe to engage in environmental flow restoration and maintenance in every river (Brisbane Declaration, 2007). Actually Truly, this issue is a global reach topic, as all dams, weirs and levees change the magnitude of peak
- 35 flood flows of rivers to a certain extent (e.g., FitzHugh and Vogel, 2010; Maheshwari et al., 1995; Miller et al., 2013; Nilsson and Berggren, 2000; Uddin et al., 2014a, b). Therefore As a result of this, there are still

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opportunities for the implementation of environmental flow restoration at hundreds of thousands of these structures worldwide (Richter and Thomas, 2007).

Environmental flows can be defined as "the quantity, timing and quality of water flows required to sustain freshwater and estuarine ecosystems, and the human livelihoods and wellbeing that depend upon these

- 5 ecosystems" (Brisbane Declaration, 2007), and they also play an essential role in the conservation of freshwater ecosystems (Arthington et al., 2006; Hughes and Rood, 2003). It is now in agreement that environmental flows must ideally be based on the ecological requirements of different biological communities (e.g., Acreman et al., 2009; Acreman and Ferguson, 2010; Acreman et al., 2014; Arthington et al., 2010; Arthington, 2012; Arthington and Zalucki, 1998; Davis and Hirji, 2003; Dyson et al., 2003;
- 10 Poff et al., 1997) and should present a dynamic and variable hydrological regime to maintain the native biodiversity and the ecological processes that portray every river (Bunn and Arthington, 2002; Lytle and Poff, 2004; Postel and Richter, 2003). In this sense, holistic methodologies meant to address river systems as a whole (Arthington et al., 1992; King and Tharme, 1994; King and Louw, 1998) are clearly being increasingly applied out of Australia and South Africa (Hirji and Davis, 2009), the origin countries of this
- 15 holistic concept. However, but the most commonly applied methods throughout the world are still hydrologically based methods (Dyson et al., 2003; Linnansaari et al., 2012; Tharme, 2003). Conversely, environmental flows ascertained through habitat simulation methods still persist generally based on the requirements of a single biological group, mostly fish (Acreman et al., 2009; Arthington, 2012; Tharme, 2003), and clearly require an input from less typically monitored taxa (Gillespie et al., 2014). Accordingly,
- 20 these biased approaches still disregard the inter-annual flow variability that rules species with longer lifecycles, like riparian vegetation, therefore lacking the long-term perspective of the riverine ecosystem (Stromberg et al., 2010). The feedbacks of these shortcomings on the riparian and aquatic communities were seldom estimated before and so, the efficiency of such approaches along with its long-term after-effects remains practically unknown.
- 25 Riparian vegetation is a suitable environmental change indicator (Benjankar et al., 2012; Nilsson and Berggren, 2000) that responds directly to flow regime in an inter-annual timeframe (Capon and Dowe, 2007; Naiman et al., 2005; Poff et al., 1997) and has a clear significance in the habitat improvement of aquatic systems (e.g., Broadmeadow and Nisbet, 2004; Chase et al., 2016; Dosskey et al., 2010; Gregory et al., 1991; Pusey and Arthington, 2003; Rood et al., 2015; Ryan et al., 2013;Salemi et al., 2012; Statzner,
- 30 2012; Tabacchi et al., 2000; Van Looy et al., 2013; Wootton, 2012). In fact, riparian vegetation and aquatic species interact biologically, physically and chemically (Gregory et al., 1991). Riparian vegetation is capable of influencing aquatic species in several ways. It affects food webs by providing an important input of nutrients that are a major food source for invertebrates, which are in turn eaten by fishes (Wootton, 2012). It influences hydrological processes (Salemi et al., 2012; Tabacchi et al., 2000) and protects aquatic
- 35 habitats by means of river bank stability (Rood et al., 2015) and providence of large woody debris (Fetherston et al., 1995). It provides thermal regulation of rivers by overshadowing (Ryan et al., 2013) and protect water quality both by trapping sediments and contaminants (Chase et al., 2016) as by chemical uptake and cycling (Dosskey et al., 2010). On the other hand, aquatic species appear also to be able to influence riparian zones, although in a much smaller magnitude, acting as ecosystem engineers (Statzner,
- 40 2012). For instance, fishes can dig in sand and gravel for food or reproductive purposes and therefore

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influence sediment surface characteristics and critical shear stress (e.g., Hassan et al., 2008; Statzner et al., 2003).

<u>Accordingly</u>, <u>Rr</u>iparian restoration is an indispensable implementation measure to recover the natural river processes and is the most promising restoration action in many degraded rivers (Palmer et al., 2014). Hence,

5 incorporating riparian vegetation requirements (the need for specific flows to preserve the naturalness of recruitment and meta-stability facing fluvial processes) into environmental flows could be an important contribution to fill in these gaps.

We have already noticed how environmental flow regimes disregarding riparian vegetation requirements allow for the degradation of riparian woodlands in the subsequent years following such river regulation

- 10 (e.g., Rivaes et al., 2015). However, we are not aware of studies assessing the comeback of this degradation again on the efficiency of those environmental flow regimes. The purpose of this study is to evaluate the effect of disregarding riparian vegetation requirements in the efficiency of environmental flow regimes regarding fish habitat availability in the long-term perspective of the fluvial ecosystem. We used an approach from an ecohydraulic point of view to evaluate the effects of riparian landscape degradation on
- 15 fish species By riparian landscape we mean the specific spatial patterns of riparian vegetation that result from ecological, geomorphological and hydrological processes, and are depicted by the existing patch mosaic with different vegetation types and succession phases. We were particularly interested in answering the following questions: i) are environmental flows exclusively addressing fish requirements capable of preserving the habitat availability of these aquatic species in the long-term? ii) If not, tolm what extent
- 20 caneould this overlook the disregard for riparian vegetation requirements derail the goals of environmental flows addressing only aquatic species as a result of the riparian landscapehabitat degradation? iii) Are environmental flows regarding riparian requirements able to maintain the habitat availability of fish species?

To approach these questions, we first modeled the structural response of riparian vegetation (please see Naiman et al., 2005 and NRC, 2002 for a better understanding about riparian vegetation structure) facing a

decade of different environmental flows in two different case studies. Next, we performed an assessment of habitat availability for fish species in each of the resulting riparian <u>landscapehabitat</u> scenarios. We are not aware of such a modeling approach ever being used in the appraisal of the long-term efficiency of environmental flow regimes, which can provide an extremely valuable insight of the expected long-term

30 effects of environmental flows in river ecosystems in advance.

2 Methods

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2.1 Study sites

The two study sites were selected in the Ocreza River, East Portugal (Figure 1). This is a medium-sized stream that runs on schistose rocks for 94 km and drains a 1429 km² watershed with a mean annual flow of 16.5 m³ s⁻¹. The flow regime is typically Mediterranean (Gasith and Resh, 1999), with a low flow period interrupted by flash floods in winter (median of mean daily discharges in the winter months is 8.8 m³ s⁻¹ and maximum annual discharges with a return period of 2, 5, 10 and 100 years are respectively 323, 549,

718 and 1314 m³ s⁻¹) and a very low flow, even null at times, during summer (the first quartile and median

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of mean daily discharges in summer months is respectively 0 and 0.1 m³ s⁻¹ (Gasith and Resh, 1999). Two study sites were considered (OCBA and OCPR) to provide a broader analysis of the aquatic habitat modifications in different hydrogeomorphological contexts. The OCBA study site (39° 44' 07.05" N, 7° 44' 16.51" W) is located 30 km upstream from the river mouth and OCPR (39° 43' 16.88" N, 7° 46' 01.05"

- 5 W) is approximately 5 km downstream of OCBA. Despite the relatively small distance between them, several characteristics differentiate the two study sites. While in OCBA, the river flows freely on a boulder substrate and is confined to steep valley hillsides, in OCPR, the river flows on a coarser boulder substrate with sparse bedrock presence and is <u>located</u> in a relatively wider valley section. OCBA and OCPR also contrast in watershed areas, representing 54 and 72% of the entire river basin, respectively. This feature
- 10 further differentiates the two case studies, as the intermediate watershed of OCPR collects water from a much rainier zone, therefore conferring an increased flow regime in this study site. The surveyed areas in the OCBA and OCPR study sites encompass a river length of approximately 500 and 300 m, respectively, laterally limited by the 100-year flooded zone, thus totaling approximately 4 and 3 ha for OCBA and OCPR study sites respectively. In both cases, the fish community is characterized by native cyprinid species,
- 15 mainly Luciobarbus bocagei (Iberian barbel, hereafter barbel), Pseudochondrostoma polylepis (Iberian straight-mouth nase, hereafter nase) and Squalius alburnoides (calandino), whereas the local riparian vegetation is composed mostly of willows (Salix salviifolia Brot. and Salix atrocinerea Brot.) and ashes (Fraxinus angustifolia Vahl).

2.2 Data collection

20 2.2.1 Hydraulic data

The riverbed topography was surveyed in 2013 using a combination of a Nikon DTM330 total station and a Global Positioning System (GPS) (Ashtech, model Pro Mark2). Altogether, 7707 points were surveyed at OCBA and 25132 at OCPR. Trees, boulders and large objects emerging from the water were defined by marking the object intersection with the riverbed and by surveying the points necessary to approximately define its shape.

25 define its shape.

Hydraulic data –, i.e., water velocities and depths – were measured as a series of points along several crosssections in the study sites. Depths were measured with a ruler and water velocities with a flow probe (model 002, Valeport) positioned at 60% of the local depth below the surface (Bovee and Milhous, 1978). Additionally, the substrate composition was visually assessed and mapped to determine posteriorly the effective roughness heights of the riverbed. These data were used to calculate river discharge in each study

30 effective roughness heights of the riverbed. These data were used to calculate river discharge in each study site and to calibrate the model. Additional information about hydraulic data and channel bed characteristics is provided as supplementary material (Appendix A – Tables A1, A2, A3 and A4).

