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Hydrology and Earth System Sciences Discussions

Interactive comment on "Variability in stream discharge and temperatures during ecologically sensitive time periods: a preliminary assessment of the implications for Atlantic salmon" *by* D. Tetzlaff et al.

D. Tetzlaff et al.

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GENERAL COMMENTS

Please find herewith the submission of a substantially revised copy of the above manuscript (hessd-2005-0023) that was submitted to HESSD. We appreciate the three extremely thorough reviews and comprehensive sets of constructive comments suggesting improvements to the original manuscript. We have attempted to revise the manuscript accordingly and have made major changes and clarified a whole series of contextual, methodological and interpretational issues. This has involved extensively restructuring and pruning some sections, adding additional information, clarifying the text in a more precise manner and changing several figures as requested. It has been a long complex revision in dealing with the general comments of the 3 reviewers as well as the 37 specific points of reviewer 1 (plus queries about figures and tables), 82 points of reviewer 2 and a final 34 comments from reviewer 3. However, we feel that the paper has benefited greatly from these extensive changes and hope that it is now suitable for publication in HESS.

List of responses to Reviewer # 1:

General comments:

1) We have re-written and restructured the paper in many sections as recommended and have been more precise in our use of scientific terms and treatment on numerical data. We recognise that the abstract and introduction in the original manuscript gave the misleading impression that the paper was going to comparatively analyse flow and temperature variability at different temporal scales. The objectives of the paper are now clearer and more sharply focused and link much more directly to the results presented.

2) We clarify in the text that in spite of a number of background studies on flows and temperatures in the Girnock, these have rarely linked inter- and intra-annual variability to ecological receptors in the way that this paper does.

3) Regarding the definition of four ecologically "sensitive" time periods; we now make clear that these refer to periods during the freshwater, post-emergence life stages of Atlantic salmon, as these are particularly susceptible to flow and temperature influences. Of course we recognise that the precise timing of these periods varies inter-annually. Salmon are selected to use intrinsic "calendars" and modify timings of certain activities according to the prevailing environmental conditions. However, the time periods specified are based on almost 40 years of empirical observations in the Girnock to identify the time "windows" that best encapsulate these periods.

4) The abstract and introduction have now been modified and the potential utility of the CDV approach in integrating flow and temperature influences has been emphasized.

The paper aims to present a preliminary analyses of how empirical data on stream temperature and discharge can be integrated using the concept of Critical Displacement Velocity (CDV) for juvenile fish based on the published approach of Graham et al., 1996. The study provides an insight into how differences in annual flow and thermal regimes might influence foraging opportunities for juvenile salmon. As we note in the introduction, temperature-driven growth models can explain around 85 % of observed fish growth at his site. The CDV approach is intended to provide an additional parameter in such models that may help account for the unexplained variance. Indeed colleagues are currently working towards this goal. However, this is a major task and clearly outwith the objectives of this paper. We have now modified the introduction, to make clearer the objectives and state that additional modelling work is underway. However, we still feel that the development of the approach provides as reported in the paper has sufficient research novelty in the potential for deriving hydraulic data from flow records and insight into potential influences on juvenile salmon.

