MS No.: esurf-2015-2

“The role of log jams and exceptional flood events in mobilizing coarse particulate organic matter in a steep headwater stream”

Replies to the comments of reviewers 1 and 2 and of associated editor R. Hilton

We are grateful to both anonymous referees and the associate editor Robert Hilton for their comprehensive and constructive comments. In the following we respond to the individual comments on passages of the manuscript in order of their appearance in our text. The technical corrections suggested by the reviewers and R. Hilton have been implemented in the text and are marked in the revised manuscript but not discussed here. The page and line numbers correspond to the published ESurfD version of our manuscript. Attached to this document is a marked-up version of our revised manuscript.

1 Abstract

- **174/1: “This needs a broader opening to make it clearer to the general reader what the issues are (why study CPOM)”** (R. Hilton)

  We appreciate the suggestion by R. Hilton to make our abstract attractive to potential readers by giving a broader framework of our study. We have therefore amended our abstract with additional information on the relevance of CPOM but also on the outcome of our work.

  New version: “Coarse particulate organic matter (CPOM) fulfills important functions in the physical and ecological system of a stream. CPOM delivery to and export from the stream has implications for the stream’s morphology and sediment transport capacity as well as the energy budget and food availability. Export rates of CPOM from mountain catchments have been observed to strongly increase with rising discharge, but the mechanism leading to this strong relationship is unclear. Here, we show that log jams in the Erlenbach, a steep headwater stream in the Swiss Prealps, are an effective barrier for the transport of CPOM pieces, and thus become sites of storage of large quantities of material over time. Exceptional discharge events with return periods exceeding 20 years play a dual role in CPOM transport in the Erlenbach. First, they appear to destroy existing log jams, releasing the stored material (wood and sediment). Second, they intensify channel-hillslope coupling, thereby recruiting new logs to the channel, around which new jams can form. This allows the formulation of a new, fully episodic end-member in a four end-member model of CPOM dynamics of steep mountain streams based on wood delivery and export.”

- **174/7: “Exceptional discharge events, if produced by rainfall or by accelerated snowmelt, would also affect CPOM dynamics by mobilizing forest litter and duff from upland areas.”** (Reviewer #2)

  We thank Reviewer #2 for pointing out additional influences of precipitation-induced discharge event on CPOM dynamics. Although we consider this fact not relevant for our abstract as it concerns an aspect of CPOM dynamics not covered here, we added this information in the discussion of the role of exceptional discharge events (section 5.1).

New version: „It should be noted that exceptional discharge events produced by heavy rainfall can be accompanied by an input of forest litter and duff from upland areas, also having an influence on CPOM dynamics of a stream."

2 Introduction

- **174/12: "The citation for the definition of CPOM is a bit misleading. Ecologists pioneered the CPOM literature, starting in the 1970s, and the size criterion mentioned here should be supported by appropriate ecological citations."** (Reviewer #2, underlined by R. Hilton)

  As already stated in the reply to Reviewer #2, we agree that the previously cited literature was not appropriate as source for the definition of coarse particulate organic matter (CPOM). We have reassessed the pioneering works regarding CPOM and substituted the reference for more relevant works.

  New version: "Coarse particulate organic matter (CPOM) in streams is typically defined as organic material with a diameter larger than 1 mm, and thus encompasses a wide range of different types and sizes, from leaves and twigs to wood fragments to entire trees (Naiman and Sedell, 1979; Bilby and Likens, 1980)."

- **174/16: "I would prefer these be separate sentences, with a little more detail on the specifics of what the CPOM actually does. Plus, a mention of export as a carbon/nutrient export"** (R. Hilton)

  We agree, split the respective sentence and added the requested information.

  New version: "CPOM is an important component both of the physical and the ecological system of the stream. It affects stream morphology, alters channel roughness and therefore flow velocity and sediment transport (Bilby and Ward, 1989). When entering the stream, organic matter is considered to be the main source of energy in headwater stream ecosystems and provides food, shelter, and variable habitats (Fisher and Likens, 1973; Harmon et al., 1986). The largest size classes of CPOM are known as large woody debris (LWD), comprising pieces longer than 1 m (e.g., Abbe and Montgomery, 2003; Wohl and Jaeger, 2009). LWD specifically affects stream morphology, habitat and riverine carbon and nutrient storage by forming log jams that act as barriers for sediment movement, and that are sites of energy dissipation (Wohl and Beckman, 2012; Beckman and Wohl, 2014)."