2.2.2 Riparian vegetation data

The riparian vegetation was assessed in 2013 to <u>support the calibration and validation of the riparian</u> vegetation model. This task consisted in recording the location and shape of all homogeneous vegetation patches with a sub-meter precision handheld GPS (Ashtech, Mobile Mapper 100), while dendrochronological methods were used to determine the approximate age of the patches. Two or three of the largest individuals in each patch were cored with a standard 5 mm increment borer, taking two Comentado [RR13]: Included according to the specific comments of reviewer 1 on Methods

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perpendicular cores at breast height in adult trees (Mäkinen and Vanninen, 1999). For individuals with a diameter smaller than 5 cm at breast height, discs were obtained for age calculation purposes, and on multistemmed trees, the cores/discs were taken from the largest stem. The patches were later classified by succession phase according to its corresponding development stage. Patch georeferencing, patch aging and

- succession phase classification followed the methodology used by Rivaes et al. (2013). 5 Five succession phases were identified in the study sites: Initial phase (IP), Pioneer phase (PP), Early Successional Woodland phase (ES), Established Forest phase (EF), and Mature Forest phase (MF). Initial phase was attributed to all patches dominated by gravel bars, sometimes covered by herbaceous vegetation but without woody arboreal species. The patches dominated by the recruitment of woody arboreal species
- 10 were considered as Pioneer phase. The Early Successional Woodland phase classification was attributed to all patches with a high standing biomass and well-established individuals, dominated by pioneer watertabledependent species, such as willows and alders (Alnus glutinosa). Older patches dominated by macrophanerophytes, such as ash-trees, were considered to be in Established Forest phase. The Mature Forest phase was considered at patches where terrestrial vegetation was also present, determining the transition phase to the upland vegetation communities. Further information on the characterization of
- succession phases is provided as supplementary material (Appendix B Table B1 and Figures B1 and B2)

2.2.3 Fish data

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Fish populations were sampled during 2012 and 2013 at undisturbed or minimally disturbed sites in the Ocreza basin, an essential requisite when studying habitat preferences of stream fishes in order to reflect

- their optimal habitat (Gorman and Karr, 1978). Sampling occurred in autumn (November, 2012), spring 20 (May, 2013) and early summer (June, 2013) when there is full connectivity among instream habitats. Overall, four native species (cyprinids) were found - barbel, nase, calandino and the Southern Iberian chub (Squalius pyrenaicus). The latter was however excluded from the present study, as an insufficient number of individuals were collected to draw unbiased conclusions. Non-native fish (the gudgeon Gobio lozanoi)
- 25 occurred in the study area, but in very low density. Field procedures followed those by Boavida et al. (2011, 2015).- Fish sampling was performed during daylight using pulsed DC electrofishing (SAREL model WFC7-HV; Electracatch International, Wolverhampton, UK), with low voltage (250 V) and a 30 cm diameter anode to reduce the effect of positive galvanotaxis. A 200 m long reach at each site was surveyed by wading upstream in a zigzag pattern to ensure full coverage of available habitats. To avoid displacements
- 30 of individuals from their original positions, a modified point electrofishing procedure was employed (Copp, 1989). Sampling points were approached discreetly, and the activated anode was swiftly immersed in the water for five seconds. Upon sighting a fish or a shoal of fishes, a numbered location marker was anchored to the streambed for subsequent microhabitat use measurements. Fish were immediately collected by means of a separate dip net held by another operator, quickly measured for total length (TL), and then placed in
- 35 buckets with portable ELITE aerators to avoid continuous shocking and repeated counting, before being returned alive to the river. Ensuing fish sampling, microhabitat measurements of flow depth (cm), mean water velocity (cm s⁻¹) and dominant substrate composition were taken in 0.8 by \times 0.8 m quadrats at the location where each fish was captured. Microhabitat availability measurements were made using the same variables by quantifying randomly selected points along 15-25 m equidistant transects perpendicular to the

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flow at each sampling site. To develop Habitat Suitability Curves (HSC) for target fish size classes, microhabitat variables (flow depth, water velocity, dominant substrate and cover) were divided into classes, and histograms of frequencies of use and availability were constructed (Boavida et al., 2011). A summary on collected fish data, as well as data analysis to determine habitat use, availability and preference of fish

5 species regarding the <u>considered</u> analyzed variables, is provided as supplementary material (<u>Appendix B –</u> <u>Table B2 and Figures B3 to B12</u>).

2.3 Flow regime definition

Three flow regimes were considered for the modeling of riparian vegetation: i) the natural flow regime (hereafter named natural flow regime), ii) an environmental flow regime considering only fish requirements

- 10 (hereafter named Eflow regime) and iii) an environmental flow regime considering both fish and riparian requirements (hereafter named Eflow&Flush regime). <u>The natural flow regime data was obtained from the Portuguese Water Resources National Information System (SNIRH, 2010). The environmental flow regimes used in this study are an adaptation from the environmental flow regime created by Ferreira et al. (2014) for the location of the study sites (Figure 2). These authors determined an environmental flow regime</u>
- 15 presented in a multiannual fashion considering a decadal time frame and accounting for two different flow regime components: a monthly flow regime addressing fish requirements and a multiannual flow regime composed by floods with different recurrence intervals addressing riparian vegetation requirements. The first component, i.e., the flow regime addressing fish requirements (Eflow), was determined according to the Instream Flow Incremental Methodology (Bovee, 1982) and The flow regime addressing fish
- 20 requirements is was built on a monthly basis to embody the intra-annual variability ruling the main life cycle events of this biological group (Encina et al., 2006; Gasith and Resh, 1999), These mean monthly discharges addressing fish requirements that compose the Eflow aimed for the following goals: i) maximize the habitat of the target species while attributing the same weight for each species; ii) privilege the spawning months (spring; Santos et al., 2005) and promote the younger life stages during summer; iii) maintain the
- 25 characteristic intra-annual variability of the river flow; and iv) preserve the natural regime whenever the environmental flows suggest higher discharges. The second component of the environmental flow regime (floods with a certain recurrence interval) proposed by Ferreira et al. (2014) was determined according to Rivaes et al. (2015) and Likewise, the flushing flows of the riparian flow regime intend to characterize the inter-annual flow variability to which the arrangement of riparian vegetation communities respond
- 30 (Hughes, 1997). The flushing flows addressing riparian requirements in the Eflow&Flush regime were defined based on the need of riparian communities for the minimum necessary flushing flow regime to maintain the viability and sustainability of riparian vegetation, particularly, avoiding vegetation encroachment and conserving the ecological succession equilibrium of the riparian ecosystem (Rivaes et al., 2015). Therefore, the environmental flow regimes used in this study are considered an adaptation from
- 35 Ferreira et al. (2014) as we used just the fish-addressing component (only mean monthly discharges) as the standard procedure of an environmental flow regime considering only fish requirements (Eflow) and both components (mean monthly discharges and flushing flows) for the environmental flow regime addressing fish and riparian requirements (Eflow&Flush).

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2.4 Riparian vegetation modeling

The riparian vegetation modeling was performed using the *CASiMiR-vegetation* model (Benjankar et al., 2009). This tool simulates the succession dynamics of riparian vegetation, based on the existing relationships of the ecological relevant hydrological elements (Poff et al., 1997) and the vegetation metrics

- 5 that reflect riparian communities to such hydrological alterations (Merritt et al., 2010). The strengths of this model are the capacity of incorporating the past patch dynamics into every model run, the ability of working at a response guild level by using succession phases as modeling units, and the ability of providing the outputs in a spatially-explicit way. In turn, main disadvantages of this model can be attributed to the inexistence of a plant competition module or the lack of an incorporated hydrodynamic model.
- 10 The rational of this model is based on the fact that riparian communities respond to the hydrological and habitat variations on a time scale between the year and the decade (Frissell et al., 1986; Thorp et al., 2008), being that the flood pulse is the predominant factor on these population dynamics (Thoms and Parsons, 2002). For these reasons, the hydrological regime is inputted into the model in terms of maximum annual discharges as these discharges are considered as the annual threshold for riparian morphodynamic
- 15 disturbance that determine the succession or retrogression of vegetation. Notwithstanding, the model also predicts the annual riparian adjustments according to its vital rates in relation to groundwater depth, as well as the annual recruitment areas, based on the annual minimum mean daily discharges. The groundwater depth corresponding to the mean annual discharge of the river is also a model input used as a reference for the general habitat conditions that determine the expected riparian landscape according to the calibrated
- 20 thresholds of the riparian succession phases. Thus, the magnitude and duration of extreme low flows are accounted by CASiMiR-vegetation model. A complete detailing of model rational and parameterization can be found in Politti and Egger (2011) and Benjankar et al. (2011).

Model calibration was carried out in accordance with the methodology described in previous studies (García-Arias et al., 2013; Rivaes et al., 2013). Particularly, calibration was performed by running the

- 25 CASiMiR-vegetation model for a decade to simulate the effect of the local historic flow regime on riparian vegetation. The result of the model was then compared with an observed vegetation map that was surveyed in the same year of the one corresponding to the result of the model. This is an iterative process of trial an error where the parameter of shear stress resistance threshold of each succession phase is tuned to obtain the best calibration outcome (see Wainwright and Mulligan, 2004, for a better understanding). All the other
- 30 parameters, namely, patch age and height above water table ranges were determined based on the data collected in the field. This information is provided as supplementary material (Appendix A Table A5). During calibration, the riparian vegetation model achieved an agreement evaluation of 0.61 by the quadratic weighted kappa (Cohen, 1960), which is considered to be in good agreement with the observed riparian landscape (Altman, 1991; Viera and Garrett, 2005). This agreement evaluation can be understood as a
- 35 <u>classification 61% better than what would be expected by a random assignment of classes.</u> The riparian vegetation model was further validated in this specific watershed (Ferreira et al., 2014) with even better results (quadratic weighted kappa of 0.68). After calibration and validation (calibrated parameters provided as supplementary material; <u>Appendix A Table A5</u>), the riparian vegetation was modeled for periods of ten years according to the corresponding flow regimes (Table 1). Such modeling period was considered to
- 40 be long enough to avoid the influence of the initial vegetation conditions, while river morphological

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changes still do not assume importance in vegetation development (Politti et al., 2014). <u>Furthermore</u>, <u>during</u> modeling, riverbed topography was considered fixed for several reasons: the study sites are located in a fairly steep valley in which river is not allowed to meander considerably during such a short time scale; the typical substrate of both study sites is armored and very coarse (boulders, large boulders and bedrock); in

- 5 these conditions the small monthly discharges intended to maintain aquatic fauna requirements are not able to create water depths and flow velocities capable of moving or eroding particles with the size of those found as substrate in the considered study sites (for a better understanding please see Alexander and Cooker, 2016; Clarke and Hansen, 1996; Hjulström, 1939); no significant differences were found during the substrate analysis of the different succession phases; prior knowledge of the authors show that the
- 10 considered floods do not bring noteworthy changes to river geomorphology during this period (Rivaes et al., 2015); the model calibration and validation results exhibited a good agreement with the observed riparian landscape while using the same methodology; by using a fixed topography it is possible to analyze the exclusive effect of riparian landscape degradation on the river hydraulics.