The reviewer expresses his doubt that the approach used may not reflect either spatial variability in velocities around the catchment, nor may measures based on velocities at 0.6 x depth be representative of those experienced by juvenile fish. We recognise that calculation of velocity based on readily available discharge data is very much a first approximation and a relatively simplistic representation of the complex velocity fields that will occur in a river such as the Girnock. But the objective of the present study was to capture temporal variability in velocity conditions in different hydrological year. In this sense, we view the Littlemill data as being a useful indicator of temporal variability of conditions in the rest of the river system. Of course we recognise that hydraulic conditions will differ in different channel types as the reviewer comments. Also, as we acknowledge (and demonstrate in Figure 2), that there will be variability along a cross-section of the channel and at different depths in the water column. There is now a much clearer evaluation of the assumptions behind the modelling approach in the methods section. To represent the range in spatial variability within a whole catchment, high spatial resolution data would need to be collected which would be a major undertaking. Moreover, at most sites even moderately high flows could not be gauged safely. An alternative would be hydraulic modelling, which previous work that we have carried out (cf Gibbins et al, 2004) has shown is difficult and potentially erroneous in a hydraulically rough, montane river channel. Thus, the authors are convinced that the approach presented is a valuable method in deriving ecologically meaningful insights from hydrological data sets particularly by focussing at this stage on temporal variability in ten hydrologically contrasting years. We believe that in understanding short-term hydroecological associations we must use existing (especially long-term) data sets where available and try and ensure that useful insights help inform river management strategies. Although the approach has limitations, it has helped in the formulation of hypotheses that can be later tested and we fail to see which alternative approaches would be free of other limitations or assumptions.

5) Spring salmon return to the Dee system from December in the year prior to spawning. They migrate slowly upstream in response to hydrological conditions throughout the year. Thus the hydrological conditions within the Dee system throughout the year (as at least generally indexed by flows in the Girnock) influence the distribution of fish within the Dee system. We know from radio tracking studies that Girnock fish gradually move towards pools in the Dee a short distance downstream from the Girnock in the final months prior to spawning. The final entry of salmon into the Girnock is generally triggered by high flow events as shown in Figure 10. Our point is that extreme hydrological years (i.e. when flow conditions are highly variable in 1995/96, or not variable (1997/98)) have the most marked influences on spawning access. In other words, high, variable flows prior to spawning allow unhindered access which permits large numbers of females to enter the burn. In contrast, low unvarying flows ($<$ 0.3 m3 s-1) hinder access, both physically, or in terms of absence of a physical cue, result in low female entry. In more "typical" years, the relationship with flow is less clear. The complex temporal variation in flow is indexed by the coefficient of variation each year. Thus, the hydrological extremes are of particular importance and analysing the data without them seems to be of limited value. However, we have now included fuller statistical

information in Table 4.

Specific comments: (sequentially dealing with each point raised)

Title:

1. Changed as requested

Abstract:

2. Terminology hydrological/ hydraulic: It is widely acknowledged that aquatic organisms experience hydraulic forces. Hence, discharge as a hydrological variable influences indirectly biota. Therefore, hydrological and hydraulic are not meant to be used as synonyms and the text was modified where necessary to clarify the differences. 3. Abstract text is modified and results are provided. 4. Text is now changed 5. Text has been modified.

Introduction:

6./7/8. The introduction has been largely re-written and the suggestions and remarks of all 3 referees considered. 9. Please see response to general comments 1). Objectives are now clearer. 10. Sentences are modified.

Study site:

11. Changed 12. Text was modified.

Data and Methods

13. See above (point 2) 14. Text was modified. 15. Text is now more precise. Please see also response to General Comments 3. 16. Section title was changed. 17. Please see modified text. 7% of the data was filled with the method which is now hopefully explaind much more clearly. As written, the methods in the original m/s implied that monthly data were used to infil the gaps. In fact hourly data were used, but air-stream temperature relationships were established for individual months. The text is more

precise now. 18. We now make clear that high CDVs do not preclude feeding but speculate - reasonably - that CDV exceedence is likely to reduce scope for movement which is a probable constraint on food acquision, particularly as high flows in Scottish rivers will increase turbidity and water colour inhibiting prey capture futher. Testing this would be a separate exercise calling for hypothesis tests on feeding and growth which is beyond the scope of this study. 19. Methodology of estimated growth estimates is fully explained and growth curves are given in given reference, Tetzlaff et al, 2005, Hydrobiologia. The different fish length information (for 2002: 504 individual 0+ salmon and 1008 individual 1+ salmon; in 2003: 183 individual 0+ salmon and 167 individual 1+ salmon) were measured at six different monitoring sites (please see details in Tetzlaff et al., 2005, in press). There were no significant differences in lengths at different monitoring sites. Given this similarity, spatially averaged fish length data for all sites were used to characterise fish sizes in the stream and these data were used to calculate CDVs at the gauging site, where the corresponding flow data are available. 20. The opinion of the authors is that these numbers are important to put the numbers of this study into the broader context (for readers which are less familiar with longer-term adult spawner numbers).

