Dear Editor,
Thanks for providing to us with two constructive and thorough reviews.
The manuscript has been modified taking into consideration their observations.
Kind regards
The authors

Reviewer 1

Reviewer quote 1: Ravazzolo et al. have provided access to an informative and thought-provoking video for the ever-growing community of scientists, engineers, and ecologists interested in roles and movement of wood in rivers. This valuable resource and their interpretations of the phenomenon will hopefully stimulate more work on the topic. I am reminded of the flurry of sharing of videos and movies of debris flows several decades ago from sites around the world; perhaps this paper will prompt more sharing of videos of congested wood movement events, although they are much rarer. Many of the best videos of debris flows were made in channels with repeated events (e.g., in cases fed by chronic landslide movement or runoff from tephra-mantled hillslopes), which made filming an event much more likely, but greatly reduced the potential to involve much wood, because the repeated flushing precluded substantial wood accumulation in the channel.
Answer quote 1: **We appreciate the comment and fully agree with the reviewer. There is an increasing interest in improving understanding of wood dynamics in rivers, which has been often neglected for different reasons. Home movies are a very valuable source of information in this regard. In fact, currently there is an ongoing community effort to collect and analyze more videos in order to extract as much information as possible.**

Reviewer quote 2: The authors present some interpretations of properties of the observed event, but admittedly fall short on description of conditions within the watershed that led to its occurrence. It is surprising to have so much wood in a runoff event from a watershed with such a small fraction of the area in forest and a recent wood-flushing event (reportedly in 2016). It seems that simple analysis of remote sensing imagery would reveal possible roles of landslides from hillslopes and/or entrainment of wood from riparian forests along the downstream flowpath. Interpretation of the potential of such events as hazards would also be informed by more comment on the influence of the setting; the recent channelization of the study reach created a straight channel with a simple cross section, and possibly with constructed berms on both sides. All these factors can contribute to long runout. If such an event emerges from a steep, narrow channel onto a natural alluvial fan, advance of the flow might thin, spread laterally, be retarded by vegetation, and dewater, causing it to quickly stop. Might channelization to facilitate water runoff exacerbate potential hazards posed by wood-rich flood waters?
Answer quote 2: **Thank you for this observation. We definitely think that exploring at the basin scale the most likely sources of large wood would shed some light on the processes and temporality involved in the recruitment and transport of those logs. Plus, this kind of analysis could help local decision-makers to take evidence-based choices on how to manage in-channel large wood and potentially unstable hillslopes connected to the river network. We tried to include some of these elements in the manuscript, even if this is a bit out of the scope of this brief communication. The surveyed artificial channel did not feature any berms and a visual inspection of two selected upstream river reaches rather supports the hypothesis that LW was mainly freshly recruited from the adjacent river banks. By taking as reference the**

phenomenon with a similar one occurred in the Elqui River (Coquimbo region, Chile) where five homemade videos allow a partial reconstruction of the flow dynamics. It is plausible that between the recruitment reaches and the confined river stretch where the wood laden flow was observed, several channel outbursts led to a net loss of water volumes at the front of the flood wave. These outburst processes apparently did not abstract significant wood volumes from the main flow path. This might have possible influenced the preferential displacement and concentration of a large amount of LW pieces (in the central part of the free surface where velocities are highest) to the front.

Specific Comments

Reviewer quote 1: The leading front of the flow is referred to as a “rather dry mass of logs” and shown in Fig. 2 as having no interstitial water or coarse, inorganic sediment. However, might the flow front has contained a great deal of water and some sediment? The advancing front appears to be faster than the stream water it is overrunning, so it must have been ingesting water from the streambed. There appear to be splashes of water from the streambed, although the amount of water may be trivial compared to the volume of the frontal phase of the flow. In addition to the assumption that no water was in the leading front of the flow, it seems possible, if not probable, that a significant component of inorganic sediment was present within the advancing front. The inorganic material may have been a small enough fraction that it does not appear when viewed from the surface in the video. If landslides were a source of wood, one would expect a significant component of the flow to be gravel and boulders. However, no root systems with soil are observed in the video. Perhaps modeling of the physics of the flow will reveal the possible significance of water and sediment within the leading edge of the flow.
Answer quote 1: **Many thanks for this perceptive observation. Form the video we can appreciate that prior to the arrival of the wood there was very little liquid discharge in the channel. We can only assume that the front of the event must have been relatively dry because of that, but a certain amount of water must have been there. We modified the text in order to acknowledge this degree of uncertainty in our observation.**
As to the amount of sediments transported on the front, unfortunately we don’t have much evidence to exclude the presence of high sediment transport rates. However, post-event field observation allowed us to see that the channel remained virtually unchanged after the flood, as little patches of herbaceous vegetation was still growing in most of the cross-section.