The resulting riparian vegetation maps were then used as the respective riparian landscapeshabitats+

15 (hereafter named natural, Eflow and Eflow&Flush <u>landscapeshabitats</u>) in the hydrodynamic modeling of fish habitat in each study site.

2.5 Hydrodynamic modeling of fish habitat

The hydrodynamic modeling was performed using a calibrated version of the River2D model (Steffler et al., 2002). This is a finite element model widely used in fluvial modeling studies for the assessment of habitat availability (Boavida et al., 2011; Jalón and Gortázar, 2007) that brings together a 2D hydrodynamic model and a habitat model to simulate the flow conditions of the river stretch and estimate its potential habitat value according to the fish habitat preferences. The strengths of this model are the fact of being public domain software and to be technically robust throughout a wide range of modeling circumstances.

- On the other hand, some limitations of this model are the non-incorporation of a morphodynamic module or the ability of embodying fuzzy logic rules during the computation of species habitat availability. The calibration procedure followed the methodology proposed by Boavida et al. (2013, 2015). Calibration was performed by iteratively adjusting the bed channel roughness to attain a good agreement of the simulated versus surveyed water surface elevations and velocity profiles in the surveyed cross-sections.
- 30 Boundary conditions were set according to the water surface elevations measured at the upstream and downstream cross-sections, and cCalibrated parameters are provided in supplementary material (Appendix A Tables A1, A2, A3 and A4).

The hydrodynamic modeling comprised the Eflow discharge ranges in the study sites $(0 - 2 \text{ m}^3 \text{ s}^{-1} \text{ and } 0 - 5.5 \text{ m}^3 \text{ s}^{-1}$ for OCBA and OCPR, respectively) and was accomplished for each riparian <u>landscape</u>

35 scenariohabitat. The different riparian landscapes were represented in the hydrodynamic model by changing the channel roughness according to the spatial extent of the riparian succession phases, i.e., the channel roughness inputted to the model are the riparian landscape maps converted into channel roughness maps. Roughness is a critical feature influencing the physical variables of flow hydraulics (Chow, 1959; Curran and Hession, 2013), whose distinct combinations typify diverse functional habitats, which are selected by Comentado [RR25]: Added to address the reviewer 1 main concern 4. Formatado: Inglês (Estados Unidos)

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Comentado [RR27]: Included to address the comments of reviewer 2 on methods Comentado [RR28]: Included according to the comment of reviewer 1 Page 6 Line 8 fish according to its preference. The roughness classification of riparian vegetation succession phases was determined based on roughness measurement literature on similar vegetation types (Chow, 1959; Wu and Mao, 2007) and expert judgment during model calibration.

After modeling the Eflow discharges in each of the riparian landscape scenarios of the two study sites, Tthe

- 5 hydraulic characteristics of each <u>riparian landscapehabitat</u> (roughness, flow depth and velocity) were compared using a t-test (confidence level of 99%) in R environment (R Development Core Team, 2011) in order to determine the existence of mean significant differences between <u>habitatsriparian landscapes</u>. Habitat simulation was achieved by the combination of the hydraulic modeling (flow depth and velocity) with preference curves information for the considered target species. The riverbed characteristics of
- 10 substrate and cover were kept unchanged during the hydrodynamic modeling. Changing the substrate according to the modifications in succession phase disposal seemed to be an incorrect practice in this case because during data treatment, no significant differences were detected in riverbed substrate between succession phases. Cover modification was also disregarded because the CASiMiR-vegetation model only reproduces the riparian area, not the aquatic zone (note that this *aquatic zone* is a definition *sensu*)
- 15 CASiMiR-vegetation model, designating the areapart of the river channel that is permanently submerged throughout the hydrologic year and where riparian vegetation is unable to establish and develop. It corresponds to only a fraction of the wetted area by river flow during the discharges considered in the subsequent hydrodynamic modeling) and therefore, this feature cannot be correctly modeled by the riparian vegetation model. Notwithstanding, the most important variables determining fish habitat availability
- 20 influenced by riparian vegetation degradation were considered, namely, depth, velocity and substrate (Parasiewicz, 2007).

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The Habitat Suitability Index (HSI) was determined for each species and life stage regarding the product of the velocity (Velocity Suitability Index – VSI), depth (Depth Suitability Index – DSI) and substrate (Substrate Suitability Index – SSI) variables, according with Eq. (1):

 $25 \qquad HSI = VSI \times DSI \times SSI$

(1)

(2)

The product of the HSI by the influencing area (A) of the corresponding model ith node defines the Weighted Usable Area (WUA) of that node. The sum of the WUA's result in the total amount of habitat suitability for the study site, as described by Eq. (2):

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WUA = \sum_{n=1}^{i} A_i \times HSI_i = f(Q)
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- 30 Considering that the BACI approach (Before-After Control-Impact) is generally the best way of detecting impacts or beneficial outcomes in river systems (Downes et al., 2002) the resulting WUA's were then compared to the natural habitat in a census-based benchmark. The equality of proportions between habitat availabilities was tested using the χ^2 test for proportions in R environment, while deviations were measured using the most commonly used measures of forecast accuracy, namely, Root Mean Square Deviation
- 35 (RMSD), Mean Absolute Deviation (MAD) and Mean Absolute Percentage Deviation (MAPD). In all cases, smaller values of these measures indicate better performance in parameter estimation.

2.6 Workflow of the modeling procedure

The workflow of the modeling procedure is presented in Figure 3. Firstly, the calibrated version of the riparian vegetation model is used to produce the riparian landscape scenarios according to each of the

considered flow regimes. In each modeling run, this model uses as inputs one of the specific flow regimes mentioned and models the effects of a decade of such flow regime in the local riparian vegetation. The output of the model is an expected riparian vegetation landscape map (detailed by succession phases) resulting from the inputted flow regime. This map is converted into a channel roughness map by attributing

- 5 to each riparian succession phase a specific effective roughness height based on the expert knowledge of the authors, on literature (e.g., Barnes, 1967; Chow, 1959; Fisher and Dawson, 2003) and on the calibration results of the models. The considered roughness values of each succession phase are provided as supplementary material (Appendix A – Tables A3 and A4). These roughness maps are one of the inputs of the River2D model.
- 10 Secondly, the hydrodynamic model River2D is used to determine the water depths and flow velocities at the microhabitat scale (already considering each of the roughness maps coming from the conversion of the CASiMiR-vegetation output vegetation maps) and to compute the weighted usable areas of the considered fish species using the previous calculated variables and the inputted information regarding the observed fish species habitat preferences for water depth and flow velocity. This is done similarly using every of the
- 15 riparian landscape scenarios. For each scenario run, the outcome of this model is therefore the weighted usable area of each of the considered species and life stages for each of the discharges considered in the Eflow regime.

3 Results

3.1 Riparian vegetation modeling

- 20 Different <u>configurations of riparian habitat landscapes</u> resulted from the riparian vegetation modeling according to the considered flow regimes in both case studies (Figure 3Figure 4). Nonetheless, the modeled response of riparian vegetation to each flow regime is similar in the two study sites. The riparian habitatlandscape, driven by the natural flow regime, presents a river channel that is largely devegetated, where Initial (IP) and Pioneer (PP) phases together represent approximately 43% and 35% of the study site
- 25 areas in OCBA and OCPR, respectively. In this habitatriparian landscape, Early Succession Woodland phase (ES) can only settle in approximately 8% of OCBA and 1% of OCPR areas. The floodplain succession phases, namely, Established Forest phase (EF) and Mature Forest phase (MF), represent nearly 40 and 10% of the study area for OCBA and, close to 42% and 23% for OCPR, respectively.
- -In contrast, the riparian habitat-landscape_created by the Eflow regime is where the riparian vegetation
 and evolves toward mature phases due to the lack of the river flood disturbance. IP is now reduced to approximately 3% in OCBA and 6% in OCPR, while PP is inexistent in both cases. ES covers up to approximately 48% and 26% of the corresponding study areas, whereas EF and MF maintain about the same area in both case studies.
 -The riparian habitat-landscape_driven by the Eflow&Flush regime shows the capacity of this flow regime
- 35 in hold back vegetation encroachment in both cases. In this habitatriparian landscape scenario, IP and PP are maintained at approximately 30% of the study site area in both case studies, whereas ES is kept under 21% in OCBA and only 2% in OCPR. Once again, EF and MF preserve their areas in both case studies.

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Comentado [RPGDRdS31]: Sub-sections added to comply with the reviewer 1 specific comments regarding the results Formatado: Título 2 -Summing up, the results of the riparian vegetation modeling show a riparian landscape degradation by vegetation encroachment in the Eflow landscape scenario when compared with the natural riparian landscape. Instead, the Eflow&Flush landscape scenario keeps approximately the same patch disposal and succession phasesphase's proportion as the natural landscape and therefore does not present significant

5 evidence offor riparian landscape degradation.

3.2 Hydrodynamic modeling

The changes undertaken by the riparian vegetation facing different flow regimes are able to modify the hydraulic characteristics of the river stretches (Figure 5Figure 4). Channel effective roughness heights (k_s) change dramatically according to the considered riparian habitatslandscapes, increasing proportionally to

- 10 the encroachment level of vegetation in the study sites. In both case studies, the k_s values of the Eflow habitats-landscape_are clearly distinct and higher compared to the other two habitatsriparian landscapes (Figure 5). The k_s values in the Eflow&Flush habitats-landscape were found to be between the values of Eflow and natural habitatslandscapes in the case of OCBA, and were very similar with the natural habitats landscape in the case of OCPR (Figure 5). Notwithstanding, in both case studies, the k_s mean values are
- 15 statistical significantly different between all three habitats riparian landscapes (test results in supplementary material; Appendix C Table C1). The mean k_s of the Eflow, Eflow&Flush and natural habitats-landscapes are 0.999, 0.709 and 0.462 m, respectively, in OCBA, and 1.034, 0.742 and 0.7178 m, respectively, in OCPR.