- **174/25: "The second paragraph of the introduction has a confusing mix of LW and CPOM. I think it would be more effective to treat CPOM that is finer than the typical LW definition (1 m long, 10 cm diameter) and then to discuss LW. Also, there is a much greater literature on downstream trends in CPOM abundance and dynamics than is reflected in this paragraph. See papers by Naiman and Sedell (1979, Archives Hydrobiology), Newbold et al. (1982, Oikos), and Webster et al. (1999, Freshwater Biology), for example."** (Reviewer #2, similarly stated by R. Hilton)

  We stated in the reply to the comments of Reviewer #2 that after revisiting size definitions given in literature on CPOM, we found no upper size limit to be mentioned. CPOM is usually defined as pieces larger than 1 mm in diameter (cf. Naiman and Sedell, 1979) and in our opinion includes large wood as its largest fraction. Therefore, our use of the terms LW and CPOM seems logical to us.

  However, we agree with the reviewer that we did not sufficiently credit the works on CPOM dynamics in this section of the introduction. We amended our manuscript with additional references.

New version: "CPOM is recruited to the stream by various processes, including litter fall, gravitational movements of the banks, and natural dieback of trees. Once in the stream, CPOM is degraded by various physical, chemical, and biological processes, or can be flushed out by fluvial processes. CPOM leaving the catchment represents a loss of nutrients and energy to the stream ecosystem (Fisher and Likens, 1973; Naiman and Sedell, 1979; Webster et al., 1999), and, in case of LWD, can lead to an increased hazard downstream (Comiti et al., 2006; Ruiz-Villanueva et al., 2014). It is known that CPOM export from a catchment strongly depends on discharge (e.g., Bormann et al., 1969; Fisher and Likens, 1973; Wallace et al., 1995; Iroume et al., 2015). From detailed short-term measurements over a range of discharges, Turowski et al. (2013a) found that 90% of the total CPOM load of the Erlenbach, a prealpine mountain stream in Switzerland, was exported by floods with return periods >5 years. There, CPOM export rates increase by a factor of more than 30000 upon a ten-fold increase in discharge. The results from Fisher and Likens (1973) and Wallace et al. (1995) indicate similarly strong relationships between CPOM export and discharge, however being derived from a very small catchment and being calculated event integrated. Still, conceptual models of wood dynamics formulated in studies of larger streams suggest more continuous export rates and seemingly do not apply to headwater streams like the Erlenbach (Hyatt and Naiman, 2001; O'Connor et al., 2003; Wohl, 2013)."

- **175/12: "Can you explain more about these `similarly strong relationships'"** (R. Hilton)

  Both studies (*Fisher and Likens, 1973 and Wallace et al., 1995*) present data that indicate a strong relationship between the export of CPOM and discharge, similar to the dependency found by Turowski et al. (2013). However, the CPOM discharge relationships were found under conditions quite different than those of the study by Turowski et al. (2013). Fisher and Likens (1973) conducted their study in a small catchment (0.13 km^2) within the Hubbard Brook Experimental Forest, which is considerably smaller than the Erlenbach catchment (0.7 km^2). Wallace et al. (1995) conducted an event integrated study. We have highlighted these facts in our manuscript.

  New version: "The results from Fisher and Likens (1973) and Wallace et al. (1995) indicate similarly strong relationships between CPOM export and discharge, however, the former derived their data from a very small catchment, and the latter did not have point measurements, but integrated over entire events."

- **175/16: "Here you need to explain what your study does differently, briefly mentioning the tracers and water discharge assessment, and the log-jam mapping (space and time). This will help the reader see what was done and highlight some of the novel aspects of this work.** (R. Hilton)

  We thank R. Hilton for this advice and agree that mentioning the approaches we chose to achieve our objectives potentially arouses more interest of the reader. For every part of our work we have now highlighted the methods we used.

  New version: "In the present contribution, we investigate the physical mechanisms behind the strong dependence of CPOM export rates and discharge in the Erlenbach by introducing tracer logs to the stream and tracking them over a series of elevated discharge events. Wallace et al. (1995) observed a strong increase in CPOM export after log jam failures. We thus hypothesize that log jams play a crucial role in CPOM transfer, and by mapping all log jams in the study reach of the tracer experiment demonstrate that they indeed represent effective barriers for transport. We elucidate the role of exceptional events in log jam stability *employing dendrochronological analyses and propose a conceptual model of wood dynamics in headwater streams."*

3 Study site

- **175/24: "A brief description of channel morphology of the investigated reach should also be provided. The mean bankfull width, which is known to control the mobility of LWD, must be indicated."** (Reviewer #1)

  The bankfull channel width indeed is an important information when assessing the mobility of LW. We have added this information as well as some words on the channel's morphology.

