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The mass distribution of coarse particulate organic matter exported from an alpine headwater stream

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Abstract

Coarse particulate organic matter (CPOM) particles span sizes from 1 mm, with masses less than 1 mg, to large logs and whole trees, which may have masses of several hundred kilograms. Different size and mass classes play different roles in stream environments, from being the prime source of energy in stream ecosystems to macroscopically determining channel morphology and local hydraulics. We show that a single scaling exponent can describe the mass distribution of CPOM transported in the Erlenbach, a steep mountain stream in the Swiss Prealps. This exponent takes an average value of −1.8, is independent of discharge and valid for particle masses spanning almost seven orders of magnitude. Together with a rating curve of CPOM transport rates with discharge, we discuss the importance of the scaling exponent for measuring strategies and natural hazard mitigation. Similar to CPOM, the mass distribution of in-stream large woody debris can likewise be described by power law scaling distributions, with exponents varying between −1.8 and −2.0, if all in-stream material is considered, and between −1.4 and −1.8 for material locked in log jams. We expect that scaling exponents are determined by stream type, vegetation, climate, substrate properties, and the connectivity between channels and hillslopes. However, none of the descriptor variables tested here, including drainage area, channel bed slope and forested area, show a strong control on exponent value. The number of streams studied in this paper is too small to make final conclusions.

1 Introduction

Coarse particulate organic matter (CPOM) plays multiple roles in stream systems. Defined as pieces of organic matter with a diameter larger than 1 mm, it spans the range from leave and wood fragments over twigs and branches to logs and complete trees. Large woody debris (LWD), at the top of this range, is often defined as having a minimum diameter of 0.1 m and a minimum length of 1 m (e.g., Wohl and Jaeger, 2009), but others have used minimum lengths of 0.5 m, 1.5 m or 3 m (e.g., Hassan et al., 2005; Jackson and Sturm, 2002; Martin and Benda, 2001). Each size group within the wide range of CPOM sizes fulfills different geomorphic and ecological roles (e.g., Harmon et al., 1986). Allochthonous organic matter, entering the stream system for example as litter fall from adjoining forest, is the prime source of energy in stream ecosystems especially in headwater catchments (e.g., Fisher and Likens, 1973). Leaves and twigs and their decay products are consumed by in-stream shredders and suspension feeders, and thus form the basis of the food chain. Larger pieces of woody debris may alter stream roughness, altering the physical conditions of the flow, feeding back to flow velocity and sediment transport rates, and affecting habitat and breeding grounds for fish and other aquatic animals (e.g., Abbe and Montgomery, 1996; Bilby and Ward, 1991; Brooks et al., 2004; Keller and Swanson, 1979; MacFarlane and Wohl, 2003; Montgomery and Piégay, 2003). Log jams are often a major element of stream morphology, and floating logs may be an important source of natural hazard (e.g., Kraft and Warren, 2003; Manga and Kirchner, 2000; Mazzorana et al., 2011; Rickenmann, 1997).

Wood budgets are a common tool to assess availability and transport of woody material (e.g., Benda and Sias, 2003; Keller and Swanson, 1979; Martin and Benda, 2001). However, these studies often focus on LWD. Budgets of smaller organic material are necessary in ecological studies to assess the availability of food in a stream (e.g., Fisher and Likens, 1973; Webster and Meyer, 1997), but they are typically focused on small streams where LWD rarely moves. Studies investigating the entire size range of transported material, from leaves to logs, are rare. It is currently unclear how the different CPOM size groups, especially LWD and leaf-size fractions, relate to each other. Size distributions have been reported for LWD only, either based on piece diameter or volume of material stored in the stream (Harmon et al., 1986; Hogan, 1987; Jackson and Sturm, 2002; Rickli and Bucher, 2006), or piece length of transported material (MacVicar and Piégay, 2012). 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. In addition, we collected data on in-stream LWD size distributions for the Erlenbach, and compared it to data from ten other mountain streams in Switzerland (Rickli and Bucher, 2006), and from the literature. We discuss the use of scaling relations in data analysis and natural hazard mitigation.

2 Field site

The Erlenbach is a small headwater stream located near Einsiedeln in the Swiss Prealps (Fig. 1), where scientific observations have been conducted since the late 1960s (Hegg et al., 2006). The channel bed has a mean gradient of around 18 % and drains an area of 0.7 km^2 at the main observation site. About 40 % of the total catchment area is forested, with the remaining 60 % consisting of wetland and alpine meadows. The forest dominantly comprises Norway Spruce (*Picea abies*) and European Silver Fir (*Abies alba*), intermingled with some Alder (*Alnus* spec.), and a wide variety of shrubs and ground plants (Schleppi et al., 1999). The Erlenbach is a step-pool channel with high sediment load, which is mainly supplied by a series of slow-moving landslides along the channel banks (Schuerch et al., 2006; Turowski et al., 2009; Molnar et al., 2010). There are two discharge gauges located immediately upstream and downstream of a sediment retention basin where automatic basket samplers and indirect bedload sensors for sediment transport measurements are available (Rickenmann et al., 2012; Turowski et al., 2011). Discharge is continuously recorded at 10 min intervals, and at 1 min intervals during bedload transport events. Unless otherwise stated, we used the 10 min data of the upper gauge throughout this paper. The mean discharge at the Erlenbach is 39 l s^{-1}, and during dry weather it is typically below 10 l s^{-1}. Floods, driven mainly by convective summer storms, are common, and stream flow quickly responds to heavy rainfall. The yearly return discharge is approximately 2000 l s^{-1}. The highest discharge recorded in the last 30 yr occurred on 20 June 2007. At $\sim 11\,100\,\mathrm{l\,s^{-1}}$ (10 min data), its return frequency is estimated at 50 yr (Turowski et al., 2009, 2013).