Changes also occur in flow depth and flow velocity for the considered discharge range of the proposed environmental flows (Figure 5). Although not so noticeable due to the great amount of data, differences are statistically significant. In OCBA, the Eflow habitat landscape creates a circumstance with statistically

- significantly higher depths (mean depth is 0.402 m) and lower flow velocities (mean flow velocity is 0.128 m s⁻¹) than the natural and Eflow&Flush habitats-landscapes. The t-tests on water depths (H0: true difference in means is equal to 0) revealed highly significant p-values (<0.001), respectively, for the
- 25 comparisons between Eflow and natural flow regimes, and Eflow and Eflow&Flush flow regimes. The ttests on flow velocities also derived a highly significant p-value (<0.001) in both the comparisons of natural versus Eflow regimes and Eflow versus Eflow&Flush flow regimes (test results in supplementary material; Appendix C – Tables C2 and C3). In contrast, depth and flow velocity are not significantly distinguishable between the natural and Eflow&Flush habitatslandscapes, where mean depth and flow velocity are 0.397
- 30 m and 0.136 m s⁻¹, respectively, in the former, and 0.399 m and 0.135 m s⁻¹ respectively, in the latter. -For the OCPR study site, flow depths are not significantly different (t-tests obtained p-values of 0.122 for natural versus Eflow regimes and 0.098 for Eflow versus Eflow&Flush flow regimes). (mMean values of flow depth for Eflow, Eflow&Flush and natural habitats-landscapes are 0.420, 0.417, 0.418, respectively.) butNonetheless flow velocities are different with statistical significance as the p-values of the t-tests for
- 35 natural versus Eflow and for Eflow versus Eflow&Flush were highly significant (<0.001), ; with tThe Eflow habitat-landscape createsing statistical significantly lower flow velocities (0.271 m s⁻¹) when compared to the statistical significantly indistinct Eflow&Flush (0.277 m s⁻¹) and natural (0.278 m s⁻¹) habitats landscapes (test results in supplementary material; Appendix C Tables C2 and C3).

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Furthermore, when comparing water depths and flow velocities point by point, one can find differences between scenarios up to 10 cm in water depth and more than 40 cm s^{-1} in flow velocity. Accordingly, there are locations where the considered hydraulic parameters change considerably, shifting the habitat preference of fishes in one or two classes of the corresponding habitat preference curves.

5 In general, the Eflow landscapes present an increased channel roughness interfering with river flow and creating increased water depths and slower flow velocities when compared with the natural landscape. On the contrary, despite the increased channel roughness of the Eflow&Flush landscape, the water depths and flow velocities are very similar to the ones in the natural landscape. These results demonstrate that an environmental flow addressing exclusively fish requirements is not capable of preserving the habitat availability of the aquatic species for which was proposed in the long-term.

3.3 Analysis of the Aaguatic habitat suitability for fish species analysis

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During a hydrological year, each riparian habitat-landscape provides different WUAs for the target fish species, with the same environmental flow regime addressing fish species (Figure 5Figure 6). Differences from the natural habitat suitability are greater in the Eflow habitat-landscape for both case studies. In OCBA, major differences in the WUA can be found almost all year round for the barbel juveniles, throughout autumn and winter months for the nase juveniles and during spring months for the calandino. Compared to the natural habitat-landscape, the WUA modifications instilled by the Eflow landscape habitat are on average approximately 12%, and are higher than 17% in a quarter of the cases reaching 80% in an extreme situation.

- Particularly, the Eflow <u>landscapehabitat</u> provides less habitat suitability during autumn and winter months for the barbel and nase juveniles, c. 17% and 14%, respectively. Likewise, in this <u>habitatriparian landscape</u>, the habitat suitability during spring months increases approximately 23% for the barbel juveniles and approximately 20 and 27% for the calandino juveniles and adults, respectively. On the other hand, throughout the year, the Eflow&Flush <u>landscapehabitat</u> provides a WUA very similar to the natural
- landscapehabitat.The habitat changes created by the Eflow&Flush landscapehabitat are on average25approximately 2% and never reach 8% for all species and life stages.

As for OCPR, major differences in WUA are seen almost all year round for calandino and nase, and exist particularly in spring months for barbel. WUA modifications due to the Eflow <u>landscapehabitat</u> are on average near 29%, being a quarter more than 50% and reaching up to more than 100% different in the most

- 30 extreme case. The Eflow <u>landscapehabitat</u> consistently provides less habitat suitability during autumn and winter months for the <u>barbel and nase juveniles and adults</u>, c. 50% and 38%, respectively, while the habitat suitability increases in approximately 46% of calandino. Moreover, the Eflow <u>landscapehabitat</u> provides an increased WUA during spring months in approximately 18% of the barbel adults and 71% of the calandino adults, while it decreases the habitat on average for approximately 7% of the remaining species and life
- 35 stages. Also in this case study, the Eflow&Flush <u>landscapehabitat</u> provides a WUA very similar to the natural <u>landscapehabitat</u> throughout the year. The habitat changes created by the Eflow&Flush <u>landscapehabitat</u> are on average near 3% and always less than 17% for all species and life stages. Accordingly, in both case studies, the WUA differences evidenced in the Eflow <u>landscapehabitat</u> revealed to be significant in several months by the χ² test whereas this were never the case for the Eflow&Flush

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Comentado [RR41]: Correction to address the specific comments about results Page 8 Line 34 of reviewer 1 <u>landscapehabitats</u> (test results provided in supplementary material; <u>Appendix C – Tables C4, C5, C6 and</u> <u>C7</u>).

The riparian-induced modifications on the WUAs are also confirmed by all the employed deviation measures (Table 2). According to RMSD, MAD and MAPD, the <u>habitat provided by the</u> Eflow <u>landscapehabitat</u> is always farther apart from the natural habitat for all species and life stages. In OCBA, the larger deviations occur for the barbel juveniles and nase adults, whereas in OCPR, the calandino adults and the barbel juveniles are the ones enduring greater habitat deviations from the natural circumstance, <u>All</u> together, these results reveal that the overlook of riparian requirements into environmental flows can derail the goals of environmental flows addressing only aquatic species by an extent of approximately an average

10 of 12 to 29% of the fish WUA's in the considered study sites as a result of the riparian habitatlandscape degradation. On the other hand, results reveal that environmental flows regarding riparian requirements are able to maintain the habitat availability of fish species as the WUA's in the study sites never change on average more the 3% in a decade.

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4 Discussion

- 15 This study evaluated the benefits of incorporating riparian requirements into environmental flows by estimating the expected repercussions of riparian long-term changes driven by regulated flow regimes on the fish long-term habitat suitability. To this end, the riparian vegetation was modeled for 10-year periods according to three different simulated-flow regimes and results were inputted as the habitat basis for the hydrodynamic modeling and subsequent assessment of the fish habitat suitability in those riparian
- 20 <u>landscapehabitats</u>. Such ecological modeling approach, where a joint analysis is performed while embracing a suitable time response for the ecosystems involved, <u>pushes throughenables a</u> realistic biological-response modeling and substantiates the long-term research that is required in environmental flow science (Arthington, 2015; Petts, 2009). Furthermore, this approach allows one to foresee and assess the outcome of recommended flow regimes, which is an essential topic but has been poorly considered in
- 25 environmental flow science (Davies et al., 2013; Gippel, 2001). This research provides an insight of the expected long-term effects of environmental flows in river ecosystems, therefore unveiling the potential remarkable role of riparian vegetation on the support of environmental flows efficiency, which can transform the actual paradigm in environmental flow science.
- During modeling geomorphology was considered immutable and sediment transport originated by the environmental flow regimes was disregarded. River morphodynamics and its interactions with riparian vegetation constitute an important river process in many rivers, particularly in fine sediment rivers (e.g., Corenblit et al., 2009; Corenblit et al., 2011; Gurnell et al., 2012; Gurnell, 2014). However, the research on the temporal scales of geomorphic and ecological processes is still scarce in coarse-bed rivers (Corenblit et al., 2011), and simultaneously more complex and uncertain (Yasi et al., 2013). The error predictions from
- 35 best hydraulic predictors in this type of rivers can range between 50 to 200% (Van Rijn, 1993; Yasi et al., 2013). Disregarding such processes in these study sites was carefully considered. Given the above and the arguments mentioned in the methods section, we are confident that this option in this case will not bring tangible shortcomings to this research. Furthermore, the possible riverbed degradation effects due to the releasing of sediment-starving floods by the dam were not tested because according to our expert

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knowledge this will not pose a problem in this case. Such floods with similar recurrence intervals were already tested by Rivaes et al. (2015) in two river stretches of much smaller grain size (pebbles and sand) and results showed in both cases that such flood discharges were not relevant for riverbed degradation. The influence of fish species on geomorphology and riparian vegetation by ecosystem engineering, as it was

5 mentioned in the introduction, was not considered also during this study as it seemed fairly unrealistic in these case studies due to the general dimension of riverbed particles.
The results of the vegetation modeling illustrate how the natural flow regime generates morphodynamic

disturbances, without which the riparian vegetation is able to settle and age in the river channel. This is an important outcome that is essential to remember when providing environmental flow instructions.

