Reply
Review #3 Jeff Warburton

We thank the reviewer for his/her comments. Below we give detailed replies and outline the changes made to the manuscript. Replies are given in *italics*.

Specific Comments
The broad definition of Coarse Particulate Organic Matter (CPOM) is any material greater than 1 mm and includes wood and non-woody material. This is derived from Cummins (1974) [Structure and function of stream ecosystems, BioScience 24, 631
We added this references, but we would like to point out that the definition was already used earlier, for example by Fisher and Likens, 1972 and 1973.
641]. It is interesting that CPOM in this paper is defined by dry mass (> 0.1 g) but in the introduction it is defined by size (> 1 mm).
The size definition is commonly used in the literature. We added 'usually' in front of the sentence. We do not define CPOM by dry mass, on the contrary, we stated in the introduction: 'Here, we hypothesize that the use of dry mass as a descriptor variable leads to a scaling relation consistently connecting all CPOM size groups transported by a stream, from leaves to large logs. We have measured transport rates and dry masses of CPOM pieces heavier than 0.1 g moving in the Erlenbach, a headwater stream in the Swiss Prealps, using several sampling methods over a large range of discharges.' The use of 0.1g as a lower limit to the material we studied is determined by our sampling methods. Much finer netting than the one we used has a low probability of survival in a high energy stream such as the Erlenbach. Note that in fact we measured smaller particles (see the scaling relation), but only measured particles heavier than 0.1g representatively.

In the following comments we had the impression that the reviewer assumed we used the sampling strategy employed for the bedload traps also for the basket samplers. This was not the case. The traps need to be operated manually, and the stream needs to be wadable. This limits the method to small discharges, and snow-melt events are advantageous, because a trip can be planned a few days in advance. Snow melt floods rarely exceed discharges of 150 l/s. Rainfall-driven events in the Erlenbach (with higher discharges) are sporadic, and hard to predict. It is common that a rain front moving through the area will not actually lead to elevated discharge, or that a localized rain cell (such as a thunderstorm) triggers an event. The first author has worked extensively in the Erlenbach for the past six years, but was present only at a handful of events with a peak discharge exceeding 500l/s. Thus, traps are most easily employed during snow melt in the spring, and we were lucky to be able to sample a few events with higher discharges. The basket samplers operate automatically, and are moved into the flow when a certain discharge threshold is exceeded and bedload transport is detected at the measurement cross section (using a geophone-based monitoring system). The earliest basket samples in the year have been obtained on 5th May, the latest on 12th November, thus covering the complete relevant runoff season. We have added explanation.

Also the smallest traps (bed load traps)had a bag mesh size of greater than 6mm hence CPOM here is defined as the fraction > 6mm? However, it does not appear a rigorous criterion for the smallest fraction has been consistently applied. The statement: 'all pieces of organic matter heavier than about 1 g were individually weighed and measured. In samples taken at lower discharges with the bed load samplers, all pieces heavier than 0.1 g or 0.01 g were individually weighed, depending on the total number of pieces.' seems vague.
We measured pieces heavier than 1g for the basket samples, and lighter pieces also for the trap samples. We have rewritten the sentence to make it clearer. Clearly, the criterion for the smallest

needs to be adjusted for the different sampling methods. For instance, it would be impossible to extract all organic material of the deposits of the retention basin, and dry, sort and measure it. We have been very clear about how we analysed the data and we have introduced the use of scaling distributions to reconcile the different lower mass limits of the various methods we exploited. Thus, we have actually provided a method in our paper to deal with the methodological short comings the reviewer criticized in his comment.
Note also that the use of a certain mesh width does not imply a redefinition of the term CPOM.

The use of bed load traps of 0.2 x 0.3 m opening is bound to be problematic in this system where much of the CPOM will exceed these dimensions and either be not captured in the traps or block the openings and reduce the catch yields.
Most of the CPOM is smaller than the trap opening (see also Fig. 1 below). Note that operators are near the traps during sampling, and would be able to spot larger passing material. Most sampling durations were between 10 and 30 minutes. During typical transport rates (10^{-6} to 10^{-5} kg/s) at the typical discharges sampled with the traps (40-150l/s), in 20 min. one obtains 1-10 grams of dry mass CPOM. The largest are small twigs with a length of around 10 cm or so. Sampling of pieces larger than the trap opening was not an issue for the discharges we used the traps for. See also reply below.
During extended periods of deployment (up to 7 hours) such effects must have an impact on yield?
We used long sampling times only for low background flow. Most samples were taken over 10-30 minutes. At the lowest sampled discharge (around 4l/s) we obtained CPOM with a total dry mass of 0.8g in nearly seven hours. It is rather clear that at these discharges shorter sampling times do not yield enough material. We have clarified in the article.