  New version: "The channel shows a pronounced step-pool morphology with some cascading and riffle reaches and has an average bankfull channel width of 3.7 m (Molnar et al., 2010). Its banks are prone to hillslope creep and are actively supplying the channel with sediment and organic matter, including wood with a wide range of sizes (Schuerch et al., 2006; Turowski et al., 2009, 2013a)."

- **176/8: "Here, briefly explain what this previous work [Turowski et al. 2013] did (what was measured/quantified) and the questions which remain which this paper addresses."**(R. Hilton, Reviewer #1)

  The work by Turowski et al. (2013a) mainly focused on the relationship between export rates and sizes of CPOM under different discharge conditions at the Erlenbach stream. Transported CPOM was measured when leaving the catchment. The main difference to our study is that we are focusing on the processes that lead to the steep rating curve of exported CPOM found in the previous study. We have therefore extended the information we give about the work by Turowski et al. (2013a) in the section on the study site.

  New version: "CPOM export from the Erlenbach was assessed in detail by Turowski et al. (2013a) by measuring transport rates and dry masses of organic matter heavier than 0.1 g leaving the catchment. However, this study did not focus on the processes within the stream leading to the observed rating curve."

4 Methods

- **176/16: "It felt like it would be useful to have more 'To determine X, we mapped… etc' in this section." (R. Hilton)**

  We agree that mentioning the objectives we tried to achieve with our set of methods enhances the comprehensibility of our overall approach. We therefore slightly extended the first two paragraphs of the methods section.

  New version: "We mapped LWD in a 320 m long study reach of the Erlenbach, focusing on log jams (Fig. 1). A log jam was defined as an accumulation of coarse wood deposited against or around at least one initial key piece of LWD (Warren et al., 2009). To determine the position of the log jams within the channel and for an analysis of deposition locations of the below-mentioned tracer logs, the perimeters of the jams were surveyed with an electronic total station, and their extent and height were recorded using a measuring tape. To check for a relationship between residence times of the jams' key pieces and log jam size, volumes and dry masses of the pieces of wood longer than 1 m stored in log jams were approximated by measuring their length and diameter in the field, and by assuming a cylindrical shape and a dry wood density of 410 kg m^{-3}, which is characteristic for P. abies (Gryc et al., 2011). The total combined volume of pieces shorter than 1 m was estimated visually with the help of a measuring tape. This estimation made up for 29% of the total volume of all log jams. Log jam *step heights were derived from long profile measurements (Turowski et al., 2013b). The analyses were conducted in July and August 2012.*

To investigate the mechanisms behind transport and storage of CPOM within the Erlenbach channel, a population of 236 cylindrical logs (Fig. 2) were tagged with Radio Frequency Identification (RFID) transponders, a technique that has successfully been employed to monitor bedload (Lamarre et al., 2005; Schneider et al., 2010, Schneider et al. 2014) and woody debris (MacVicar et al., 2009; Schenk et al., 2013; Ravazzolo et al., 2015).“

- **176/16: "Why not measure the CPOM stored with pebble & finer size sediment upstream from and apart from jams? This can be substantial in some streams, although the photos included in this manuscript suggest that it is not likely to be as important in this very steep and dynamic stream. Even if this storage is not substantial, it would provide the basis for a very interesting comparison with the ecological literature from equally small and steep but more stable streams, such as Hubbard Brook." (Reviewer #2)**

  We thank the reviewer for this suggestion. We agree that it would be interesting to measure the carbon content of sediment wedges in between the log jams, and their size distribution. We will consider and discuss this suggestion in the discussion section of our revised manuscript. Unfortunately, for various reasons, it will not be possible to complement our study with additional measurements for the current contribution. The suggested measurements include measurement techniques and heavy field work not previously done by the authors. In addition, both MJ and JMT have left the WSL since completion of the field work, making it necessary to do the work during an expedition and extended field stay. This is not easily organized on short notice. Nevertheless, we think that the measurement of CPOM stored in sediment in the vicinity and between log jams would pose a valuable amendment of our analysis and enable an interesting comparison to other sites of CPOM studies. It would potentially explain the log jams' capability of retaining small sized CPOM. We will aim to organize the necessary field work sometime in the future.

  New version: "Analogous to the impact of log jams on CPOM transport, it seems that there is also a similar influence of log jams on the transport of clastic sediments. Wedges of sediment are building up between the log jams (also storing organic matter) and the export rating curve of bedload shows a similarly steep increase with discharge as the CPOM export rating curve (cf. Turowski et al., 2009). It seems likely that considerable volumes of CPOM are stored in those sediment wedges and are mobilized and exported from the catchment after log jam destruction."