Results:

21. Text is modified. 22. Mean and Standard deviation were also calculated for the whole hydrological year and each of the sensitive periods. Coefficient of variation is an index of variability of streamflow for a given period. As spawners migrate into the river in relation to spates, it indexes the opportunity for access. 23. The paragraph is clarified now and more precise. 24. Text (section title) was modified 25. Cumulative temperature was and is still described in methodology section. 26. Section title is changed 27. Graham et al. developed CDV for 0+ and 1+ (see Graham et al., 1996). In addition, for 2+ fish much coarser fish length information was available, hence for a “time series” of daily fish length assumptions would have been even greater for those for 0+ and 1+ fish. For details please see Tetzlaff et al., Hydrobiologia (“in press”). 28.

We think this sentence paragraph is required as an introduction and explanation. 29. Please see general comment 5. 30. In Table 4 (where P values are given now) the relationship between flow variability and spawning returners is indexed by the CoV of flow and the correlations are provided.

Discussion:

31. Discussion is now restructured. 32. / 33. Text is modified. 34. This point is mistaken since we refer only to the final phase of upstream migration - we make this clear in the revised text. 35. See general comments. Numerically full juvenile recruitment means that spawning salmon are distributed throughout the burn, thus allowing juvenile habitat to be fully occupied. This is now clarified in the text. 36. Text is modified 37. Whole MS is modified. We don't understand the point re. validation of the periods chosen for study, we have chosen them based on long-term experiences and knowledge. However, we make the rationale, and basis for it, much clearer in the revised text.

Tables: Combination of Table 1 and 2 would result in a huge, complex table that would lose clarity. Terminology modified as requested.

Table 3: Please, see point 27.

Table 4: Correlations are now expressed as coefficients of correlations (r), p-values are listed, Standard deviation is listed.

Figures: Figure 1 Modified as requested

Figure 2: Modified. The relatively low velocities reflect the relatively high hydraulic roughness of the stream channel.

Figure 3: Caption is modified

Figure 4: This shows flow duration curves and the axes are conventionally log-scale axes.

Figure 5: The cumulative curves allow a direct comparison of intra-and inner annual

variability, again, conventionally used in the hydrological literature. The curves start on 1st October, as the hydrological year starts conventionally at 1st October (until 30th September).

Figure 6: Now just optimum temperature after Elliot and Hurley (2003) is given as orientation (for biologically less informed readers). Figure caption is clarified.

Figure 8: Modified to make cleaered. Fry are given included.

Figure 9: Statistics are provided as requested.

List of responses to Reviewer # 2:

General comments:

This reviewer clearly has the erroneous impression that the paper intends to compare how data of different temporal resolution may affect our understanding of biophysical influences on the hydroecology of streams. From the misleading way in which the introduction in the original manuscript was written, we understand why he/she developed this impression. Reviewer 3 was also confused in this manner, though he/she recognises that this issue diverts attention away from the main innovation in the paper - i.e. looking at tools for examining hydroecological associations for juvenile salmonids and returning spawners. The main point which we wish to emphasize regarding data resolution is that many of the approaches suggested as tools for river management (e.g. setting Ecologically Acceptable Flows) are based on averaged data (e.g. weekly, monthly), which would be insufficient to assess the role of short-term hydrological/thermal dynamics in aquatic ecosystems where Atlantic salmon are an important target species. Also, we would argue that the flow data/velocity estimates that we have are not especially rare. They can be derived from any standard gauging station. Temperature data are much less common, but the most unique aspect of our data (recognised by reviewer 3) is that it represents paired physical and biological data sets. Thus it is the insight as to how short-term dynamics may affect - for example - juvenile feeding opportunities or spawning entry to the study stream that we seek to explore more fully in this paper. We think that such short term understanding needs to be factored into river management strategies for salmon rivers, though - as we acknowledge, and the reviewer recognises - this study represents only preliminary steps along this path. We have clarified our objectives more clearly now in the manuscript and further underlined the preliminary nature of this work, but re-emphasised the importance of such longer-term, paired physical-biological data sets and the need to glean information and understanding from them.