Although it is acknowledged in the paper that the different sampling methods capture different fractions of the CPOM load and some components are 'missed' there is very little said about the different sampling efficiencies of the various methods? This is an important and needs to be accounted for when deriving the scaling relationships.
Basket samplers sample the complete flow (for pictures see Rickenmann et al., ESPL 2012). Bedload traps sample the complete water column (that is from the bed to the surface). The sampling efficiency is only determined by sampled minimum and sampled maximum size. Based on the mass distributions, we have estimated the sampled minimum sizes for the different methods (discussed in detail in the manuscript). As far as we can see, for the discharges sampled, we should catch the largest pieces sampled at that time. Large logs are transported at discharges above a few m3/s, so the basket samplers (samples up to 1500l/s) should not be affected by them.

Because of the relatively low density of CPOM and its strong shape characteristics (twigs and logs) then rating relationships derived from a characteristic length scale (e.g. particle diameter) and discharge might be expected to be weaker than in classic alluvial systems. These relations will vary with the nature of the CPOM (organic particles – leaves – twigs – logs – whole trees (LWD)) so sampling efficiencies and transport behaviours will differ across the full 'particle' size range. For example the definition of large woody debris outlined in the introduction has an aspect ratio of 10:1. Fine CPOM will tend to 'drift' through the stream showing a weak relation with discharge whereas LWD may have a very high threshold discharge before it is entrained. Given these characteristics it is perhaps surprising that there is such a clear dependence on discharge. I would like to see greater discussion of the significance of shape in the CPOM components and an evaluation of its potential significance in affecting transport relations.
Shape indeed is an interesting parameter for CPOM. The wide variations in shape prompted us in the first place to investigate mass as a descriptor variable. Clearly, transport behavior differs for different size classes. However, we see little relevance to the topic discussed in the article, as we only have

data on what comes out of the system, and not what happens in it. Nevertheless, we added a paragraph in section 5.4.
Most of the CPOM material we have sampled consists of small wood chips with dry masses up to a few grams. Typically, these chips are waterlogged and denser than water (2/3 by dry mass on average). Note that we measure at a cross section, and do not know what happens in the catchment. The different shapes of the various size fractions may thus contribute to the definition of the scaling relation.

Fig. 1: To the left: typical CPOM pieces found in the basket samplers. To the right: log congestion in the Erlenbach channel, with a large log and smaller pieces incorporated into the stream bed.

Another key element in explaining the CPOM dynamics in any stream system is defining the 'residence times' of the different fractions of the CPOM. We can probably assume the residence times of small fractions e.g. leaves and small twigs is very short but for larger logs these may form semi-permanent features of the channel.
This is probably true. But note that our aim here is not to explain the CPOM dynamics in the stream. We report data of catchment output and focus on the mass distribution. We added a paragraph in section 5.4.

Furthermore, is there any bias introduced by sampling during mainly snowmelt events? The supply of CPOM to the channel will vary seasonal so sampling will reflect the seasonal flux to the channel.
This is a misunderstanding. Our samples were taken over the whole season. We stated that measurements with the traps are mainly made during snow melt (discharges between 40l/s and 150l/s). See our comments above for a more detailed answer. We have added some more detail.

In the final paragraph of Section 5.2, there is the bold statement that 'CPOM export for all size fractions can be estimated from [is] the volumes of LWD exported in a large event, : : : ' However, there is no indication of the error or uncertainty associated with such a procedure.
The error of the estimates is a function of the error in the original measurements, the data coverage, and the statistical methods used to obtain the scaling exponents and the rating curve. Here, our aim is merely to show the possibility of the approach and we have not provided a detailed error analysis. Note that an independent confirmation of the method would require some additional field effort and is beyond the scope of our paper. We have added a note in the text.

In section 5.3 it would be interesting to produce a Figure which shows the relation between wood mass (kg), frequency of delivery and flow.
We have not provided such a figure. The fraction of a certain mass range of the total transport is always a constant fraction, which can easily calculated with equation 3. We have provided an example using a lower limit of 3kg for hazard-prone material, and it is simple to obtain estimates for other lower mass limits (eq. 3). We have clarified in the text.

A 3 kg mass is an arbitrary definition of hazardous wood as in different situations a different mass would be significant.
This is true. The Erlenbach is a research catchment and is not prone to hazard damage. We merely intended to supply an example. We have rephrased to make this clearer.

Also the hazard is not only related to the mass (impact potential) but also frequency, as high frequencies of woody debris can lead to blockage and damming e.g. culverts.
This is a very good point. We had actually calculated frequencies in our example and added a sentence to clarify. In addition, we added a figure showing the relation between total cumulative CPOM delivered from the catchment and discharge.