- Subsequently, Consequently, of the latter, the mmicrohabitat analysis demonstrated that changes in the riparian landscapehabitat induce modifications in the hydraulic characteristics of the river stretches. The differences in mean values of these parameters are subtle between habitats-riparian landscapes but are statistically significant. Furthermore, Aa detailed analysis using a pairwise comparison of flow depths and velocities between scenarios show that modifications can reach 10 cm in water depth and more than 40 cm
- 15 s⁻¹ in flow velocity in some places. The hydrodynamic modeling results show that the water flowing near the margins is more affected than the water flowing in deeper areas of the river channel. One reason for these results is certainly because this study is about the effects of riparian vegetation encroachment on the physical habitat due to the colonization of the river margins by woody riparian vegetation. Accordingly, there are locations where the considered hydraulic parameters change considerably, shifting
- 20 the habitat preference of fishes in one or two classes of the corresponding habitat preference curves. Such change can shift the habitat preference of fishes in one or two classes of the corresponding habitat preference curves. These changes are particularly important considering that an alteration of one class regarding these parameters is sufficient to change fish preferences from near null to maximum and vice-versa in many cases, as it can be seen in the preference curves provided in the supplementary material (Appendix B Figures B10, B11 and B12).
- 25 (Appendix B Figures B10, B11 and B12). The hydrodynamic modeling also indicated changes directly affecting the habitat suitability of the existing fish species according to the riparian landscapehabitat. Through time, the habitat riparian landscape shaped by the Eflow regime diverged substantially-in habitat suitability from the natural and Eflow&Flush landscapehabitats, and there were cases where the habitat suitability was modified by more than double.
- 30 The relationship between fish assemblages and habitat has long been acknowledged (e.g., Clark et al., 2008; Matthews, 1998; Pusey et al., 1993) and can have a significant impact on the ecological status and function of the existing fish communities (Freeman et al., 2001; Jones et al., 1996; Randall and Minns, 2000). Effectively, habitat loss is the major threat concerning fish population dynamics and biodiversity (Bunn and Arthington, 2002), thereby promoting population changes with a proportional response to the enforced
- 35 habitat change (Cowley, 2008). This is particularly true for the fish species considered in this study (Cabral et al., 2006). The habitat decrease for barbel and nase during autumn and winter months jeopardizes those species survival by refuge loss, which is particularly important in flashy rivers (Hershkovitz and Gasith, 2013), such as the Ocreza river and Mediterranean rivers in general. On the other hand, the habitat change during spring months undermines the spawning activity and consequently the sustainability of future
- 40 population stocks (Lobón-Cerviá and Fernandez-Delgado, 1984). The habitat increase of calandino during

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this period can be ecologically tricky due to the habitat plasticity of this species (Doadrio, 2011; Gomes-Ferreira et al., 2005), as well as its characteristic adoption for an r-selection strategy as an evolutionary response to frequently disturbed environments (Bernardo et al., 2003). Above all, one should not ignore that the relationships between fish assemblages and habitat are extremely complex (e.g., Diana et al., 2006;

5 Hubert and Rahel, 1989; Santos et al., 2011), being a consequence of the actual natural conditions (Poff and Allan, 1995; Poff et al., 1997) that when disrupted, may allow the expansion of more generalist and opportunistic fauna (Poff and Ward, 1989).

Our results indicate that environmental flows taking into account riparian vegetation requirements are able to preserve the naturalness of the riparian <u>landscapehabitat</u> and consequently, the maintenance of the fish

- 10 habitat suitability. Accordingly, the implementation of such measure <u>measure in place of using environmental flows addressing only fish requirements</u> can provide significant positive ecological effects in downstream reaches (Lorenz et al., 2013; Pusey and Arthington, 2003) and <u>results in additional ecosystem services like stream bank stability, flood risk reduction or wildlife habitat</u> (Berges, 2009; Blackwell and Maltby, 2006) while imposing minor revenue losses to dam managers (Rivaes et al., 2015).
- -The implementation of such environmental flows could provide an additional way to attain the "good ecological status" required by the Water Framework Directive (WFD). In addition, taking up a procedure such as this one can act both as 'win-win' and 'no-regret' adaptation measures during the second phase of the WFD, because it potentiates the improvement of other ecological indicators and mitigates the impacts of flow regulation, while being robust enough to account for different scenarios of climate change (EEA, 2005)
- Water science still lacks strong links between flow restoration and its ecological benefits (Miller et al.,

2012), particularly regarding long-term monitoring of environmental flow performance (King et al., 2015 and citations herein). Nevertheless, the outcomes of this study are a product of long-term simulations by models that were calibrated and validated for the corresponding watershed with local data in natural river

- 25 flow conditions. This standard procedure in modeling strengthens confidence in our predictions as the models proved to correctly replicate the response of the riparian and fish communities when paralleled with simultaneous observational data. In addition, model uncertainty due to estimation uncertainty in input parameters was previously assessed by means of sensitivity analyses on both models. In either case the models showed to be quite robust to the uncertainty of estimated parameter inputs (see Rivaes et al., 2013)
- 30 and Boavida et al., 2013) which reveal a relatively small uncertainty in the models outputs and provides additional confidence on the results.

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In conclusion, we predict a change in fish habitat suitability according to the long-term structural adjustments that riparian <u>landscapehabitats</u> endure following river regulation. These changes can be attributed to the effects that altered riparian <u>landscapehabitats</u> have on the hydraulic characteristics of the river stretches. In our view, environmental flow regimes considering only the aquatic biota are expected to become obsolete in few years due to the alteration of the habitat premises in which they were based. This situation points to the unsustainability of these environmental flows in the long-term perspective of the fluvial ecosystem, failing to achieve the desired effects on aquatic communities to which those were proposed in the first place. An environmental flow regime that simultaneously considers riparian vegetation

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requirements contributes to the preservation of the hydraulic characteristics of the river channel at the natural riverine habitat standards, therefore maintaining the habitat assumptions that support the environmental flow regimes regarding aquatic communities. Consequently, accounting for riparian vegetation requirements poses as an essential measure to assure the effectiveness of environmental flow

regimes in the long-term perspective of the fluvial ecosystem. 5

Data availability

Riverbed topography, hydraulic measurements, riparian vegetation and fish sampling were collected by the authors and are available at http://doi.org/10.5281/zenodo.839531. Both River2D and CASiMiR-vegetation models are freeware available at http://www.river2d.ualberta.ca/download.htm and http://www.casimirsoftware.de/ENG/download_eng.html, respectively.

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References

Acreman, M.: Ethical aspects of water and ecosystems, Water Policy, 3, 257-265, 20 http://dx.doi.org/10.1016/S1366-7017(01)00009-5, 2001.

Acreman, M. C., and Ferguson, J. D.: Environmental flows and the European Water Framework Directive, Freshwater Biology, 55, 32-48, 10.1111/j.1365-2427.2009.02181.x, 2010.

Acreman, M. C., Aldrick, J., Binnie, C., Black, A., Cowx, I., Dawson, H., Dunbar, M., Extence, C., Hannaford, J., Harby, A., Holmes, N., Jarritt, N., Old, G., Peirson, G., Webb, J., and Wood, P.: Environmental flows from dams: the water framework directive, Proceedings of the Institution of Civil

Engineers - Engineering Sustainability, 162, 13-22, 10.1680/ensu.2009.162.1.13, 2009. Acreman, M., Arthington, A. H., Colloff, M. J., Couch, C., Crossman, N. D., Dyer, F., Overton, I., Pollino, C. A., Stewardson, M. J., and Young, W.: Environmental flows for natural, hybrid, and novel riverine ecosystems in a changing world, Frontiers in Ecology and the Environment, 12, 466-473, 10.1890/130134,

30 2014

25

Allan, J. D., and Castillo, M. M.: Stream Ecology: Structure and function of running waters, Second edition ed., Springer, Dordrecht, NL, 436 pp., 2007.

Altman, D. G.: Practical Statistics for Medical Research, Chapman & Hall, London, UK, 613 pp., 1991. Arthington, A. H.: Environmental flows: saving rivers in the third millennium, Freshwater Ecology Series,

4, Univ of California Press, 406 pp., 2012. 35

Arthington, A. H.: Environmental flows: a scientific resource and policy framework for river conservation and restoration, Aquatic Conservation: Marine and Freshwater Ecosystems, 25, 155-161, 10.1002/aqc.2560, 2015.

Arthington, A. H., and Zalucki, J. M.: Comparative Evaluation of Environmental Flow Assessment
Techniques: Review of Methods, in, Land and Water Resources Research and Development Corporation, Canberra, AUSTRALIA, 141, 1998.

Arthington, A. H., King, J. M., O'Keeffe, J. H., Bunn, S. E., Day, J. A., Pusey, B. J., Blüdhorn, D. R., and Tharme, R. E.: Development of an holistic approach for assessing environmental water requirements of riverine ecosystems, Proceedings of an International Seminar and Workshop on Water Allocation for the Environment, Armidale, Australia, 1992, 69-76, 1992.

Arthington, A. H., Bunn, S. E., Poff, L. N., and Naiman, R. J.: The challenge of providing environmental flow rules to sustain river ecosystems, Ecological Applications, 16, 1311-1318, 2006.
Arthington, A. H., Naiman, R. J., McClain, M. E., and Nilsson, C.: Preserving the biodiversity and ecological services of rivers: new challenges and research opportunities, Freshwater Biology, 55, 1-16,

- 15 10.1111/j.1365-2427.2009.02340.x, 2010.
 Barnes, H. H.: Roughness Characteristics of Natural Channels, Washington, USA, 1967.
 Benjankar, R., Egger, G., and Jorde, K.: Development of a dynamic floodplain vegetation model for the Kootenai river, USA: concept and methodology, 7th ISE and 8th HIC, 2009.
 Benjankar, R., Egger, G., Jorde, K., Goodwin, P., and Glenn, N. F.: Dynamic floodplain vegetation model
- 20 development for the Kootenai River, USA, Journal of Environmental Management, 92, 3058-3070, 10.1016/j.jenvman.2011.07.017, 2011.

Benjankar, R., Jorde, K., Yager, E. M., Egger, G., Goodwin, P., and Glenn, N. F.: The impact of river modification and dam operation on floodplain vegetation succession trends in the Kootenai River, USA, Ecological Engineering, 46, 88-97, http://dx.doi.org/10.1016/j.ecoleng.2012.05.002, 2012.

- 25 Berges, S. A.: Ecosystem services of riparian areas: stream bank stability and avian habitat, Master of Science, Iowa State University, Ames, Iowa, USA, 106 pp., 2009. Bernardo, J. M., Ilhéu, M., Matono, P., and Costa, A. M.: Interannual variation of fish assemblage structure in a Mediterranean river: implications of streamflow on the dominance of native or exotic species, River Research and Applications, 19, 521-532, 10.1002/rra.726, 2003.
- Blackwell, M. S. A., and Maltby, E.: How to use floodplains for flood risk reduction, in, European Communities, Luxembourg, Belgium, 144, 2006.
 Boavida, I., Santos, J., Cortes, R., Pinheiro, A., and Ferreira, M.: Assessment of instream structures for

habitat improvement for two critically endangered fish species, Aquatic Ecology, 45, 113-124, 10.1007/s10452-010-9340-x, 2011.