3 Methods

Transported CPOM was sampled using three different methods. At low to intermediate discharge (from 1 to $\sim 1000\,\mathrm{l\,s^{-1}}$, with most samples below $250\,\mathrm{l\,s^{-1}}$), when the stream was wadable, we used bedload traps (Bunte et al., 2004, 2007). Automatic basket samplers were used at higher discharges (from 200 to $1500\,\mathrm{l\,s^{-1}}$, with most samples above $400\,\mathrm{l\,s^{-1}}$) (Rickenmann et al., 2012). Two samples were obtained from measuring woody material accumulated in the retention basin after two large floods that occurred in 1995 and 2010 (cf., Turowski et al., 2009, 2013).

Bedload traps are portable samplers installed on metal plates placed on the channel bed. They are specifically designed for obtaining samples of gravel bedload (Bunte et al., 2004, 2007), but are also suitable for sampling CPOM. Bedload traps consist of an aluminium frame, with a width of 0.3 m and a height of 0.2 m, to which a net 1–2 m long is attached. Bedload trap samples were obtained from three channel locations across a step-pool unit located ~ 20 m upstream of the discharge gauge: at the crown and the foot of a step and at the end of the associated pool. A single trap was sufficient to cover the whole flow width at the crown and the foot of the step. At the pool exit, two traps were used to sample the flow width of approximately 2.6 m. The transport rates measured with these two traps were extrapolated to the unmeasured parts of the channel cross section, using additional information on local flow depth. The traps used at the Erlenbach have a net opening size of 6 mm, and sampling times ranged from a few minutes to nearly seven hours, depending on the variability of discharge and on transport rates. Samples were taken in the spring of 2012, mainly during snow-melt events, with a few samples taken later in the year at higher discharges in rain-driven flow events and at low background discharges.

The automatic basket samplers consist of metal cubes with 1 m edges (Rickenmann et al., 2012). The baskets' walls and floors are made of a metal mesh of square holes with an edge length of 10 mm. Sampling is triggered when thresholds of stage level and indirect bedload sensor activity are exceeded. The entire flow width is sampled at discharges up to around $1500\,\mathrm{l\,s^{-1}}$. Samples were taken between 2009 and 2012 during rainfall-driven floods.

Organic matter from basket and trap samples was separated from clastic material and weighed wet in the field. Subsequently, the samples were oven-dried over 24 h at 80 °C in the laboratory, and the dry mass was obtained. For a total of 18 out of 42 basket samples, all pieces of organic matter heavier than about 1 g were individually weighed and measured. In samples taken at lower discharges with the bedload samplers, all pieces heavier than 0.1 g or 0.01 g were individually weighed, depending on the total number of pieces.

After two large floods in July 1995 and August 2010 with peak discharges of $\sim 10\,100\,\mathrm{l\,s^{-1}}$ and $\sim 9300\,\mathrm{l\,s^{-1}}$, respectively (10 min data) (Turowski et al., 2009, 2013), pieces of woody debris with diameters larger than 0.05 m were collected from the sediment retention basin, and their lengths and diameters were measured in the field. The measurements were converted to mass assuming a cylindrical shape and a dry wood density of $410\,\mathrm{kg\,m^{-3}}$, which is typical for the Norway Spruce (*Picea Abies*) that is common in the catchment. To obtain a representative discharge for these data points, we assumed that large pieces of wood are dominantly transported at discharges higher than $5000\,\mathrm{l\,s^{-1}}$, using discharge measurements at 1 min resolution. This discharge was exceeded for 20 and 18 min, respectively, during the events, and accordingly we averaged all discharge measurements exceeding it.

In addition to sampling material transported by the stream, the length and diameter of all woody debris pieces stored in log jams longer than 1 m (LWD) were recorded in the field. LWD masses were calculated assuming a cylindrical shape and a dry wood density of $410\,\mathrm{kg\,m^{-3}}$.

4 Results and analysis

The occurrence of sampled CPOM particles is tightly related to their masses; the number of CPOM pieces in transport strongly decreased with increasing particle mass. At particle masses greater than a threshold value of ~ 1 g for the basket samples and ~ 3 kg for the retention basin samples, the relative frequencies of occurrence of masses in the samples plot on a straight line in log-log space (Fig. 2). No such threshold was observed for the bedload trap data, because the smaller net size trapped finer particles. The relationships can be described by the equation:

$$C = kM^{-\alpha}. \tag{1}$$

Here, C is the relative fraction of CPOM of the respective particle mass M, k is a constant and α is the scaling exponent. The relative fraction is proportional to the measured fraction of CPOM in each mass class, but may be normalized for example by bin width. For each CPOM sample, scaling exponents were obtained by fitting a linear relation to the log-transformed data in the long falling branch. Minimum and maximum values of α were 1.41 and 2.26, respectively, and the mean was 1.84 ± 0.04 (range gives standard error of the mean). For all discharges where samples contained enough individual pieces of material to derive a relation between piece numbers and mass, scaling exponents were independent of discharge (Fig. 3).