- **176/20: "Link to other methods used in published literature" (R. Hilton)**

  We agree with the suggestion to link our methods of log jam surveying and piece size and volume estimation to the methods used in other studies. We have therefore added references in this paragraph.

  New version: "To determine the position of the log jams within the channel and for an analysis of deposition locations of the below-mentioned tracer logs, the perimeters of the jams were surveyed with an electronic total station, and their extent and height were recorded using a measuring tape (cf. Wohl and Beckman, 2012). To check for a relationship between residence times of the jams' key pieces and log jam size, volumes and dry masses of the pieces of wood longer than 1 m stored in log jams were approximated by measuring their length and diameter in the field (cf. May and Gresswell, 2003), and by assuming a cylindrical shape and a dry wood density of 410 kg m^{-3}, which is characteristic for P. abies (Gryc et al., 2011)."

- **177/1: “The main technical features of the RFID tags (dimensions, shape, and emission frequency) must be provided.” (Reviewer #1)**

  We have supplemented the second paragraph of the method section with the properties of the applied RFID transponders.

  New version: “The RFID glass transponders we used were 3.12 cm long, 0.38 cm in diameter, emitting on a 134.2 kHz frequency and glued into holes drilled into the tracer logs.”

- **177/2: “Explain why these size fractions were chosen. I think it would be useful to compare these sizes to the measured distributions of wood exported by this channel (e.g. from Turowski et al., 2013).” (R. Hilton)**

  The size distribution of our tracer logs is not representative of the distribution transported by the Erlenbach stream. However, this does not matter as we are interested in the relative mobility (in/out of log jams) of individual size classes. Our field experiment was carried out in a single summer season, which corresponds to the period of the year with the highest probability of elevated discharge in the Erlenbach. We could not expect exceptional discharge events during that single season and therefore had to design our experiment in a way so that we could get data even with rather small discharge events. This lead to the size classes of tracer logs. We expected those sizes to move even under moderate discharge conditions. However, one has to keep in mind that those sizes rank at the lower end of what is defined as large woody debris. We added information on the choice of our size fractions to the methods section.

  New version: “The tracer logs were divided in four classes with approximate lengths of 10, 20, 50, and 100 cm. The lengths were chosen as a compromise between log size and potential log mobility, suitable for our study period covering only one summer (discharge) season. Longer pieces would have rarely moved in common flood events during the study period. For shorter pieces, it would not have been possible to equip them with RFID transponders. The size distribution of the tracers did not cover the whole size range of CPOM transported by the Erlenbach stream. However, our study analyses the relative mobility of single size classes in and out of log jams and therefore the size distribution is suitable for our purpose.”

- **177/7: “Are the branches mentioned again?” (R. Hilton)**

  No, the branches are not mentioned again. Therefore, this information is superfluous and was deleted from the text.

- **177/8: “The presentation of the deployment strategy of tracer logs in the field is not very clear. It is said in the text that tracer logs were deployed in June 2012, but in Fig. 3, four periods of deployment are indicated. The location of the deployment sites must be shown in Fig. 1 and 4.” (Reviewer #1, underlined by R. Hilton)**

  The explanation of our deployment strategy is indeed not detailed enough in the earlier version of the manuscript. We emitted the original population of tracer logs to the stream in June 2012. The other deployment dates that are given in Fig. 3 were only reemissions of already used tracer logs. Just upstream of the Erlenbach stream`s confluence with the Alp river is a sediment retention basin where we were able to recover some tracer logs that were mobilized and left the study reach. We have changed our presentation of the deployment strategy in the revised manuscript to account for these reemissions. Furthermore, we have added the emission locations to Figures 1 and 4.

  New version: “The initial population of tracer logs was emitted in the stream in June 2012, and the positions of the logs were surveyed six times after rainfall events until October 2012

(Fig. 3). Tracer logs that left the stream after being mobilized and could be recovered in the sediment retention basin were re-emitted in July, August and September 2012 (Fig. 3). Two locations for the emission of the tracers were chosen because of the relative absence of obstacles, steps and pools compared to most other channel reaches and were hypothesized to enhance the probability of a first displacement. The tracer pieces were spread out along approximately 5–10 m of the thalweg axis without trying to mimic a natural deposition. It was assumed that after an initial mobilisation during a flood event, tracers would be deposited in a natural way."