Reviewer quote 2: The term “mobile organic dam” and “dam-break floods” have been used for phenomena like this in the Pacific Northwest of the USA (https://www.ce.washington.edu/sites/cee/files/pdfs/research/hydrology/water-resources/WRS138.pdf). Are these useful terms for making the distinction with congested flow which has much higher water content?
Answer quote 2: **We really appreciate this comment. We considered using these terms in defining this event, but finally decided to stick with the “wood-laden flow” terms, which seemed to us more suited to represent what we could observe in the video.**

Reviewer quote 3: The information on p 3, lines 18-20 is somewhat confusing as to what velocity estimates pertain to which phases of the flow. What is the significance of higher velocity of later phases of the event; what are the mechanisms that lead the phases to be separated and why has the later phase not caught up with the leading phase?

Answer quote 3: **Thanks for pointing out this weakness. We rephrased slightly in order to make clearer the point. However, it is difficult to accommodate a proper discussion of the mechanisms involved in this increase of velocity in this brief communication, and we also don't have all the elements to provide a full explanation of it right now.**

Reviewer quote 4: In reference to wood production at a rate of 0.3 m3 ha-1 on p. 3 line 21, what is the area referred to? Is it the entire watershed or only the forested portion or some other?
Answer quote 4: **In this case we used the area of the surveyed channel.**

Reviewer quote 5: P. 4, lines 3-5: statements attributed to Johnson et al and Swanston and Swanson are not entirely clear. Johnsons et al found zones of severe disturbance to riparian vegetation downstream of confluences where debris flows from tributaries delivered batches of big wood, thereby creating a brief period of congested wood movement in the mainstream channel that could severely disturb riparian vegetation. Concerning reference to "debris torrent" in Swanston and Swanson, that was a case where the term had common use in the region, but without concise definition, and thereafter the community moved to use the internationally accepted term debris flow.
Answer quote 5: **Thank you for pointing this out. We corrected the statements, and removed the mention to "debris torrent".**

Technical corrections

Reviewer quote 1: Although the manuscript is very readable, it would benefit by some editorial assistance by a native English speaker.
Answer quote 1: **We reviewed the text.**

Reviewer quote 2: The name of the river is misspelled in the caption for Fig. 3.
Answer quote 2: **Many thanks for noticing it. We corrected it accordingly.**

<u>Reviewer 2</u>

Reviewer quote 1: This short communication with a video tape presents an interesting example of massive movement of large wood in a straighten channel. I think it is worth publishing this paper with the video tape. I agree with the authors who interpreted this massive movement of large wood pieces as "debris flow", and this may be the first paper and video tape which clearly showed us how large wood pieces interact each other in the front and rear parts, and how the phenomenon changes with the passage of debris flow.
I wonder how this massive movement can be sustained with a low-velocity of the front part and a high-velocity of the rear part (Figure 2). I can image that the large wood pieces of rear part are gradually conveyed and supplied to the front part like caterpillar mode, which may contribute to maintaining and developing the large wood-laden debris flow. If the authors discuss more about the above processes, it is very interesting.
Answer quote 1: **Thank you for this comment. It is difficult for us to provide a thorough interpretation of the process dynamics based on the video, but we added some more details on that in the text.**

Reviewer quote 2: The weakness of the present MS is there are no information regarding supply processes of large woods. The authors said that “virtually all transported logs were recruited from upstream reaches or mass wasting processes at the basin scale.” I think it is not so difficult to identify the approximate sources of large woods using drone or air-photos, or satellite images. The authors discussed the magnitude of event, but it should be varied with supply processes. This basin is mainly covered by bushes and bare land with very little precipitation (250mm per year), and forests cover only 16 % of the basin. I am very curious how these massive large wood pieces are produced by what kinds of recruitment processes.
Answer quote 2: **We thank the reviewer for this comment. Understanding the supply processes of logs at the basin scale during these types is definitely worth analyzing. However, the variety of recruitment processes with respect to different temporal and spatial scales is still a challenge to the quantitative prediction of LW transport during flood events. We tried to add deeper insights on that the manuscript, although this goes a bit out of the scope of this brief communication, mainly aimed at presenting the event and also describing salient features of its flow behavior.**

Brief communication: The curious case of the large wood-laden flow event in the Pocuro stream (Chile)

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Abstract. Large wood transported during extreme flood events can represent a relevant additional source of hazards that should be taken into account in mountain environments. However, direct observation and monitoring of large wood transport during floods are difficult and scarce. Here we present a video of a flood characterized by multiple phases of large wood transport, including an initial phase of wood-laden flow, rarely described in literature. Estimations of flow velocity and transported wood volumes provide a good opportunity for developing models of large wood congested transport.