By dividing total CPOM mass by sampling time, we obtained CPOM transport rates. These show a clear relation with discharge, defined by a straight line in log-log space (Fig. 4). However, it needs to be born in mind that we used different sampling devices with different net sizes (bedload traps: 6 mm; basket samplers: 10 mm; LWD from the retention basin). Below we will show how the scaling relation of Eq. (1) can be used to make the samples comparable.

As long as the scaling exponent $\alpha > 1$, the total mass M_{tot} of the sample above a minimum mass M_{min} can be obtained by using the integral

$$M_{\text{tot}} = \int_{M_{\text{min}}}^{\infty} kM^{-\alpha}\text{d}M = \frac{kM_{\text{min}}^{1-\alpha}}{\alpha - 1}. \tag{2}$$

The ratio between the total mass $M_{1,\text{tot}}$ larger than a threshold mass $M_{1,\text{min}}$, and the total mass $M_{2,\text{tot}}$ larger than a threshold mass $M_{2,\text{min}}$ can thus be written as:

$$\frac{M_{1,\text{tot}}}{M_{2,\text{tot}}} = \left(\frac{M_{1,\text{min}}}{M_{2,\text{min}}}\right)^{1-\alpha}. \tag{3}$$

To be able to compare the samples taken with bedload traps and basket samplers, we estimated the minimal particle mass that is sampled representatively by the baskets at 1 g. The lack of a further increase in relative counts for smaller particles indicates that not all material of smaller masses was sampled (see Fig. 2). Particles lighter than 1 g were omitted from the samples, and the remainder was used for further analysis. For basket samples where the mass distribution was not measured, we used the average fraction of mass contributed by 1 g particles to the total mass from the basket samples where it was measured. This value of 0.48 was multiplied with the total measured CPOM mass. For each basket sample, the total mass above 0.1 g was then calculated using Eq. (3). For the bedload trap samples, we only used samples for which the mass distribution was measured and which included individual pieces heavier than 0.1 g.

The corrected samples were plotted against discharge to obtain a rating curve (Fig. 4). The rating exponent of 4.47 was obtained by fitting a linear relationship to the log-transformed data. The data points from the two extreme events were not included in the fit. There, all particles heavier than about 3 kg (dry mass) were sampled representatively, and the measured mass of 219 kg was extrapolated down to piece masses of 0.1 g using the average scaling exponent of 1.84 (Fig. 3). The resulting points plot close to the rating curve between CPOM transport rate and discharge derived from the trap and basket measurements and confirm the validity of the CPOM transport rating relation at high discharges (Fig. 4).

Locked in nine log jams along the Erlenbach channel, we measured a total of 79 pieces of LWD. The size distribution of this material likewise decreased with particle mass (Fig. 5), although with a value of 1.26 the scaling exponent was lower than observed for transported material. Scaling exponents similar to those from the Erlenbach were also obtained from 6700 wood pieces measured in ten other Swiss mountain streams (Rickli and Bucher, 2006; see Table 1). Power function scaling exponents ranged within 1.78 to 2.04 for all wood pieces in the channel and within 1.39 and 1.75 for those locked in log jams (Fig. 6) (the two extraordinary low values were from derived from small sample sizes at the Brueggenwaldbach and the Grossbach are unreliable). Scaling exponents appeared unrelated to basin area size, stream width and gradient, and the percent forested area (Fig. 7).

5 Discussion

5.1 Masses of CPOM input and piece break down

Various processes in the stream work together to produce the observed mass distribution of CPOM particles from the original mass distribution of organic material supplied to the stream. Coarse particulate organic matter enters the stream either as litter fall directly from the trees or blown in by wind, or via the stream banks either as material advected into the channel by landslides and snow creep, or flushed into it by overland flow. Litter typically comprises leaves with dry masses below 0.1 g and twigs with masses smaller than about 5 g. Larger material, often whole trees, can enter the channel due to wind throw or by riding on top of landslides. A number of slow-moving landslide complexes have been identified along the banks of the Erlenbach, causing efficient channel-hillslope connectivity (Schuerch et al., 2006). Trees, tree trunks and large

branches are abundant in the Erlenbach channel and along the banks. Thus, based on preliminary data from litter traps installed above the stream channel and from field observations, we can assume that the input distribution of CPOM masses is strongly bimodal, with one peak lying between 0.1 g and 1 g (leaves and twigs), and one at >100 kg (whole trees). The mass distribution of the material flushed out of the stream therefore does not correspond to the input distribution, and in-stream processes must break down larger material while it resides in the channel. These processes can be broadly divided into physical, chemical and biological processes (although these may interact) (Harmon et al., 1986; Merten et al., 2013; Webster et al., 1999). The physical processes include breakage and detachment of pieces by fluid stressing, grinding of woody debris by gravel bedload, wood-wood interaction (for example a floating log impacting stationary material), or the break-up of log jams (Harmon et al., 1986). In addition, wetting/drying cycles and possibly freezing/thawing may lead to swelling and cracking of wood. Parts of woody material can be dissolved in water and carried out in solution (e.g., Yoshimura et al., 2010). This loss of material may destabilize the structure of the debris and make it more prone to physical erosion. Finally, bacteria and fungi colonize dead wood and decompose it, while animals, for example fresh-water invertebrates or certain types of insects such as Plecoptera larvae, may attack CPOM pieces to obtain food or to create shelter (e.g., Webster and Benfield, 1986; Montemarano et al., 2007). As pointed out by Hassan et al. (2005), little is known about the relative importance of different wood depletion processes. Merten et al. (2013) found that physical breakage was responsible for a mass loss of around 7.3 % in LWD, while decay contributed around 1.9 % in streams in northern Minnesota, USA. However, it is currently unclear how these results transfer to other regions. In addition, it is not known what piece sizes are produced by the various decay processes, how fluvial transport affects the CPOM/LWD size distribution, and how exactly the different processes play together to produce the observed output mass distribution.