- **177/30: "none of this chronology data is shown (apart from the residence time in the table). You need to at least provide some example of how this was done, and assessment of uncertainty in these chronologies." (R. Hilton)**

  We thank R. Hilton for the suggestion to give more details about the crossdating procedure we used. The crossdating itself was conducted visually by plotting the reference chronology derived from living trees standing in the vicinity of the Erlenbach channel and matching it with the increment curves of each sampled log stored in the channel (Lombardi et al., 2008). The crossdating of the logs was checked using *Gleichlaeufigkeit* (GLK), a value that shows the percent agreement in the signs of the first differences of two time series (Kaennel and Schweingruber, 1995). The value of significant GLK depends on the length of the overlapping time series, e.g. the GLK of a 50-year overlapping time series becomes significant at a value of 62. Each visually crossdated log was therefore checked individually and crossdating was considered successful if a significant GLK was achieved. This was possible for all 24 logs included in the results.

  New version: "All deadwood samples were first visually crossdated using their increment curves and the reference chronology and then their accuracy checked with the crossdating function of the dendrochronology software TSAP-WIN. Our accuracy check was based on Gleichlaeufigkeit (GLK), which is the percent agreement in the signs of the first differences of two time series (Kaennel and Schweingruber, 1995). The significance of the GLK value depends on the length of the overlap of the reference and undated time series, e.g. for a 50-year overlap, a GLK of 62 is significant ($p < 0.05$). Depending on length of the respective series we considered crossdating successful if a significant GLK value was achieved (Lombardi et al., 2008), which was possible for all of our sampled logs."

- **178/6: "While this does seem like a sensible conclusion, Smith et al., (2013) Earth and Planetary Science Letters, measure 14C ages of wood in bank-landslide deposits of 1000 yrs and 4000 yrs. It would be useful to explain more cautiously and perhaps outline any implications of this assumption not being valid." (R. Hilton)**

  The size of wood pieces described in Smith et al. (2013) and referred to by the editor differs substantially from the size of what we consider to be jam forming key pieces and what we cross-dated. The log jam forming large wood in the Erlenbach predominantly originates from trees that were undercut by the stream up to the point when they fell across the channel. This size of large wood is hardly believed to be buried on the hillslope rather than falling across the channel. We explained this issue in more detail in the manuscript and referred to the work of Smith et al. (2013).

  New version: "The kill date is assumed to be the year when the logs were introduced to the channel. There is a chance that trees remained outside the channel for an unknown period of time before entering the stream. Smith et al. (2013) found fragments of wood in bank-landslide deposits at the Erlenbach that showed 14C ages of approximately 1000 and 4000 years BP. However, our assumption is based on the fact that the channel slopes are very steep *and that those large, jam forming pieces of wood are unlikely to remain on the slopes above the channel for extended times or be buried like the fragments analysed of Smith et al. (2013), which would cause a longer time of storage."*

5 Results and Interpretation

- **178/10: "throughout this section I wondered if subheadings may be useful (e.g. 'Dynamics of log-jam recruitment', 'Dynamics of CPOM transport'. Also, the text jumps between the log-jam data and the tracer data, and I wonder if a clearer separation of these aspects (before bringing them back together) would be a better way to structure. (again subheadings could help here)." (R. Hilton)**

  We thank R. Hilton for this comment and agree that our manuscript needs some restructuring. Therefore, we have split our former chapter 4 ("Results and interpretation") in two separate sections in the revised manuscript (4. Results and 5. Discussion). Moreover, we added subheadings to each of the two chapters. Our structure now looks as follows:

  4 Results

    4.1 Log jam survey

    4.2 Tracer study

    4.3 Log jam dating

  5 Discussion

    5.1 Interpretation

    5.2 Conceptual model

    5.3 Differences to larger streams

    5.3 Four end-member models

- **178/24: "It would be useful to explain some of these results quantitatively." (R. Hilton) and "In the presentation of the results from wood tracing, the recovery rates of the tracer logs as well as the percentages of mobile tracers for each survey should be provided. Figure 4 is not easy to read, and it may have been better to propose a diagram of tracer density as a function of distance along the talweg, with the position of log jams and deployment sites." (Reviewer #1)**

  We agree with R. Hilton and Reviewer #1 that additional information on our data as well as adding some quantitative information to the text (not only in the Figures) would be useful and would enable the reader to better judge the quality of our assumptions. We have therefore added numbers on the average and the range of tracer recovery rates, percentages of mobilized and immobile tracers as well as the density of tracers within and outside the perimeter of log jams. However, we would like to keep Figure 4, as it contains not only information on tracer density along the thalweg and inside/outside of log jams but also shows active landslide complexes which are an important party of the conceptual model proposed in our manuscript.