35 Boavida, I., Santos, J. M., Katopodis, C., Ferreira, M. T., and Pinheiro, A.: Uncertainty in predicting the fish-response to two-dimensional habitat modeling using field data, River Research and Applications, 29, 1164-1174, 10.1002/rra.2603, 2013.

Boavida, I., Santos, J. M., Ferreira, M. T., and Pinheiro, A. N.: Barbel habitat alterations due to hydropeaking, Journal of Hydro-environment Research, http://dx.doi.org/10.1016/j.jher.2014.07.009, 2015.

40 2015

10

Bovee, K. D.: A guide to stream habitat analysis using the Instream Flow Incremental Methodology, in, U.S.D.I. Fish and Wildlife Service, Office of Biological Services, Washington, 248, 1982.

Bovee, K. D., and Milhous, R. T.: Hydraulic simulation in instream flow studies: Theory and techniques. Instream Flow Information Paper: No. 5. FWS/OBS-78/33., Fish and Wildlife Service, Fort Collins, Colorado, USA, 1978.

5

Brisbane Declaration: The Brisbane Declaration. Environmental flows are essential for freshwater ecosystem health and human well-being, Declaration of the 10th International Riversymposium and International Environmental Flows Conference, Brisbane, AUS, 2007, 1-7, 2007.

Broadmeadow, S., and Nisbet, T. R.: The effects of riparian forest management on the freshwater
environment: a literature review of best management practice, Hydrology & Earth System Sciences, 8, 286-305, 10.5194/hess-8-286-2004, 2004.

Bunn, S. E., and Arthington, A. H.: Basic Principles and Ecological Consequences of Altered Flow Regimes for Aquatic Biodiversity, Environmental Management, 30, 492-507, 10.1007/s00267-002-2737-0, 2002.

- Cabral, M. J., Almeida, J., Almeida, P. R., Dellinger, T., Ferrand de Almeida, N., Oliveira, M. E.,
 Palmeirim, J. M., Queiroz, A. I., Rogado, L., and Santos-Reis, M.: Livro vermelho dos vertebrados de Portugal, in, Instituto da Conservação da Natureza/Assírio & Alvim, Lisboa, 660, 2006.
 Capon, S. J., and Dowe, J. L.: Diversity and dynamics of riparian vegetation, in: Principles for riparian lands management, edited by: Lovett, S., and Price, P., Land & Water Australia, Canberra, AUS, 3-33, 2007.
- 20 Chase, J. W., Benoy, G. A., Hann, S. W. R., and Culp, J. M.: Small differences in riparian vegetation significantly reduce land use impacts on stream flow and water quality in small agricultural watersheds, Journal of Soil and Water Conservation, 71, 194-205, 10.2489/jswc.71.3.194, 2016. Chow, V. T.: Open channel hydraulics, McGraw-Hill, New York, USA, 680 pp., 1959.

Chow, v. 1.. Open channel hydraulies, McOraw-Thil, New Tork, OSA, 080 pp., 1959.

Clark, J. S., Rizzo, D. M., Watzin, M. C., and Hession, W. C.: Spatial distribution and geomorphic condition
 of fish habitat in streams: an analysis using hydraulic modelling and geostatistics, River Research and
 Applications, 24, 885-899, 10.1002/rra.1085, 2008.

Cohen, J.: A coefficient of agreement for nominal scales, Educational and Psychological Measurement, XX, 37-46, 10.1177/001316446002000104, 1960.

Copp, G. H.: The habitat diversity and fish reproductive function of floodplain ecosystems, Environmental
Biology of Fishes, 26, 1-27, 10.1007/bf00002472, 1989.

Corenblit, D., Steiger, J., Gurnell, A. M., and Naiman, R. J.: Plants intertwine fluvial landform dynamics with ecological succession and natural selection: a niche construction perspective for riparian systems, Global Ecology and Biogeography, 18, 507-520, 10.1111/j.1466-8238.2009.00461.x, 2009.

Corenblit, D., Baas, A. C. W., Bornette, G., Darrozes, J., Delmotte, S., Francis, R. A., Gurnell, A. M.,
Julien, F., Naiman, R. J., and Steiger, J.: Feedbacks between geomorphology and biota controlling Earth surface processes and landforms: A review of foundation concepts and current understandings, Earth-Science Reviews, 106, 307-331, http://dx.doi.org/10.1016/j.earscirev.2011.03.002, 2011.

Curran, J. C., and Hession, W. C.: Vegetative impacts on hydraulics and sediment processes across the fluvial system, Journal of Hydrology, 505, 364-376, http://dx.doi.org/10.1016/j.jhydrol.2013.10.013, 2013.

Davis, R., and Hirji, R.: Environmental flows: concepts and methods. Water Resources and Environment Technical Note nº C1, Environmental Flow Assessment series, World Bank, Washington, DC, 27 pp., 2003. Davies, P. M., Naiman, R. J., Warfe, D. M., Pettit, N. E., Arthington, A. H., and Bunn, S. E.: Flow-ecology relationships: closing the loop on effective environmental flows, Marine and Freshwater Research, 65, 133-

141, http://dx.doi.org/10.1071/MF13110, 2013. Diana, M., Allan, J. D., and Infante, D.: The influence of physical habitat and land use on stream fish assemblages in southeastern Michigan, American Fisheries Society Symposium, 48, 359-374, 2006. Doadrio, I.: Ictiofauna continental española: bases para su seguimiento, Ministerio de Medio Ambiente y Medio Rural y Marino, Centro de Publicaciones, Madrid, Spain, 2011.

5

10 Dosskey, M. G., Vidon, P., Gurwick, N. P., Allan, C. J., Duval, T. P., and Lowrance, R.: The Role of Riparian Vegetation in Protecting and Improving Chemical Water Quality in Streams1, JAWRA Journal of the American Water Resources Association, 46, 261-277, 10.1111/j.1752-1688.2010.00419.x, 2010. Downes, B. J., Barmuta, L. A., Fairweather, P. G., Faith, D. P., Keough, M. J., Lake, P., Mapstone, B. D., and Quinn, G. P.: Monitoring ecological impacts: concepts and practice in flowing waters, Cambridge

University Press, 434 pp., 2002. 15 Dudgeon, D., Arthington, A. H., Gessner, M. O., Kawabata, Z. I., Knowler, D. J., Lévêque, C., Naiman, R. J., Prieur-Richard, A. H., Soto, D., Stiassny, M. L. J., and Sullivan, C. A.: Freshwater biodiversity: importance, threats, status and conservation challenges, Biological Reviews, 81, 163-182, 10.1017/S1464793105006950, 2006.

Dyson, M., Bergkamp, G., and Scanion, J.: Flow. The Essentials of Environmental Flows, in, IUCN, Gland, 20 Switzerland and Cambridge, UK, 118, 2003.

EEA: Vulnerability and adaptation to climate change in Europe. Technical report No 7/2005, European Environment Agency, Copenhagen, DNK, 79, 2005.

Encina, L., Granado-Lorencio, C. A., and Rodríguez Ruiz, A.: The Iberian ichthyofauna: ecological 25 contributions, Limnetica, 25, 349-368, 2006.

Ferreira, M. T., Pinheiro, A. N., Santos, J. M., Boavida, I., Rivaes, R., and Branco, P.: Determinação de um regime de caudais ecológicos a jusante do empreendimento de Alvito, Instituto Superior de Agronomia, Universidade de Lisboa, Lisboa, 136, 2014.

Fetherston, K. L., Naiman, R. J., and Bilby, R. E.: Large woody debris, physical process, and riparian forest 30 development in montane river networks of the Pacific Northwest, Geomorphology, 13, 133-144, 10.1016/0169-555X(95)00033-2, 1995.

Fisher, K., and Dawson, H.: Reducing uncertainty in river flood conveyance - roughness review, Department for Environment, Food & Rural Affairs, Environment Agency, Lincoln, UK, 209 pp., 2003.

FitzHugh, T. W., and Vogel, R. M.: The impact of dams on flood flows in the United States, River Research 35 and Applications, 27, 1192-1215, 10.1002/rra.1417, 2010.

Freeman, M. C., Bowen, Z. H., Bovee, K. D., and Irwin, E. R.: Flow and Habitat Effects on Juvenile Fish Abundance in Natural and Altered Flow Regimes, Ecological Applications, 11, 179-190, 10.2307/3061065, 2001.

Frissell, C., Liss, W., Warren, C., and Hurley, M.: A hierarchical framework for stream habitat 40 classification: Viewing streams in a watershed context, Environmental Management, 10, 199-214, 1986.

García-Arias, A., Francés, F., Ferreira, T., Egger, G., Martínez-Capel, F., Garófano-Gómez, V., Andrés-Doménech, I., Politti, E., Rivaes, R., and Rodríguez-González, P. M.: Implementing a dynamic riparian vegetation model in three European river systems, Ecohydrology, 6, 635-651, 10.1002/eco.1331, 2013.

Gasith, A., and Resh, V. H.: Streams in Mediterranean Climate Regions: abiotic influences and biotic
responses to predictable seasonal events, Annu. Rev. Ecol. Syst., 30, 51-81, 0066-4162/99/1120-0051\$08.00, 1999.

Gregory, S. V., Swanson, F. J., McKee, W. A., and Cummins, K. W.: An Ecosystem Perspective of Riparian Zones: Focus on links between land and water, Bioscience, 41, 540-551, 10.2307/1311607, 1991.

Gillespie, B. R., Desmet, S., Kay, P., Tillotson, M. R., and Brown, L. E.: A critical analysis of regulated
river ecosystem responses to managed environmental flows from reservoirs, Freshwater Biology, 60, 410425, 10.1111/fwb.12506, 2014.

Gippel, C.: Australia's environmental flow initiative: Filling some knowledge gaps and exposing others, Water Science & Technology, 43, 73-88, 2001.

Gomes-Ferreira, A., Ribeiro, F., Moreira da Costa, L., Cowx, I. G., and Collares-Pereira, M. J.: Variability

15 in diet and foraging behaviour between sexes and ploidy forms of the hybridogenetic Squalius alburnoides complex (Cyprinidae) in the Guadiana River basin, Portugal, Journal of Fish Biology, 66, 454-467, 10.1111/j.0022-1112.2005.00611.x, 2005.