5.2 Implications for sampling strategies

Using the rating curve and measured discharge, CPOM export during individual events and over longer time scales can be calculated. Due to the strong dependence of CPOM on discharge with a rating curve exponent of 4.47, CPOM transport is dominated by large discharge events. For instance, applying the rating curve to the measured discharge from the extreme event in August 2010, this event alone exported nearly 2×10^6 kg of CPOM, comprising 94 % of the total export for the year 2010. Without deriving a detailed rating curve, similarly strong dependences on discharge have been reported previously (e.g., Fisher and Likens, 1973). This suggests that CPOM measurements conducted at low discharges give an incomplete picture of overall CPOM transport. However, if the scaling exponent of the mass distribution is known, and for a given event a certain size fraction has been sampled representatively, the complete CPOM export can be calculated. Our study results suggest that CPOM export for all size fractions can be estimated from is the volumes of LWD exported in a large event, for example by measuring piece sizes trapped in a reservoir or by video monitoring the passage of wood pieces (e.g., MacVicar and Piégay, 2012; MacVicar et al., 2009; Seo et al., 2008; West et al., 2011). In addition to scaling down from LWD deposits to estimate CPOM export, the scaling functions also permit scaling up from CPOM transport to estimate LWD transport. The combination of a rating curve of CPOM transport rates with discharge and the mass distribution obtained from samples collected at low and intermediate flows can be used to discuss the mobility of LWD.

5.3 Mobility of large woody debris and hazard assessment

Floating wood is a source of hazard in many mountain streams (e.g., Mazzorana et al., 2011; Rickenmann, 1997). For example, woody debris can jam in channel constrictions or at bridges, which may trap sediment and force water to overflow and leave the channel. In addition, logs floating at the surface of the stream can achieve considerable velocities, leading them to cause considerable damage upon impact on infrastructure

elements such as bridge piers. Using the definition that LWD pieces have a diameter larger than 0.1 m and a length larger than 1 m (Wohl and Jaeger, 2009), and assuming a dry wood density of $410\,\mathrm{kg\,m^3}$ and a cylindrical shape, LWD has a minimum dry mass of ~ 3.2 kg. We will here use a mass of 3 kg as the minimum value for pieces relevant to natural hazards or stream dynamics. According to Eq. (3), the mass of all transported pieces heavier than 3 kg is 1.73×10^{-4} times the total load of pieces heavier than 0.1 g. Using the rating curve, the transport rate of LWD can thus be obtained. According to our results, at the Erlenbach a potentially hazardous piece of wood with a mass of 3 kg or more arrives on average every ten minutes at a discharge of $\sim 3400\,\mathrm{l\,s^{-1}}$, every minute at a discharge of $\sim 5800\,\mathrm{l\,s^{-1}}$, every ten seconds at a discharge of $\sim 8600\,\mathrm{l\,s^{-1}}$ and every second at a discharge of $14\,400\,\mathrm{l\,s^{-1}}$. Calculations like this may help to assess the potential hazard of floods of certain sizes. Mobility of wood of all sizes may of course be limited by the ready availability of the material in or near the stream.

5.4 Transferability of the results to other catchments

We have presented results on the mass distribution of transported material for a single small headwater catchment, the Erlenbach. We hypothesize that a similarly consistent, i.e., discharge-independent scaling relation of transported CPOM masses can be found in other streams, with a scaling exponent that is characteristic of catchment size, forest type, vegetation growth rates, channel hydraulics, and the relative importance of different decay and transport processes in the stream. The quality of the connectivity between channels and hillslopes should also play a role. The data collected by Rickli and Bucher (2006) on distributions of in-stream LWD in ten mountainous catchments of Switzerland provides some evidence for the transferability of the Erlenbach observations. We found consistent power-law distributions for all of these streams, indicating that there is some generality in this type of distribution (cf., Fig. 6 and Table 1). In general, the scaling exponent for LWD in log jams is smaller than the scaling exponent for all in-stream wood (Table 1). Similarly, for the Erlenbach, the log jam scaling exponent is smaller than for the transported material. This implies that coarser material is stored in log jams, and is moved less frequently than smaller material. This reflects the selective transport of large pieces of wood and the fact that jamming makes coarse material less mobile. 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 (Fig. 7). However, the range of conditions in the investigated streams is small and a final assessment would need a larger data base.