Specific comments:

We have stream lined and clarified the introduction now. It contains less “jargon” and links the background context more clearly to the papers objectives. Regarding issues of data resolution that the reviewer raises these have now been clarified in the methods section. Our original description of how the temperature data were in-filled was unclear; hourly data were used to infill missing data, but the regression equations were developed for individual months (as noted in the response to reviewer 1 above). Also, although our temperature data were collected for a tree-lined section of the catchment; data analysis of spatially distributed temperature loggers have revealed that spatial variations in thermal regime are extremely limited and mainly occur during uncommon, extremely hot conditions when river flows are low (Malcolm et al., 2004). This has insignificant implications for the issues of Critical Displacement Velocities. We clarify the justification for our use of one gauging station in response to the comments of reviewer 1 and it is now clearer in the text.

Technical Corrections:

1/2/3/4/5/ Text is modified and more precise. 6. It means, tools and approaches with an ecological context and not just based on engineering design criteria. 7./ 8./9./10/11 Introduction is widely modified. Longer means “monthly” or “yearly”. 12. Rationale is given in methodology section, text in introduction modified and more precise. 13. Text is modified and more precise. 14. Correspondingly in the manner of hydrological and thermal (as said in text). More consistence in referring to Atlantic salmon throughout the manuscript. 15. Smaller than areas of moorland. 16. The authors think that the number of quoted papers and the data sets that they contain allows the term "extensive" to be used in a common sense way. 17. Results and data set relating to hydrology (i.e. different time series, parameter), water quality and geomorphology exist. We want to refer to this literature to direct interested readers to background information. Explaining all parameters within these studies is not directly relevant to this paper. We do not think it is unreasonable to expected interested readers to refer directly to the listed literature for further details. 18. Please see General Comment response to Reviewer #2. 19. The rationale for the periods is now given in the method section (as suggested by Reviewer#3). 20. Text is modified, please see in methodology section. 21. Please also see the responses to Reviewer #1. The gauging was carried out by the Scottish Environment Protection Agency (SEPA) and kindly provided for this study. These gauging are conventionally measured at 0.6 of the depth and this might masks differences in absolute hydraulic conditions. However, this is acknowledged in the methods and discussion section and does not detract from the papers aim of deriving hydraulically meaningful measurements from a pre-existing data set. We recognise that calculation of velocity based on empirical, readily available discharge data is very much a first approximation and relatively simplistic representation of the complex velocity fields that will occur in a river such as the Girnock. But the objective of the presented study was to capture temporal variability in flow conditions. In this sense, we view the Littlemill data as being a useful indicator of temporal variability of conditions in the rest of the river system. Of course we recognise that hydraulic conditions will differ in different channel types as the reviewer comments. This is now much more clearly stated in the method section. To represent the range in spatial variability within a whole catchment, high spatial resolution data would need to be collected which would be a major undertaking. Moreover, at most sites even moderately high flows could not be gauged safely. Thus, the authors are convinced that the approach presented is a valuable method in deriving ecologically meaningful insights from hydrological data sets particularly by focussing at this stage on temporal variability in ten hydrologically contrasting years. 22. +/- errors 23. Text is now modified. 24. Correspondingly = unable to hold station and constraints in feeding opportunities. 25. Please see responses to Referee #1, General Comments 4 and revised methodology section regarding using flume-based data. 26. Text is modified. 27. Methodology of estimated growth is now summarised in the methods section. It is fully explained and growth curves are given in given reference, Tetzlaff et al, 2005, Hydrobiologia (In press). Also see response to Reviewer#1 (point 19). 