  New version: "The tracer study revealed that log jams in the Erlenbach are an efficient barrier to the movement of CPOM pieces. The overall average recovery rate of tracers during the six survey amounted to 34% with the rates of the individual surveys varying between 29% and

45%. These values are similar to the rates observed in a study of bedload motion at the same site using RFID equipment (Schneider et al., 2010, 2014). The tracer logs preferably deposited in log jams (Fig. 4), showing an average of 0.46 tracers per m2 in the perimeter of log jams while the obstruction free parts of the bankfull channel only saw 0.13 pieces per m2 over the study season. Once deposited in the perimeter of a log jam, it was very unlikely that the tracer logs moved further downstream during the study period (Fig. 6)."

- **180/7: "My main concern is about the insufficient credit paid to previous works dedicated to LWD dynamics in steep mountain streams, which already proposed some conceptual models not so different from the one proposed in this paper. See for example May and Gresswell 2003 (ESPL) work in the Oregon Coast Range" (Reviewer #1)**

We thank Reviewer #1 for pointing out the article of May and Gresswell (2003) that we had not been aware of. The paper is very interesting indeed, and we see three main differences between their study and ours. First, CPOM and sediment transport in the Erlenbach mountain stream is fluvial, and there are no signs and records of debris flow activity (cf. Turowski et al., 2009). We will put more emphasis on this important fact in our manuscript. Second, the conceptual model of May and Gresswell (2003) assumes temporally constant input of LW. Total wood input is related to the time since the last debris flow event. The correlation shows an exponential increase of material with time, which to some extent contradicts the hypothesis of steady supply. In contrast, we propose that LW input occurs mostly during and shortly after extreme events. Third, the space-for-time approach employed in the study of May and Gresswell (2003) raises questions on the inter-comparability of the different streams. For example, for a direct comparison one needs to assume that supply rate is the same in each of the studied catchments. For the Erlenbach we have some constraints on the variability of supply within a single stream.

We added a section with a direct comparison of our model to the model of May and Gresswell (2003), but also to the models of Wohl et al. (2012) by discussing their dominant LWD delivery and export characteristics.

New version:

"FOUR END-MEMBER MODEL

An important precondition for our conceptual model appears to be the debris flow (in-) activity of the respective stream as there are no signs of debris flows at the Erlenbach and sediment is only fluvially transported (Turowski et al., 2009). In a conceptual model developed for similar order streams in the Central Coast Range (USA) (May and Gresswell, 2003), the evacuation of the stream channel is debris flow rather than discharge-driven. Also, the input of LWD in their model is assumed to be temporally constant; total wood input is related to the time since the last debris flow event. In contrast, we propose that LWD input occurs mostly during and shortly after extreme events.

Wohl et al. (2012) formulated a two end-member model for neotropical low-order headwater streams based on the dominating delivery process of LWD. It features a steady-state and an episodic end-member. The steady-state end-member is characterized by individual tree delivery and gradual export of specific pieces. The dominating processes of the episodic end-member are an event-based recruitment and gradual but more accentuated export.

To merge the existing models, we do not only consider the temporal characteristics of LDW delivery but also put emphasis on the export characteristics. By placing the four models in a temporal continuum of LWD input and export (Fig. 9), we define a new four end-member *model, consisting of an event driven delivery end-member (Wohl et al., 2012), an event driven export end-member (May and Gresswell, 2003), a fully continuous end-member (Wohl et al., 2012) and a fully episodic end-member."*

- **180/30: "I think it would be useful and appropriate to comment on how these dynamics of OM transport correspond to clastic sediments. For instance, the processes described here could be analogous to coarse bed load vs finer particles which can be exported in the suspended load." (R. Hilton)**

  We thank R. Hilton for this suggestion, which we indeed consider a valuable addition to our study. However, it would require the measurements suggested by Reviewer #2 (see the comment "176/16" in the Methods section of this document) to make well-founded statements on this matter. As we have written, it will unfortunately not be possible to acquire this data and include it in our discussion. Still, we consentingly assume that log jams influence clastic sediments in the same way like they influence CPOM and that the fine CPOM vs. large CPOM rating curve looks similar to the suspended load vs. bedload curve. We have added this point to our discussion and propose future research on this aspect.

  New version: "Analogous to the impact of log jams on CPOM transport, it seems that there is also a similar influence of log jams on the transport of clastic sediments. Wedges of sediment are building up between the log jams (also storing organic matter) and the export rating curve of bedload shows a similarly steep increase with discharge as the CPOM export rating curve (cf. Turowski et al., 2009). It seems likely that considerable volumes of CPOM are stored in those sediment wedges and are mobilized and exported from the catchment after log jam destruction."