Gorman, O. T., and Karr, J. R.: Habitat Structure and Stream Fish Communities, Ecology, 59, 507-515, 10.2307/1936581, 1978.

20 Gurnell, A.: Plants as river system engineers, Earth Surface Processes and Landforms, 39, 4-25, 10.1002/esp.3397, 2014.

Gurnell, A. M., Bertoldi, W., and Corenblit, D.: Changing river channels: The roles of hydrological processes, plants and pioneer fluvial landforms in humid temperate, mixed load, gravel bed rivers, Earth-Science Reviews, 111, 129-141, 10.1016/j.earscirev.2011.11.005, 2012.

25 Hassan, M. A., Gottesfeld, A. S., Montgomery, D. R., Tunnicliffe, J. F., Clarke, G. K. C., Wynn, G., Jones-Cox, H., Poirier, R., MacIsaac, E., Herunter, H., and Macdonald, S. J.: Salmon-driven bed load transport and bed morphology in mountain streams, Geophysical Research Letters, 35, L04405, 10.1029/2007GL032997, 2008.

Hershkovitz, Y., and Gasith, A.: Resistance, resilience, and community dynamics in mediterranean-climate
streams, Hydrobiologia, 719, 59-75, 10.1007/s10750-012-1387-3, 2013.

- Hirji, R., and Davis, R.: Environmental Flows in Water Resources Policies, Plans, and Projects, Environment and Development, The World Bank C1 Findings and Recommendations, 189 pp., 2009.Hubert, W. A., and Rahel, F. J.: Relations of Physical Habitat to Abundance of Four Nongame Fishes in High-Plains Streams: A Test of Habitat Suitability Index Models, North American Journal of Fisheries
- Management, 9, 332-340, 10.1577/1548-8675(1989)009<0332:rophta>2.3.co;2, 1989.
 Hughes, F. M. R.: Floodplain biogeomorphology, Progress in physical geography, 21, 501-529, 1997.
 Hughes, F. M. R., and Rood, S. B.: Allocation of River Flows for Restoration of Floodplain Forest Ecosystems: A Review of Approaches and Their Applicability in Europe, Environmental Management, 32, 12-33, 10.1007/s00267-003-2834-8, 2003.

Jalón, D. G. d., and Gortázar, J.: Evaluation of instream habitat enhancement options using fish habitat simulations: case-studies in the river Pas (Spain), Aquatic Ecology, 41, 461-474, 10.1007/s10452-006-9030-x, 2007.

Jones, M. L., Randall, R. G., Hayes, D., Dunlop, W., Imhof, J., Lacroix, G., and Ward, N. J. R.: Assessing the ecological effects of habitat change: moving beyond productive capacity, Canadian Journal of Fisheries and Aquatic Sciences, 53, 446-457, 1996.

5

15

20

30

35

King, J. M., and Tharme, R. E.: Assessment of the Instream Flow Incremental Methodology and Initial Development of Alternative Instream Flow Methodologies for South Africa, South African Water Research Commission, 604, 1994.

10 King, J., and Louw, D.: Instream flow assessments for regulated rivers in South Africa using the Building Block Methodology, Aquatic Ecosystem Health and Management, 1, 109-124, 10.1016/S1463-4988(98)00018-9, 1998.

King, A., Gawne, B., Beesley, L., Koehn, J., Nielsen, D., and Price, A.: Improving Ecological Response Monitoring of Environmental Flows, Environmental Management, 55, 991-1005, 10.1007/s00267-015-0456-6, 2015.

Linnansaari, T., Monk, W. A., Baird, D. J., and Curry, R. A.: Review of approaches and methods to assess Environmental Flows across Canada and internationally. Research Document 2012/039, Canadian Science Advirosy Secretariat (CSAS), 75, 2012.

Lobón-Cerviá, J., and Fernandez-Delgado, C.: On the biology of the barbel (Barbus barbus bocagei) in the Jarama River, Folia zoologica, 33, 371-384, 1984.

Lorenz, A. W., Stoll, S., Sundermann, A., and Haase, P.: Do adult and YOY fish benefit from river restoration measures?, Ecological Engineering, 61, 174-181, http://dx.doi.org/10.1016/j.ecoleng.2013.09.027, 2013.

Lytle, D. A., and Poff, N. L.: Adaptation to natural flow regimes, Trends in Ecology & Evolution, 19, 94-100, http://dx.doi.org/10.1016/j.tree.2003.10.002, 2004.

Maheshwari, B. L., Walker, K. F., and McMahon, T. A.: Effects of regulation on the flow regime of the river Murray, Australia, Regulated Rivers: Research & Management, 10, 15-38, 10.1002/rrr.3450100103, 1995.

Mäkinen, H., and Vanninen, P.: Effect of sample selection on the environmental signal derived from treering series, Forest Ecology and Management, 113, 83-89, 1999.

Matthews, W. J.: Patterns in freshwater fish ecology, Springer Science & Business Media, Norman, Oklahoma, USA, 756 pp., 1998.

Merritt, D. M., Scott, M. L., Poff, L. N., Auble, G. T., and Lytle, D. A.: Theory, methods and tools for determining environmental flows for riparian vegetation: riparian vegetation-flow response guilds., Freshwater Biology, 55, 206-225, 10.1111/j.1365-2427.2009.02206.x, 2010.

Miller, K. A., Webb, J. A., de Little, S. C., and Stewardson, M.: Will environmental flows increase the abundance of native riparian vegetation on lowland rivers? A systematic review protocol, Environmental Evidence, 1, 1-9, 10.1186/2047-2382-1-14, 2012.

Miller, K. A., Webb, J. A., de Little, S. C., and Stewardson, M. J.: Environmental Flows Can Reduce the Encroachment of Terrestrial Vegetation into River Channels: A Systematic Literature Review, Environmental Management, 1-11, 10.1007/s00267-013-0147-0, 2013.

Naiman, R. J., Décamps, H., and McClain, M. E.: Riparia - Ecology, conservation and management of streamside communities, in, Elsevier academic press, London, UK, 430, 2005.

Nilsson, C., and Berggren, K.: Alterations of Riparian Ecosystems Caused by River Regulation, Bioscience, 50, 783-792, 10.1641/0006-3568(2000)050[0783:aorecb]2.0.co;2, 2000.

NRC, N. R. C.: Riparian Areas: Functions and Strategies for Management, The National Academies Press, Washington, D.C., USA, 444 pp., 2002.

10 Palmer, M. A., Hondula, K. L., and Koch, B. J.: Ecological Restoration of Streams and Rivers: Shifting Strategies and Shifting Goals, Annual Review of Ecology, Evolution, and Systematics, 45, 247-269, doi:10.1146/annurev-ecolsys-120213-091935, 2014.

Parasiewicz, P.: Using MesoHABSIM to develop reference habitat template and ecological management scenarios, River Research and Applications, 23, 924-932, 10.1002/rra.1044, 2007.

15 Petts, G.: Instream flow science for sustainable river management, Journal of the American Water Resources Association, 45, 1071-1086, 10.1111/j.1752-1688.2009.00360.x, 2009. Poff, N. L., and Ward, J. V.: Implications of streamflow variability and predictability for lotic community

structure: a regional analysis of streamflow patterns, Canadian Journal of Fisheries and Aquatic Sciences, 46, 1805-1818, 1989.

20 Poff, N. L., and Allan, J. D.: Functional Organization of Stream Fish Assemblages in Relation to Hydrological Variability, Ecology, 76, 606-627, 10.2307/1941217, 1995.

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

Politti, E., and Egger, G.: Casimir Vegetation Manual, Environmental consulting Ltd, Klagenfurt, AT, 76
 pp., 2011.

Politti, E., Egger, G., Angermann, K., Rivaes, R., Blamauer, B., Klösch, M., Tritthart, M., and Habersack,
H.: Evaluating climate change impacts on Alpine floodplain vegetation, Hydrobiologia, 737, 225-243, 10.1007/s10750-013-1801-5, 2014.

Postel, S., and Richter, B.: Rivers for life: managing water for people and nature, Island Press, Washington30 DC, USA, 243 pp., 2003.

Pusey, B. J., and Arthington, A. H.: Importance of the riparian zone to the conservation and management of freshwater fish: a review, Marine and Freshwater Research, 54, 1-16, 10.1071/MF02041, 2003.

Pusey, B. J., Arthington, A. H., and Read, M. G.: Spatial and temporal variation in fish assemblage structure in the Mary River, south-eastern Queensland: the influence of habitat structure, Environmental Biology of Fishes, 37, 355-380, 10.1007/bf00005204, 1993.

R Development Core Team: R: A language and environment for statistical computing, R Foundation for Statistical Computing, Vienna, AT, 2011.

Randall, R. G., and Minns, C. K.: Use of fish production per unit biomass ratios for measuring the productive capacity of fish habitats, Canadian Journal of Fisheries and Aquatic Sciences, 57, 1657-1667, 10, 1130/aifca, 57, 8, 1657, 2000

40 10.1139/cjfas-57-8-1657, 2000.

35

5

Revenga, C., Brunner, J., Henninger, N., Kassem, K., and Payne, R.: Pilot Analysis of Global Ecossystems: Freshwater Systems, in, World Resources Institute, Washington, DC, 65, 2000.

Richter, B. D., and Thomas, G. A.: Restoring environmental flows by modifying dam operations, Ecology and Society, 12, 12, 2007.

5 Rivaes, R., Rodríguez-González, P. M., Albuquerque, A., Pinheiro, A. N., Egger, G., and Ferreira, M. T.: Riparian vegetation responses to altered flow regimes driven by climate change in Mediterranean rivers, Ecohydrology, 6, 413-424, 10.1002/eco.1287, 2013.

Rivaes, R., Rodríguez-González, P. M., Albuquerque, A., Pinheiro, A. N., Egger, G., and Ferreira, M. T.: Reducing river regulation effects on riparian vegetation using flushing flow regimes, Ecological Engineering, 81, 428-438, 10.1016/j.ecoleng.2015.04.059, 2015.

Rood, S. B., Bigelow, S. G., Polzin, M. L., Gill, K. M., and Coburn, C. A.: Biological bank protection: trees are more effective than grasses at resisting erosion from major river floods, Ecohydrology, 8, 772-779, 10.1002/eco.1544, 2015.