Not many reports of size distributions of CPOM can be found in the literature, and the majority of the available studies used piece diameter as descriptor variable (e.g., Harmon et al., 1986; Jackson and Sturm, 2002). We were able to find a single study using volume as a descriptor variable (Hogan, 1987). We digitized the data for the unlogged reaches, and found power law scaling with exponent values of 1.72 for the small watershed (3.9 km^2), 1.61 for the medium watershed (6.9 km^2) and 1.90 for the large watershed (20.2 km^2) (here, the depiction of "small", "medium" and "large" is after Hogan's (1987) own terminology). MacVicar and Piégay (2012) reported the distribution of LWD piece length in transport, observed using a video camera during floods of the Ain River, France. We digitized that data and converted from piece length to mass using a power-law fitted to the relationship of Erlenbach LWD taken from the retention basin samples (Fig. 8). Clearly, this is a rough approach, but when the data of MacVicar and Piégay (2012) are converted to mass using this relationship, a well-defined power-law scaling with a scaling exponent of 1.62 is obtained (Fig. 9). The scaling exponent is similar to the one observed at the Erlenbach (1.84). The slightly smaller value implies the occurrence of large CPOM pieces is more frequent in comparison. The Ain River is a much larger stream than the Erlenbach, with a drainage area of 3630 km^2 (compared to 0.7 km^2 at the Erlenbach) and a width of ~65 m (compared to ~4 m at the Erlenbach). LWD pieces longer than the channel width are rarely transported (Bilby and Ward, 1989; Nakamura and Swanson, 1993), and it has been shown in field studies that LWD moves further and more frequently in larger streams (e.g., Lienkamper and Swanson, 1987). Thus, the slightly greater abundance of long pieces in the Ain River

in comparison to the Erlenbach seems reasonable. In addition, with the video method used by MacVicar and Piégay (2012), smaller pieces are more likely to be missed in the analysis, and the data may be biased towards larger material.

In summary, we have found similar scaling exponents for in-stream LWD of eleven Swiss mountain streams, including the Erlenbach, and small forested catchments in British Columbia, Canada (Hogan, 1987). In addition, we found similar scaling exponents for transported LWD in the Erlenbach headwater stream, Switzerland (this study) and the Ain River, France (MacVicar and Piégay, 2012). This suggests that at least for large woody debris, in general piece mass scales as a declining power law with scaling exponents in a narrow range between about 1.4 and 2.0.

6 Conclusions

We have demonstrated that the masses of coarse particulate organic matter (CPOM) transported in the Erlenbach, a steep mountain headwater stream in the Prealps of Switzerland, display a well-defined scaling behavior, which is consistent over almost seven orders of magnitude of particle masses and independent of discharge. Such scaling information can be used to make comparable CPOM transport rates collected from different sampling methods and to estimate the total masses of exported material from small samples comprising only a few size classes of CPOM. Currently, our results have been demonstrated to hold fully for the Erlenbach only. However, the comparison of the Erlenbach data with the scaling distributions of large woody debris transported in the Ain River, France, and of in-channel material in ten small Swiss mountain streams and forested catchments in British Columbia, Canada, suggests that a similarly consistent scaling behavior between CPOM masses and the number of pieces exist for other streams. We found that the watershed/channel parameters examined in the eleven Swiss data sets did not determine LWD scaling; however, the number of streams and the ranges of the observed values are too small to make final conclusions. Thus, it remains to be determined in how far the scaling exponent depends on stream type, vegetation, climate, substrate properties, and on the connectivity between channels and hillslopes. High quality data on piece mass of transported CPOM spanning the full range of masses is rare, and a full evaluation of our findings is not possible at this stage. If a scaling similar to the one observed at the Erlenbach, which consistently holds over nearly seven orders of magnitude in particle mass and three orders of magnitude in discharge, is correct, measurements of scaling exponents on a small fraction of transported or stored material can be used to extrapolate from LWD to CPOM or vice versa. This may be useful to assess the hazard potential of large woody debris during floods, it may simplify the planning and logistics of measurement campaigns, and it may help in obtaining woody debris budgets for stream reaches.

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Table 1. Characteristics of the Swiss streams and scaling exponents.

	Stream	Community, Canton	Drainage area (km^2)	% forested	Mean elevation (m a.s.l.)	Channel bed slope	Mean channel width (m)	Scaling exponent (all data)	Scaling exponent (log jams)	# data points used for fit
1	Erlenbach	Brunni, SZ	0.7	40	1347	0.105	4.0		1.26	79
2	Brüggenwaldbach	Gersau, SZ	0.81	33	804	0.341	8.7	2.04	0.93	472/14
3	Steinibach	Flühli, LU	1.49	17	1160	0.164	8.8	1.89	1.75	679/106
4	Seeblibach	Romoos, LU	1.16	47	950	0.104	6.3	1.85	1.68	781/173
5	Ibach	Weissbad, AI	1.64	26	880	0.070	8.3	1.90	1.64	485/112
6	Büetschligraben	Schangnau, BE	2.24	18	1040	0.155	10.9	1.86	1.64	567/33
7	Steiglebach	Marbach, LU	3.02	40	1180	0.074	10.2	1.85	1.39	572/177
8	Grossbach	Molinis, GR	2.40	38	1190	0.278	11.2	1.88	0.97	687/8
9	Chreuelbach	Goldingen, SG	0.88	65	920	0.132	6.9	1.78	1.69	857/98
10	Geissbach	Ebnat-Kappel, SG	1.63	45	1080	0.095	9.5	1.84	1.52	749/104
11	Ursprung	Wiesen, GR	1.33	50	1610	0.089	8.9	1.87	1.71	879/252