28. Text is modified. 29. We think the scientific readership in a hydrology journal with less biological background might find this summarised information as helpful. 30. Text is modified. 31. Text is modified. 32. Flow duration curves are conventionally used in hydrological publications to show inter- and intra annual variability. 33. Sentence is re-worded. 34. Text is modified. 35. Text is modified. 36. Expresses the low rate of change in discharge during this period thus indicating flow stability. Text is modified. This is a result, therefore written here instead of in methods. 37. As explained in the study site section, discharge is calculated from a calibrated section of the river using standard flow velocity cross-section methods, monitored by SEPA. Such high discharges ($>$ 50 m3 s-1) are impossible to gauge accurately (due to safety legislation constraints) and are therefore calculated using stage-discharge relation with a higher uncertainty than lower discharges, where velocity measurements (and this gauging) is possible. 38./ 39./ 40. Text is modified. 41. More variable than the mean temperatures. 42. This is clearly for the results section and information about variability in stream temperature, are needed for understanding of thermal conditions. Exceedence curves are conventionally used in hydrology, therefore the we think that there is no need for any further explanation in (the already lengthy) methods section. 43./44. Text and Figure is modified. 45./46./47. Text is modified. 48. We also report on 0+ fish. See also changes in Figure 8. 49. The authors think figures show the results clearly and it seems unnecessary to repeat in the text what is clear in the figure. 50. We are unclear as to what exactly the reviewer means with this point. The CDV is based on the flume relationship established by Graham et al. (1996). It is a dynamic parameter on daily time steps, as velocity, temperature and fish length change. 51. Our use of CDV is aiming to apply it as an index as to when fish movement may be affected. Of course in the absence of detailed behavioural studies beyond the scope this paper we don't know of the biological relevance directly. As now stressed in the text and noted in the response to Reviewer #1, we were simply inferring it on the basis of reasonable assumptions. 52. The differences are evident from the results (calculated percentage of time when mean stream velocity exceeds CDV) in table 3. 53/54/55/56 Text was modified. 57. Text changed and p value added. 58. We didn't re-analyze the data as noted above, this analysis focussed on "sensitive" periods (the reasons for this are given already in introduction and methods). The authors' opinion was and is that the analyses of the whole hydrological year shows that this results in overly simplistic results. We wanted to highlight that approaches which are still common in many eco-hydrological studies are not satisfying. 59. As noted several times above CoV is an index of complex temporal variability in flow. This is now clarified in the methods. 60./61 Text was modified. 62. Figure 9 has been changed as requested. 63. Our point is that extreme hydrological years (i.e. when flow conditions are highly variable in 1995/96, or not variable (1997/98)) have the most marked influences on spawning access. Thus it seems meaningless to take these data points out of the analysis. Please see also the responses to Reviewer #1, General Comment 5. 64. The text has been modified. 65. Figure 10 was not originally so small, but was changed within the format process of the EGU production office (to reach standard format). We also think that showing the discharge plots gives important information about the nature of hydrological conditions during this time period. Figure 10 shows clearly the high natural variability in hydrological conditions in relation to spawning. 66. Text is modified. 67. Local adaptation is not revealed through rigid stereotyped behavior but through the modification of the same driving mechanisms to match local variations in environmental conditions. Applicability is therefore likely general, even in the presence of local adaptation, since we are considering the mechanisms. 68. Text is modified and now more clearer. 69/70 Text is modified. 71. Text is more precise. 72. Lower than average. Clear in context. 73. Text has been modified to show that “short-temporal” scale variations in flow that have the main influence. 74. Text has been modified. 75. Text is changed and moved to results. 76/ 77. Text is modified. 78. Discussion has been modified to more properly reflect the objectives of the paper. 79. Text is modified.