10

Ryan, D. K., Yearsley, J. M., and Kelly-Quinn, M.: Quantifying the effect of semi-natural riparian cover
 on stream temperatures: implications for salmonid habitat management, Fisheries Management and Ecology, 20, 494-507, 10.1111/fme.12038, 2013.

Salemi, L. F., Groppo, J. D., Trevisan, R., Marcos de Moraes, J., de Paula Lima, W., and Martinelli, L. A.: Riparian vegetation and water yield: A synthesis, Journal of Hydrology, 454, 195-202, http://dx.doi.org/10.1016/j.jhydrol.2012.05.061, 2012.

20 Santos, J. M., Ferreira, M. T., Godinho, F. N., and Bochechas, J.: Efficacy of a nature-like bypass channel in a Portuguese lowland river, Journal of Applied Ichthyology, 21, 381-388, 10.1111/j.1439-0426.2005.00616.x, 2005.

Santos, J. M., Reino, L., Porto, M., Oliveira, J. o., Pinheiro, P., Almeida, P., Cortes, R., and Ferreira, M.:
Complex size-dependent habitat associations in potamodromous fish species, Aquatic Sciences, 73, 233245, 10.1007/s00027-010-0172-5, 2011.

Steffler, P., Ghanem, A., Blackburn, J., and Yang, Z.: River2D, in, University of Alberta, Alberta, CANADA, 2002.

SNIRH: National Water Resources Information System, in, Instituto da Água, I. P. (INAG), 2010.

Statzner, B.: Geomorphological implications of engineering bed sediments by lotic animals, 30 Geomorphology, 157–158, 49-65, http://dx.doi.org/10.1016/j.geomorph.2011.03.022, 2012.

- Statzner, B., Sagnes, P., Champagne, J.-Y., and Viboud, S.: Contribution of benthic fish to the patch dynamics of gravel and sand transport in streams, Water Resources Research, 39, 1309, 10.1029/2003WR002270, 2003.
- Stromberg, J. C., Tluczek, M. G. F., Hazelton, A. F., and Ajami, H.: A century of riparian forest expansion
 following extreme disturbance: Spatio-temporal change in Populus/Salix/Tamarix forests along the Upper
 San Pedro River, Arizona, USA, Forest Ecology and Management, 259, 1181-1198, 10.1016/j.foreco.2010.01.005, 2010.

Tabacchi, E., Lambs, L., Guilloy, H., Planty-Tabacchi, A.-M., Muller, E., and Décamps, H.: Impacts of riparian vegetation on hydrological processes, Hydrological processes, 14, 2959-2976, 2000.

Tharme, R. E.: A global perspective on environmental flow assessment: emerging trends in the development and application of environmental flow methodologies for rivers, River Research and Applications, 19, 397-441, 10.1002/rra.736, 2003.

Thoms, M. C., and Parsons, M.: Eco-geomorphology: an interdisciplinary approach to river science, The
Structure and Management Implications of Fluvial Sedimentary Systems, Alice Springs, Australia, 2002, IAHS Publ. no. 276, 113-119, 2002.

Thorp, J. H., Thoms, M. C., and Delong, M. D.: The Riverine Ecosystem Synthesis. Toward Conceptual Cohesiveness in River Science, Elsevier, London, UK, 208 pp., 2008.

Uddin, F. M. J., Asaeda, T., and Rashid, M. H.: Factors affecting the changes of downstream forestation in the South American river channels, Environment and Pollution, 3, 24 - 40, 10.5539/ep.v3n4p24, 2014a.

Uddin, F. M. J., Asaeda, T., and Rashid, M. H.: Large-Scale Changes of the Forestation in River Channel Below the Dams in Southern African Rivers: Assessment Using the Google Earth Images, Polish Journal of Ecology, 62, 607-624, 10.3161/104.062.0407, 2014b.

10

20

Van Looy, K., Tormos, T., Ferréol, M., Villeneuve, B., Valette, L., Chandesris, A., Bougon, N., Oraison,

F., and Souchon, Y.: Benefits of riparian forest for the aquatic ecosystem assessed at a large geographic scale, Knowl. Managt. Aquatic Ecosyst., 06, 10.1051/kmae/2013041, 2013.
 Van Rijn, L. C.: Principles of sediment transport in rivers, estuaries and coastal seas, Aqua Publications, Delft, NLD, 1993.

Viera, A. J., and Garrett, J. M.: Understanding interobserver agreement: the Kappa statistic, Family Medicine, 37, 360-363, 2005.

Wainwright, J., and Mulligan, M.: Environmental Modelling: Finding Simplicity in Complexity, in, John Wiley & Sons, Ltd, London, UK, 430, 2004.

Wootton, J. T.: River Food Web Response to Large-Scale Riparian Zone Manipulations, PLOS ONE, 7, e51839, 10.1371/journal.pone.0051839, 2012.

25 Wu, R., and Mao, C.: The assessment of river ecology and habitat using a two-dimensional hydrodynamic and habitat model, Journal of Marine Science and Technology, 15, 322-330, 2007. Yasi, M., Hamzepouri, R., and Yasi, A. R.: Uncertainties in Evaluation of the Sediment Transport Rates in Typical Coarse-Bed Rivers in Iran, Journal of Water Sciences Research, 5, 1-12, 2013.

		OCB	A	OCPR					
Year	natural	Eflow	Eflow&Flush	natural	Eflow	Eflow&Flush			
1	671	0.99	0.99	951	5.51	5.51			
2	203	0.99	167	287	5.51	237			
3	327	0.99	0.99	464	5.51	5.51			
4	217	0.99	167	308	5.51	237			
5	316	0.99	0.99	449	5.51	5.51			
6	371	0.99	167	526	5.51	237			
7	702	0.99	0.99	995	5.51	5.51			
8	202	0.99	167	286	5.51	237			
9	195	0.99	0.99	276	5.51	5.51			
10	440	0.99	371	624	5.51	527			

 $Table \ 1. \ Maximum \ annual \ discharges \ (m^3 \ s^{-1}) \ considered \ in \ the \ CASiMiR-vegetation \ model \ for \ each \ study \ site.$

-	OCBA study site					OCPR study site						
-	Eflow			Eflow&Flush			Eflow			Eflow&Flush		
-	RMSD	MAD	MAPD	RMSD	MAD	MAPD	RMSD	MAD	MAPD	RMSD	MAD	MAPD
	(m ²)	(m ²)	(%)	(m ²)	(m ²)	(%)	(m ²)	(m ²)	(%)	(m ²)	(m ²)	(%)
Luciobarbus bocagei (juv.)	86.00	72.10	15.40	12.17	7.24	2.52	26.23	17.37	35.55	2.51	1.50	0.63
Luciobarbus bocagei (adult)	29.46	20.55	5.83	2.87	2.12	1.55	12.94	7.73	23.15	3.44	1.79	3.01
Pseudochondrostoma polypepis (juv.)	128.21	86.14	11.58	9.42	5.72	2.26	45.42	32.71	34.43	1.55	0.92	2.51
Pseudochondrostoma polypepis (adult)	7.32	5.85	18.70	2.17	1.37	2.10	9.00	7.00	10.34	0.51	0.35	2.42
Squalius alburnoides (juv.)	44.05	28.16	8.46	6.20	4.06	2.10	33.10	27.78	28.37	2.44	1.35	2.18
Squalius alburnoides (adult)	92.41	52.47	10.23	7.49	5.31	2.37	61.76	47.83	40.54	0.96	0.63	2.90

Table 2. Deviation analysis of the weighted usable areas for the considered regulated flow regimes benchmarked by the natural flow regime (RMSD – Root Mean Square Deviation, MAD – Mean Absolute Deviation, MAPD – Mean Absolute Percentage Deviation). Values stand for the habitat availability deviation, in area and percentage, of the environmental flow regimes compared to the natural habitat availability of each species and life stage.



stand for direct inputs, striped white arrows for model outputs and grey arrows for variable conversion processes.

Comentado [RPGDRdS52]: Included according to the main concern 1 of reviewer 1



Comentado [RR53]: Modified according to the specific comments of reviewer 1 on Methods Comentado [RR54]: Modified according to the specific comments of reviewer 1 on Methods

Figure 112. Location and characterization of the study sites OCBA and OCPR.

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Figure 2. Environmental flow regime addressing fish (black line, left axis) and riparian (grey bars, right axis) requirements considered for the habitat modeling in OCBA study site. Fish requirements are addressed by a constant monthly discharge and riparian requirements by a flushing flow in the years in which are planned (duration of the flushing flow is similar to a natural flood with equal recurrence interval). The hydrograph for the Eflow&Flush flow regime is similar in the OCPR study site.



Figure 3. Methodological scheme representing the workflow of the modeling procedure. White arrows stand for direct inputs, striped white arrows for model outputs and grey arrows for variable conversion processes.



Figure 23. Environmental flow regime addressing fish (black line, left axis) and riparian (grey bars, right axis) requirements considered for the habitat modeling in OCBA study site. Fish requirements are addressed by a constant monthly discharge and riparian requirements by a flushing flow in the years in which are planned (duration of the flushing flow is similar to a natural flood with equal recurrence interval). The hydrograph for the Eflow&Flush flow regime is similar in the OCPR study site.



Figure 34. Expected patch mosaic of the riparian vegetation habitats shaped by the natural, Eflow and Eflow&Flush flow regimes (detailed by succession phase, namely, initial phase – IP, pioneer phase – PP, early succession woodland phase – ES, established forest phase – EF and mature forest phase – MF) in the OCBA study site (on the left) and in the OCPR study site (on the right).



Figure 4<u>5</u>. Hydraulic characterization of OCBA (top) and OCPR (bottom) according to the different expected riparian vegetation habitats driven by the Eflow, Eflow&Flush and natural flow regimes (data obtained from 2D hydrodynamic modeling). Different letters stand for statistical significant differences between groups (t-test). Boxplots portray non-outlier value range, thick black lines the median value and black dots the mean values.

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Figure 56. Fish weighted usable areas provided by the fish-addressed environmental flow regime (Eflow) flowing through the different riparian landscapehabitat scenarios originated by a decade of three different flow regimes (natural, Eflow&Flush and Eflow) at the OCBA (top three graphics) and OCPR (bottom three graphics) study sites.

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Comentado [RR55]: Changed according to comments of reviewer 1