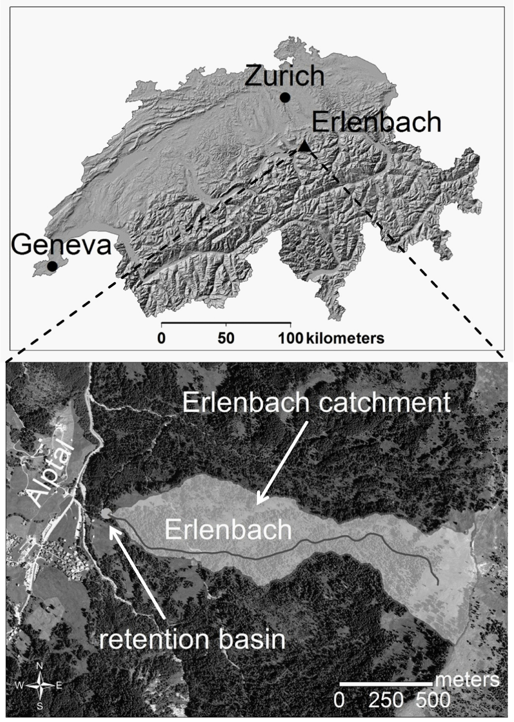

Fig. 1. Location map of the Erlenbach in Switzerland and bird's eye view of the catchment.

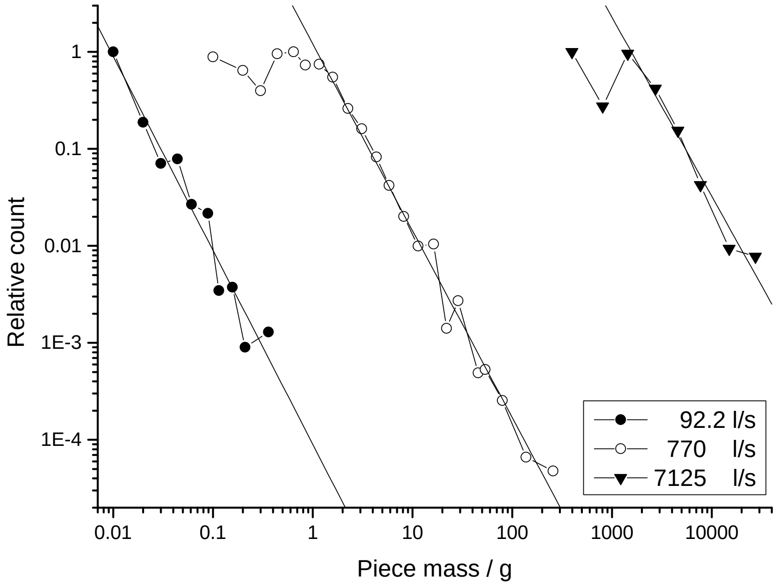

Fig. 2. Examples of histograms of CPOM particle masses at three different discharges, spanning two orders of magnitude in discharge and more than six orders of magnitude in particle mass. To reduce the extent of the axes, and to demonstrate the general similarity of the CPOM piece count vs. mass relations, each of the histograms was normalized such that the most common fraction plots at a relative count of one. The sample collected at 92.2 $\mathrm{l\,s^{-1}}$ is typical of those taken with bedload traps, the one at 770 $\mathrm{l\,s^{-1}}$ of those with basket samplers, and the one at 7125 $\mathrm{l\,s^{-1}}$ was collected from the debris basin.

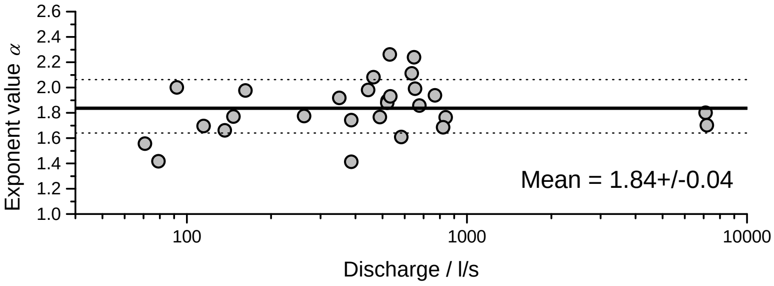

Fig. 3. Scaling exponents of the mass distribution as function of discharge for the Erlenbach samples. No trend is visible. The solid line gives the mean value, dotted lines depict one standard deviation around the mean.