Tables and Figures:

80. P values are listed now. Number of samples = 10 hydrological years were basis. 81. Figure 2 has been changed as requested. 82. Figure 6 has been changed as requested.

List of responses to Reviewer # 3:

General comments

We are pleased that the reviewer recognises the unique nature of the data sets that we analyse and states that the paper can make a “very useful contribution to the literature”. We agree that - as originally worded - the introduction gave a misleading impression that the paper would consider issues of data resolution in more detail. We also agree that the analysis of hydroecological associations (e.g. via analysis of CDVs) is the more important aspect of the paper and we have re-emphasised this in the introduction and abstract (as noted above in response to reviewer 1). The reviewer highlights the confusing overlapping of the “Study site” and “Data and methods” sections in the original manuscript, we have thus re-arranged these sections so that they are more consistent. Finally, we have restructured the discussion so the results of this study are discussed in a manner more directly linked to previous work.

Specific comments:

Introduction 1. Text is more precise. Objectives are now clearer. 2. Please see revised manuscript. 3. The text has been modified. 4. The text has been modified (paragraph now before Scottish Highland section). 5./6. Text has been modified. 7. Text has been modified and uniqueness of this data set more emphasised. 8. Text has been modified.

Study site 9. Text has been modified. More clear separation between study site description and later methodology section has been achieved. 10. Text is modified and rationale for time periods is now given in the methods section. We are surprised that the reviewer does not seem to see that these periods are plotted onto the flow and temperature accumulation curves (Fig. 5 and 7). This implicitly captures the long-term average in a clearer way than spikey daily mean plots would.

Data and Methods 11. As it is explained in the revised paper and the responses to Reviewer #1, it was not our intention to provide such nested analyses, nor give such emphasis of data resolution. Regarding longer term data, there are, for some periods concerns regarding data quality, particularly in relation to flows. Thus we focussed on the long-term period with highest quality environmental data. 12. Much clearer explanation of methodology is now given. In addition, the CDV approach is already reported in the introduction. 13./14. Text has been modified. 15. The incorrectly expressed text of the methodology of gap filling is now modified as noted above. The authors meant that they developed air-stream temperature relationship on an hourly basis, but separately for each month over the time period of ten years. 16. As explained in the text, the degree days approach is a widely used approach in ecological literature to express relationships between cumulative temperature and ecological processes. It was used as additional indicator instead of using it “over hourly observations”. 17. This is now explained in the biology section. For more details please see details in reference given (Tetzlaff et al., in press). Please see also point 19, referee#1. 18. Objectives are more clearer.

Results 19. The authors think that flow duration curves are conventionally used in hydrological publications to show intra- and inter annual variability. Due to the fact that the velocity time series is derived from discharge time series Figure 8 shows more a hydrograph form and can be used as additional explanation of variability. After suggestions of all three referees, Figure 8 shows now daily mean stream velocities. 20.

Text was modified. 21. Commonly used statistical values to characterise hydrological conditions and allow comparisons between years and periods. 22. Text was modified. 23. Text is more clearer. 24. Explained more precisely. 25. Text was modified (already in earlier para, point 22). 26. Text has been modified.

Discussion 27. The text has been modified in relation to responses to the comments of reviewer 2. 28. This threshold was a result of plotting discharge against returning spawners. The result was that below 0.3 m3 s-1 no returning spawners were found at the fish trap. 29./30. The discussion is restructured to provide paper emphasis.

Figures 31. Figure has been changed 32. Caption has been changed 33. In hydrology, this is a common approach to cumulate discharge volumes under consideration of catchment size and time resolution (unit mm instead m3 s-1).

Tables: 34. Please see modified methodology section.

Interactive comment on Hydrology and Earth System Sciences Discussions, 2, 691, 2005.