181/5: "I think this is a bit strong worded. I would argue that this has not been fully assessed because we don't have the coupled data on wood transport and water discharge variability like you do in the Erlenbach. Please rephrase." (R. Hilton)

We agree with R. Hilton that this formulation should be refraised. Other studies probably had no data available to consider the discharge history. Therefore, we have changed our formulation.

New version: "In the latter type of streams, supply and evacuation of logs is generally assumed to occur more or less continuously and the recent discharge history was not considered, probably due to the unavailability of discharge measurements.

6 Conclusions

- **182/11: "These management issues come out of thin air a little, no mention of them previously, and they are not well supported by literature from this field. Please reorganise." (R. Hilton)**

  We agree with R. Hilton upon his comment that our management recommendations are not well supported enough and therefore not appropriate to make here. We have therefore decided, to refrain from making any suggestion on how to manage riparian forest stands. In the new version of our conclusions, we will rather focus on our conceptual model and the its comparison to the concepts formulated in other studies.

References

Abbe, T. B., and Montgomery, D. R., 2003, Patterns and processes of wood debris accumulation in the Queets river basin, Washington: Geomorphology, v. 51, p. 81-107.

Beckman, N. D., and Wohl, E., 2014, Carbon storage in mountainous headwater streams: The role of old-growth forest and logjams: Water Resources Research, v. 50, no. 3, p. 2376-2393.

Bilby, R. E., and Likens, G. E., 1980, Importance of organic debris dams in the structure and function of stream ecosystems: Ecology, v. 61, no. 4, p. 1107-1113.

Bilby, R. E., and Ward, J. W., 1989, Changes in Characteristics and Function of Woody Debris with Increasing Size of Streams in Western Washington: Transactions of the American Fisheries Society, v. 118, no. 4, p. 368-378.

Bormann, F. H., Likens, G. E., and Eaton, J. S., 1969, Biotic regulation of particulate and solution losses from a forest ecosystem: Bioscience, v. 19, no. 7, p. 600-610.

Comiti, F., Andreoli, A., Lenzi, M. A., and Mao, L., 2006, Spatial density and characteristics of woody debris in five mountain rivers of the Dolomites (Italian Alps): Geomorphology, v. 78, p. 44-63.

Fisher, S. G., and Likens, G. E., 1973, Energy Flow in Bear Brook, New Hampshire - Integrative Approach to Stream Ecosystem Metabolism: Ecological Monographs, v. 43, no. 4, p. 421-439.

Gryc, V., Vavrčik, H., and Horn, K., 2011, Density of juvenile and mature wood of selected coniferous species: Journal of Forest Science, v. 57, no. 3, p. 123-130.

Harmon, M. E., Franklin, J. F., Swanson, F. J., Sollins, P., Gregory, S. V., Lattin, J. D., Anderson, N. H., Cline, S. P., Aumen, N. G., Sedell, J. R., Lienkaemper, G. W., Cromack, K., and Cummins, K.W., 1986, Ecology of coarse woody debris in temperate ecosystems: Adv. Ecol. Res., v. 15, p. 132–302.

Hyatt, T. L., and Naiman, R. J., 2001, The Residence Time of Large Woody Debris in the Queets River, Washington, USA: Ecological Applications, v. 11, p. 191-202.

Iroumé, A., Mao, L., Andreoli, A., Ulloa, H., and Ardiles, M. P., 2015, Large wood mobility processes in low-order Chilean river channels: Geomorphology, v. 228, p. 681-693.

Lamarre, H., MacVicar, B. J., and Roy, A. G., 2005, Using Passive Integrated Transponder (PIT) Tags to Investigate Sediment Transport in Gravel-Bed Rivers: Journal of Sedimentary Research, v. 75, p. 736-741.

Lombardi, F., Cherubini, P., Lasserre, B., Tognetti, R., and Marchetti, M., 2008, Tree rings used to assess time since death of deadwood of different decay classes in beech and silver fir forests in the central Apennines (Molise, Italy), Canadian Journal of Forest Research, v. 38, no. 4, p. 821-833.

MacVicar, B. J., Piégay, H., Henderson, A., Comiti, F., Oberlin, C., and Pecorari, E., 2009, Quantifying the temporal dynamics of wood in large rivers: field trials of wood surveying, dating, tracking, and monitoring techniques: Earth Surface Processes and Landforms, v. 34, p. 2031-2046.