1 Introduction

Large wood is widely recognized as a positive element of a river system as it increases its ecological properties and functions (Gurnell, 2013). On the other hand, it represents a source of potential risks for humans when transported during high-magnitude flood events (Lucia et al., 2015). Especially in mountain rivers, floods tend to be flashy, and are thus poorly investigated and rarely observed directly. During these types of events, large quantities of both sediments and large wood (commonly defined as logs $\geq$ 1.0 m in length and $\geq$ 0.1 m in diameter) are supplied into the channels and can generate serious harms to buildings and infrastructures within the river corridor (Lucia et al., 2015; Steeb et al., 2017). In order to assess and mitigate risks associated to large wood transport in rivers, it is crucial to properly understand the dynamics of wood during floods (Ruiz-Villanueva et al., 2016). In small high-gradient streams, logs are intrinsically more stable and tend to move only during high-magnitude events than in lowland rivers (Wohl and Jaeger, 2009), and the volume of logs transported depends on the land-use and mass wasting processes occurring at the scale of drainage basin and riparian areas along the river network (Lucia et al., 2015). Although empirical formulas have been developed for estimating the potential volume of wood transported during floods (e.g. Rickenmann,1997; Comiti et al., 2016), these are heavily dependent on wood supply conditions and of little predictive power, mainly due to the lack of field data. Indeed, field observations of large wood dynamics during floods are scarce. However, recent advances in monitoring techniques allowed to track or observe wood dynamics using metal tags (Iroumé et al., 2015), active and passive radio frequency identification tags (Schenk et al., 2014), GPS devices (Ravazzolo et al., 2015), and video cameras (Benacchio et al., 2017).

In this paper we report on an extreme flood event occurred in February 2017 in the Pocuro stream (Central Chile). The event was captured by a local resident with a smartphone and the video was posted on the social networks. The video shows that the front of the event was characterized by a large wood mass transport, more similar to a debris-flow than a congested transport of floating logs, a phenomenon which has only been ~~anecdotically~~ rarely reported in literature. Evidence on flow velocity and volume of large wood transported by the event has been gathered from the video. This dataset is presented in order to improve the current understanding of flood processes in forested mountain streams, and may represent a significant set of data to develop and test a numerical model able to simulate such extreme event.

2 Analysis of the 25th February 2017 event

In the second half of February 2017, a series of convective rainfall events occurred in central Chile, producing several flash floods in mountain rivers. These events resulted in considerable loss of properties, several villages had to be evacuated, and five people lost their lives. The event described in this work occurred on the Pocuro stream, a stream located near the city of Los Andes, approximately 60 km north of Santiago, on the 25th February 2017. At the study reach, the basin drains an area of 227 km^2, which is highly mountainous (minimum and maximum elevation of 870 and 3550 m a.s.l.). The basin is mainly covered by sparse bushes and bare land (73 %), and only 16 % of the basin is covered by forest. The mean annual precipitation in the basin is around 250 mm, with strong Mediterranean regime, although convective rainfall events in late summer are not uncommon in Central Chile.

The 25th February event in the Pocuro stream caused several problems of accessibility, access to drinkable water, and the loss of one life. The event was triggered by relatively intense precipitations (15 mm day^{-1} as registered by the Vilcuya station located within the basin). The event was recorded by a local resident using a smartphone, and the video was quickly posted on social networks.

The video was downloaded as MP4 file at the maximum possible resolution (see supplement material). Two weeks after the event, an intense field investigation allowed us to identify the exact position from which the video was taken (32°53’11.19”S – 70°35’18.99”W). Local residents reported that the event was flashy and characterized by huge amount of transported logs, not recalling the occurrence of secondary following surges or pulses of log transport. However, several interviewees reported that a similar event (albeit with significantly less amount of transported wood) occurred in 2016, without major adverse consequences on that occasion. The longitudinal profile and several cross-sections of the reach visible from the video were surveyed using a laser distance meter with clinometer and a prism pole. Also, a series of photos was taken using a drone survey. The reach was straight, and featured a regular trapezoidal shape (due to river engineering carried out the year before for flood protection purposes), with a slope of 0.04 m m^{-1} (Figure 1). A grid-by-number survey revealed that the channel bed had a D_{50} of 50.5 mm. High-water marks (i.e. wood deposits and marks left by mud) were clearly visible, and allowed to calculate that at the peak of the event the channel width was around 14 m, with a wetted area of about 25 m^2. The distances between four control points (boulders or distinct bushes clearly visible on the video and straightforwardly recognizable in the field) were taken using the laser distance meter.