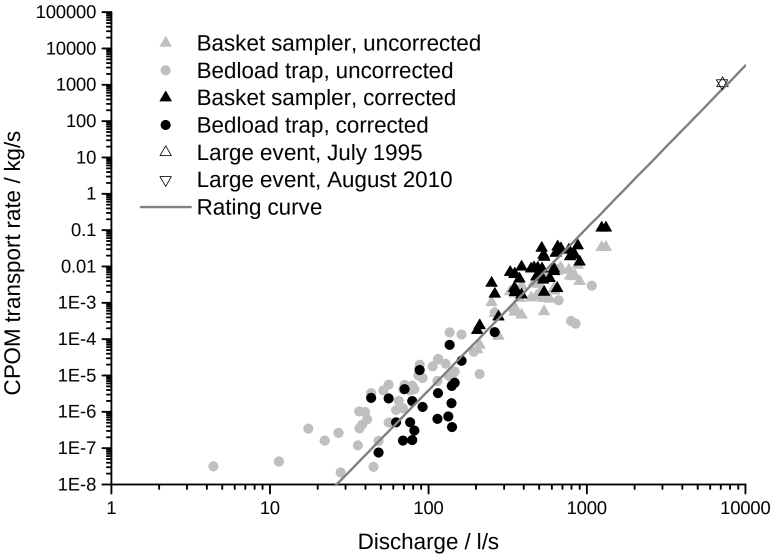

Fig. 4. CPOM transport rates as a functions of discharge. Both the untreated data (light grey) and the values corrected for transport rates of all particles heavier than 0.1 g (black) are shown. The rating curve is of the form $Q_{\mathrm{CPOM}} = aQ^b$, with $a = 4.42 \times 10^{-15}$ and $b = 4.47 \pm 0.21$, with an R value of 0.94. The two data points from the large events (open triangles) plot nearly at the same location. They were not used in the regression to obtain the rating curve.

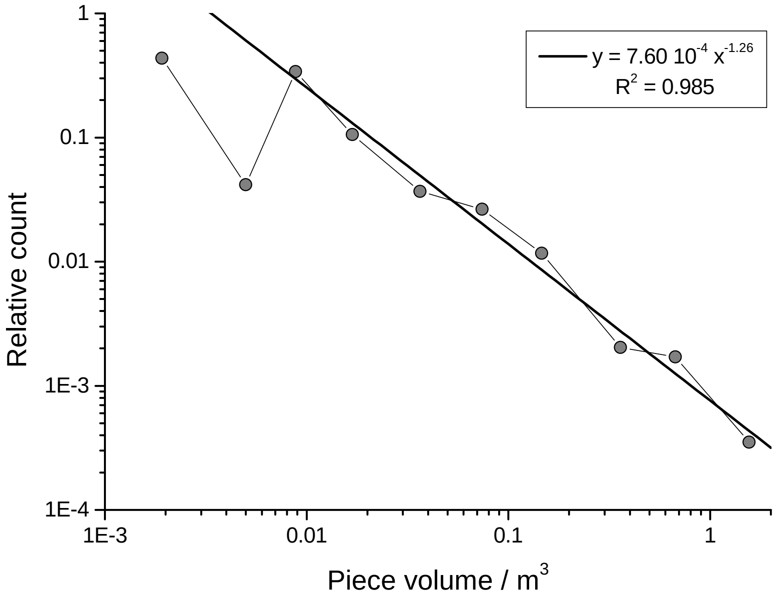

Fig. 5. Scaling distributions of piece mass for LWD locked in log jams in the Erlenbach channel.

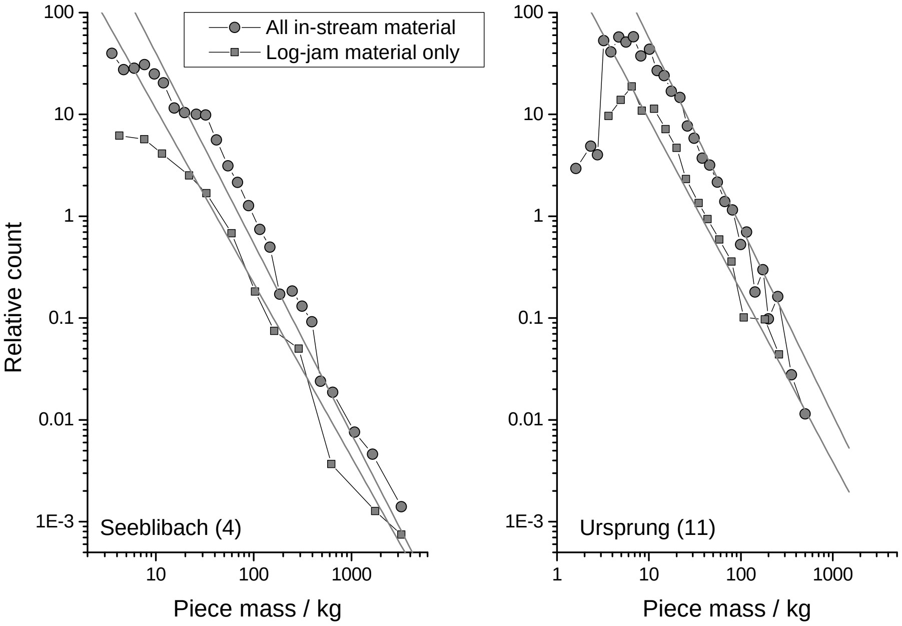

Fig. 6. Scaling distributions of piece mass for LWD in the Seeblibach (4) and Ursprung (11) (see Table 1), as examples for distributions observed in the Swiss mountain streams (Rickli and Bucher, 2006). Distributions both for material locked in log jams (square symbols) and for all material (circles) stored in the channel are shown.