May, C. L., and Gresswell, R. E., 2003, Large wood recruitment and redistribution in headwater streams in the southern Oregon Coast Range, USA: Canadian Journal of Forest Research, v. 33, no. 8, p. 1352-1362.

Naiman, R. J., and Sedell, J. R., 1979, Benthic organic-matter as a function of stream order in Oregon: Archiv für Hydrobiologie, v. 87, no. 4, p. 404-422.

O'Connor, J. E., Jones, M. A., and Haluska, T. L., 2003, Flood plain and channel dynamics of the Quinault and Queets Rivers, Washington, USA: Geomorphology, v. 51, no. 1-3, p. 31-59.

Ravazzolo, D., Mao, L., Picco, L., and Lenzi, M. A., 2015, Tracking log displacement during floods in the Tagliamento River using RFID and GPS tracker devices: Geomorphology, v. 228, p. 226-233.

Ruiz-Villanueva, V., Díez-Herrero, A., Ballesteros, J. A., and Bodoque, J. M., 2014, Potential large woody debris recruitment due to landslides, bank erosion and floods in mountain basins: a quantitative estimation approach: River Research and Applications, v. 30, no. 1, p. 81-97.

Schenk, E. R., Moulin, B., Hupp, C. R., and Richter, J. M., 2013, Large wood budget and transport dynamics on a large river using radio telemetry: Earth Surface Processes and Landforms, v.39, no. 4, p. 487-498.

Schneider, J. M., Hegglin, R., Meier, S., Turowski, J. M., Nitsche, M., and Rickenmann, D., Studying Sediment Transport in Mountain Rivers by Mobile and Stationary RFID Antennas, in Proceedings 5th International Conference on Fluvial Hydraulics, Braunschweig, 2010, Bundesanst. für Wasserbau, p. 1723-1730.

Schneider, J. M., Turowski, J. M., Rickenmann, D., Hegglin, R., Arrigo, S., Mao, L., and Kirchner, J. W., 2014, Scaling relationships between bed load volumes, transport distances, and stream power in steep mountain channels: Journal of Geophysical Research: Earth Surface, v. 119, no. 3, p. 533-549.

Schuerch, P., Densmore, A. L., McArdell, B. W., and Molnar, P., 2006, The influence of landsliding on sediment supply and channel change in a steep mountain catchment: Geomorphology, v. 78, p. 222-235.

Smith, J. C., Galy, A., Hovius, N., Tye, A. M., Turowski, J. M., and Schleppi, P., 2013, Runoff-driven export of particulate organic carbon from soil in temperate forested uplands: Earth and Planetary Science Letters, v. 365, p. 198-208.

Turowski, J. M., Badoux, A., Bunte, K., Rickli, C., Federspiel, N., and Jochner, M., 2013a, The mass distribution of coarse particulate organic matter exported from an alpine headwater stream: Earth Surface Dynamics, v. 1, p. 1-29.

Turowski, J. M., Badoux, A., Leuzinger, J., and Hegglin, R., 2013b, Large floods, alluvial overprint, and bedrock erosion: Earth Surface Processes and Landforms, v. 38, no. 9, p. 947-958.

Turowski, J. M., Yager, E. M., Badoux, A., Rickenmann, D., and Molnar, P., 2009, The impact of exceptional events on erosion, bedload transport and channel stability in a step-pool channel: Earth Surface Processes and Landforms, v. 34, p. 1661-1673.

Wallace, J. B., Whiles, M. R., Eggert, S., Cuffney, T. F., Lugthart, G. H., and Chung, K., 1995, Long-term dynamics of coarse particulate organic-matter in three Appalachian mountain streams: Journal of the North American Benthological Society, v. 14, no. 2, p. 217-232.

Webster, J. R., Benfield, E. F., Ehrman, T. P., Schaeffer, M. A., Tank, J. L., Hutchens, J. J., and D'angelo, D. J., 1999, What happens to allochthonous material that falls into streams? A synthesis of new and published information from Coweeta: Freshwater Biology, v. 41, no. 4, p. 687-705.

Wohl, E., 2013, Floodplains and wood: Earth-Science Reviews, v. 123, p. 194-212.

Wohl, E., and Beckman, N., 2012, Controls on the longitudinal distribution of channel-spanning logjams in the Colorado Front Range, USA: River Research and Applications, v. 30, p. 112-131.

Wohl, E. and Jaeger, K., 2009, A conceptual model for the longitudinal distribution of wood in mountain streams, Earth Surf. Process. Landforms, v. 34, p. 329–344, doi:10.1002/esp.1722.