The video was taken by looking two times at the upstream and downstream direction, respectively. For this reason, the full video was divided in four parts: a) looking upstream (0 to 45 s), b) looking downstream (45 to 61 s), c) looking upstream (61 to 84 s), and d) looking downstream (84 to 94 s). Two control points were always visible on each portion of the video (A-B and C-D, Figure 1). Control points A and B were used to calculate flow velocity for the portions of the video looking upstream, whereas control points C and D for the portions of the video looking downstream from the observation point (see Figure 1). The video lasts 94 s, but for the sake of the following analysis, the first 22 s (before the flow arrives to the upstream control point) were eliminated.

The freeware Pelscope software (www.codecian.com/pelscope.html) was used to produce frames at 3 Hz. Then, we identified features clearly visible on several frames (e.g. a distinctly coarser or protruding logs) in order to calculate the surface flow velocity.

3 Results and discussion

The video shows that a huge volume of logs was transported in the Pocuro stream, and that the arrival of the front of the event was very impulsive. The video reveals that ~~Indeed,~~ liquid discharge was almost negligible in the channel before the arrival of the large wood front. The ~~video shows that the~~ front was characterized by logs of different sizes, clearly moving as a mass pushed from behind, and not floating on water. ~~The~~ The front moved at a mean velocity of 4.7 m s^{-1} (Figure 2), and this first phase of the event was named wood-laden flow (WLF) for its appearance and behaviour. The front moved at a speed close to 5 m s^{-1} for approximately 12 s. After the first WFL phase, ~~, and then~~ the velocity increased sensibly (to around 5.8 m s^{-1}) for the following 16 s. During this second phase of the event (named congested wood transport, CWT), the surface of the log raft appears to feature waves, suggesting that the logs were floating on water, which would be consistent with the increase of mean velocity. On a third phase (called floating wood transport, FWT), the mean surface velocity was significantly higher (8.1 m s^{-1}). The logs were floating as a continuous raft, but occupying only a portion of the cross-section. The video does not allow to infer any information on bedload transport occurring during the event. However, post-event field observations revealed that the channel remained virtually unchanged after the flood, as little patches of herbaceous vegetation was still growing in most of the cross-section.

Based on a series of flume experiments, Braudrick et al. (1997) described the dynamics of log transport in rivers as congested, semi-congested and uncongested, being the first one reporting the case in which logs are floating with intense piece-to-piece interactions, and occupying more than a third of the channel area. In the case of the Pocuro stream, only the third phase of the event could thus be classified as congested transport, being the first two phases fundamentally different, and more similar to a mass or a debris flow-type of transport, with imbricated structure and partly collisional regime. Braudrick et al. (1997) presented a preliminary attempt to model the mobility of uncongested individual pieces of wood, highlighting the challenges in modelling complex interactions between logs, characterizing the congested transport mode. Although recent efforts in modelling allow to produce reliable 2-D description of individual logs entrainment, transport, and deposition in river system (e.g. Mazzorana et al., 2011; Ruiz-Villanueva 2014), the congested wood transport is far from being properly understood. Previous works reported that wood transport in mountain streams is likely to occur under congested conditions (Johnson et al., 2000), and that debris flows are important in supplying wood material to main rivers (e.g. Nakamura et al., 2000; Wohl et al., 2009). However, despite an some early mention to "debris torrents" events transporting large amounts of wood in highly-congested ways (e.g. made by Swanston and Swanson, (1976;) (see Ruiz-Villanueva and Stoffel, 2017) a proper description of a wood mass moving as a debris-flow has not been fully reported in literature yet (e.g. Ruiz-Villanueva et al., 2017). During the first phase of the event in the Pocuro stream (WLF), the mass of logs appeared not saturated with water, thus log collisional and frictional stresses might be expected to dominate, and the phenomena was likely moving as a rock avalanche. Also, the video shows that some longer elements appear to snag on the channel bed and act as pivoting elements, thus likely increasing fictional stress on the channel bed. Instead, during the second phase (CWT) the water content appeared much higher, likely increasing the solid-fluid interactions and the role of viscous forces in the motion of the mass. Current debris-flow models consider sediment the only component of the solid fraction, but logs can definitely play a major role in determining the rheology of these phenomena. Because the contribution of debris-flows to the wood budget of extreme events can be very relevant (see Lucia et al., 2015; Steeb et al., 2017), there is an urgent need to develop better models for large wood congested transport, and even more to consider large wood mass transport in the models.