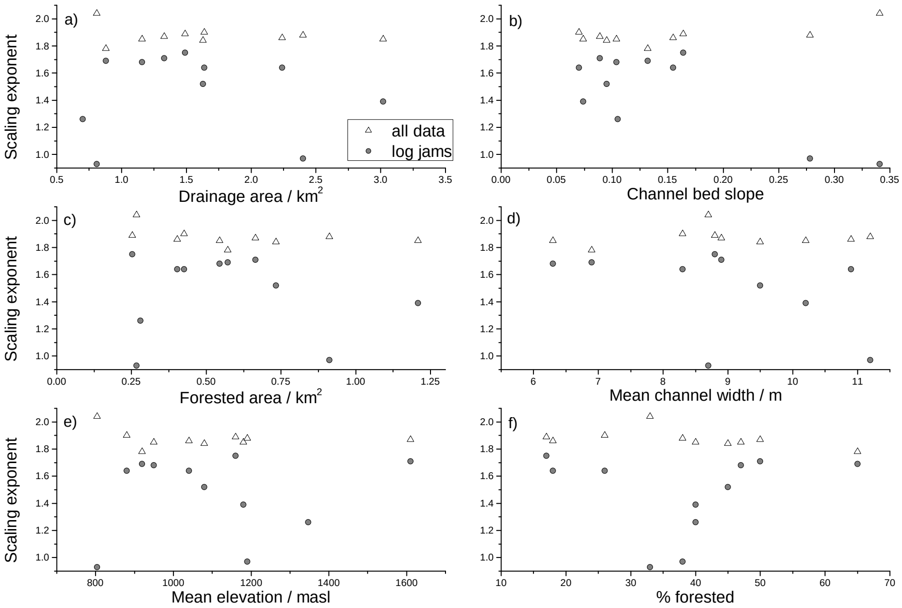

Fig. 7. Scaling exponents of eleven Swiss mountain streams (Table 1) as functions of **(a)** drainage area, **(b)** channel bed slope, **(c)** forested area, **(d)** mean channel width, **(e)** mean elevation above sea level, and **(f)** percent fraction of the catchment covered by forest. Note that the two lowest scaling exponents for log jam material at 0.93 and 0.97, corresponding to the Brüggenwaldbach and Grossbach (Table 1), are based on a small number of measurement and are probably spurious. No strong correlations or trends are obvious.

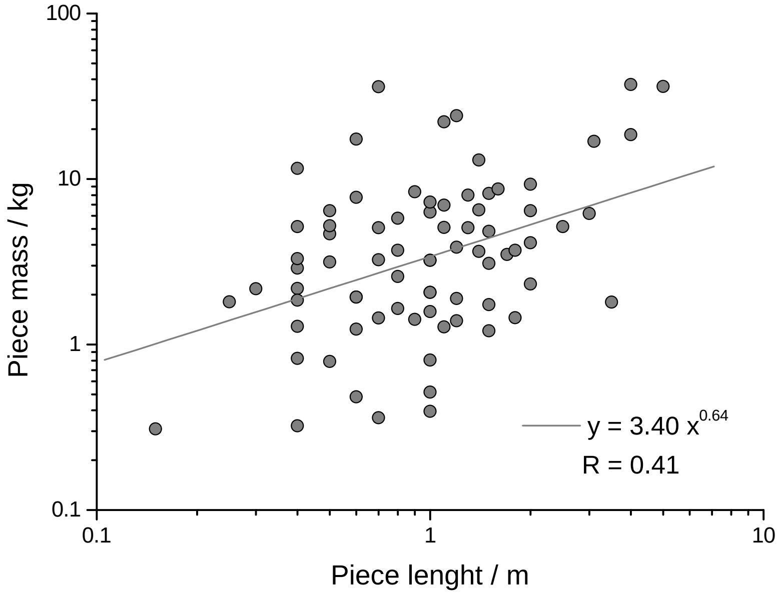

Fig. 8. Relationship between piece mass and length for material from the Erlenbach retention basin samples.

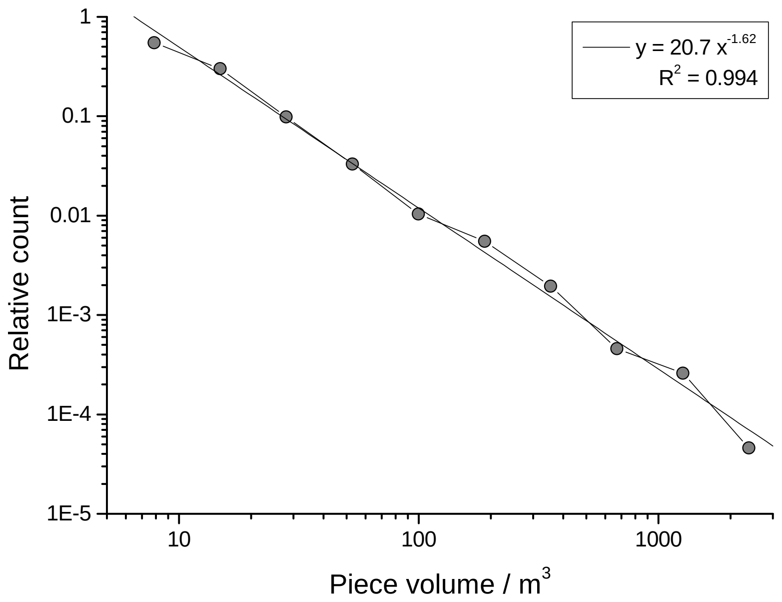

Fig. 9. Scaling distribution of piece mass for LWD transported in the Ain River, France, obtained from the data published by MacVicar and Piégay (2012) for November 2007 (the other data are similar). Piece number and mass are also related by a power law with a scaling exponent of 1.62 (R^2 = 0.994).