At the start of section 5.4 it is argued that the scaling component (P12, L16-20) is characteristic of catchment and channel characteristics. However, the discussion of Table 1 and Figure 7 provides little evidence to support this hypothesis and it is stated 'The scaling exponents do not show a strong correlation with any of the tested predictor variables mean elevation above sea level, drainage area, channel bed slope, channel width, forested area, and percent forested area ' (P13, L3-5). Thus there is some uncertainty of what the range in the exponent is telling us about the catchment and instream processes.
We have rewritten the paragraph somewhat, but we would like to note that the criticized statements are not contradictions. First, we have stated that we hypothesize the relationship, and a hypothesis can turn out to be wrong (in fact, it is widely thought that the disproval of hypotheses is the preferred way of scientific advancement). Second, we have tested the hypothesis to only a limited extent, and also we have not been able to 'support' it (if this indeed is possible), we neither have disproved it, as is clear from the discussion. Third, even if the exponent lies in a narrow range, there can be tight relationships with predictor variables, and whether this is the case remains to be seen. In predictive exercises (see for instance the example in section 5.3), one can obtain very different results when the scaling exponent is 1.4 or 2.0.

Much more could be said about the difference between the exponents for transported CPOM and the CPOM locked in the bed material / bed structure. CPOM exponents for material that is 'locked-in' should be more clearly explained in terms of the physical processes that produce the difference.
This is true and we have augmented the discussion somewhat.

Furthermore, it is noted (P14, L9-10) that 'in general piece mass scales as a declining power law with scaling exponents in a narrow range between about 1.4 and 2.0' but what justification can be given that this is a 'narrow' range when the value of the scaling exponent cannot be correlated with catchment or channel characteristics?
See reply above. We have removed 'in a narrow' in the criticized statement.

Finally, it would be neat to compare thee scaling relationship for the components of a whole tree (possibly through tree allometry) with those that are transported in the stream system as this might reveal some interesting features of the breakdown of woody debris and transfer by fluvial processes?
We have tried to obtain data of mass of branches, twigs etc of living trees. Although this seems to have been measured on multiple occasions, it seems that the mass distribution has not been reported in the literature. We have written to various researchers involved in these endeavors, without receiving a reply. We have added a note in the paper, but we are currently not able to take this point any further.

Technical corrections:

Jackson and Sturm (2002) is missing from the reference list.

Reference added.

P2, L24 the sentence ' : : : from leave and wood fragments over twigs and branches to logs and complete trees.' should be rewritten ' : : : from leaf and wood fragments through twigs and branches to logs and complete trees.'

Changed to something similar.

P4, L26 – 'annual' rather than 'yearly'

Changed.

P3, L91 – Better expressed in m3 s-1 than l s-1 e.g. 50 year return frequency is 11.1 m3 s-1.

We used l/s consistently throughout the manuscript. It is more convenient for the lower discharges seen at the Erlenbach.

P6, L21-22 – It is not clear to me from the description provided how the representative discharge values were determined for the larger events. The methods seem prone to large uncertainty. Why was a value of 5000 l s-1 chosen?

The assumption was made based on long-term observations of the catchment. Flood events with peak discharges below 5m3/s export at most a few pieces of LWD (Fig. 2). Interestingly, in about 40 years of measurements we have not observed any flood events with peak discharge between about 5 and 9 m3/s, and only four exceptional events showed higher peaks (1984, 1995, 2007, 2010, see Turowski et al., 2009 and 2013). The results are not very sensitive to the assumption, i.e., the data points always plot close to the regression line. We have tried to clarify in the manuscript.

Fig. 2: Pictures of the retention basin after the flood event from the 4th July 2009 (on the left, picture taken on the 4th July 2009) with a peak discharge of 4990 l/s (upper gauge, 1-min. data), and after the flood event from the 20th June 2007 (on the right, picture taken on the 21st June 2007) with a peak discharge of 14560 l/s (lower gauge – the upper gauge malfunctioned in this event, 1-min. data).

P7, L14 – Better to talk about 'limb' than 'branch' – confusing in the context of CPOM.

P7, L21 – it is 'borne' not 'born'.

Changed.

P9, L4 – Change to 'In nine log jams : : :'.

Changed.

Table 1 – Why is the scaling exponent for the Erlenbach not shown in the table? Add to caption explanation why two values (a/b) are given in the '#data points used for fit' column.

In the Erlenbach, only log jam material was measured, as is explained in the text. We added (all/log jams) in the last column header.

Fig 1. – Detail of the Erlenbach catchment is not well shown in the annotated aerial photograph. Also could the other catchments used in Table 1 be added to main Swiss map?

We have removed the detail and added the 11 streams to the Swiss map.

Fig 2. – A threshold value of 2 kg for the retention basin samples appears to be a better value.

We have shown here only one example. The threshold size was chosen based on both data points.
Fig 5. - When describing Figure 5 on P9, L6 – you talk about particle mass but the figure shows piece volume. Fig 8. – X axis ‘Piece Length’
Our mistake. Corrected.
Fig 9. – Contradiction between the caption which states x axis is mass and the graph which shows it as volume. Given values I guess this is probably mass - a 2000 m3 piece of wood is very large!
Our mistake. Corrected.