The availability of the channel geometry and the mean velocity of the wood mass allowed us to estimate the volume of wood transported during the event. Even considering only the first two phases of the event (i.e. WLF and CWT), and assuming that a third of the cross-section was occupied by water, the estimated volume of transported wood is around 3680 m^3. This volume is remarkably high, provided that in a recent review, Ruiz-Villanueva et al. (2016) reported that large wood exported from basins > 100 km^2 generally ranges from 500 to 4000 m^3 (Figure 3). To put this value into perspective, the volume of large wood measured within the channel after the event accounts for only 0.3 m^3 per hectare of surveyed channel areaha^{-1} (mean log length and diameter of 1.53 and 0.08 m, respectively), which is well below other values available in literature for basins of comparable size (see Ruiz-Villanueva et al., 2016). All evidence This thus thus suggests that this was an extreme high-magnitude event, and that virtually all transported logs were recruited from upstream reaches or mass wasting processes at the basin scale, making the estimation of large wood transport from in-channel large wood deposition very difficult in these conditions. This evidence is in concert with recent studies (e.g. Lucia et al. 2015; Streeb et al., 2017), which proved that most of large wood transported during extreme events in mountain rivers were recruited from the basin, being thus the in-channel wood load a poor proxy for estimating potential hazards due to wood during extreme events. In the case of the Pocuro stream, further investigations on recruitment mechanisms could shed further light on the origin of the phenomena.

The video allows to appreciate that most of transported logs lacked fresh branches. Also, all of the logs found in the channel at the post-event surveys were not freshly recruited, and most of them were in an advanced state of decay. This would suggest that recruitment of tress from landslides and bank erosion was probably a minor source of logs during the event. Local residents claim that several tributaries in the lower part of the basin were left unmanaged and featured large volumes of in-channel wood, which was eventually transported to the main channel during the flood event. However, this should be verified in the field by assessing the presence and extent of mass movement or bank erosion that could have provided a fresh source of large wood during the event. Indeed, exploring the most likely sources of large wood at the basin scale would shed some light on the processes and temporality involved in the recruitment and transport of logs during the event.

It is also worth noticing that the massive amount of wood flushed during the event (3680 m^3) was transported within 29 s, which accounts for a mean wood transport discharge of around 85 m^3 s^{-1}. This value is virtually not comparable with any other in literature, as the transport of large wood is rarely observed and monitored, at least under congested transport conditions. To put it into perspective, the liquid discharge after the wooden front was calculated to be around 200 m^3 s^{-1} (and a 1-D simulation with Hec-Ras confirmed this value), so that more than a third of the average discharge of the rising limb of the event was composed by wood.

4 Final remarks

- To the best of our knowledge, this is the first reported observation of a wood-laden flow, i.e. an event characterized by congested wood transported not as floating material but as a rather dry mass of logs. These type of events can be very important in mountain environments due to their direct impacts on infrastructures and their contribution to wood budgets of lowland rivers, but are particularly difficult to observe and monitor as they are arguably flashy, impulsive, and highly unpredictable.
- There are multiples open questions about the genesis and the dynamics of the event, such as the origin of the logs (basin vs. upstream reaches or minor tributaries), the fate of the wood material, and the best hazards management strategy to be adopted, that are worth exploring in the area.
- The availability of channel geometry and surface flow velocity data provide an unprecedented opportunity to develop and calibrate models of large wood congested transport.
- Monitoring large wood transport in rivers is still very challenging. Recent use of active transmitters (Ravazzolo et al., 2015) or ground cameras (Benacchio et al, 2017) provided useful insights on the dynamics of logs during floods, but are still experimental. The present paper shows that conventional methods may be successfully complemented by participatory sensing (Michelsen et al., 2016), that despite some relatively minor issues (i.e., access to internet technology, geographic and demographic biases) offers an interesting alternative for collecting relevant information of infrequent events in remote areas.

Acknowledgments

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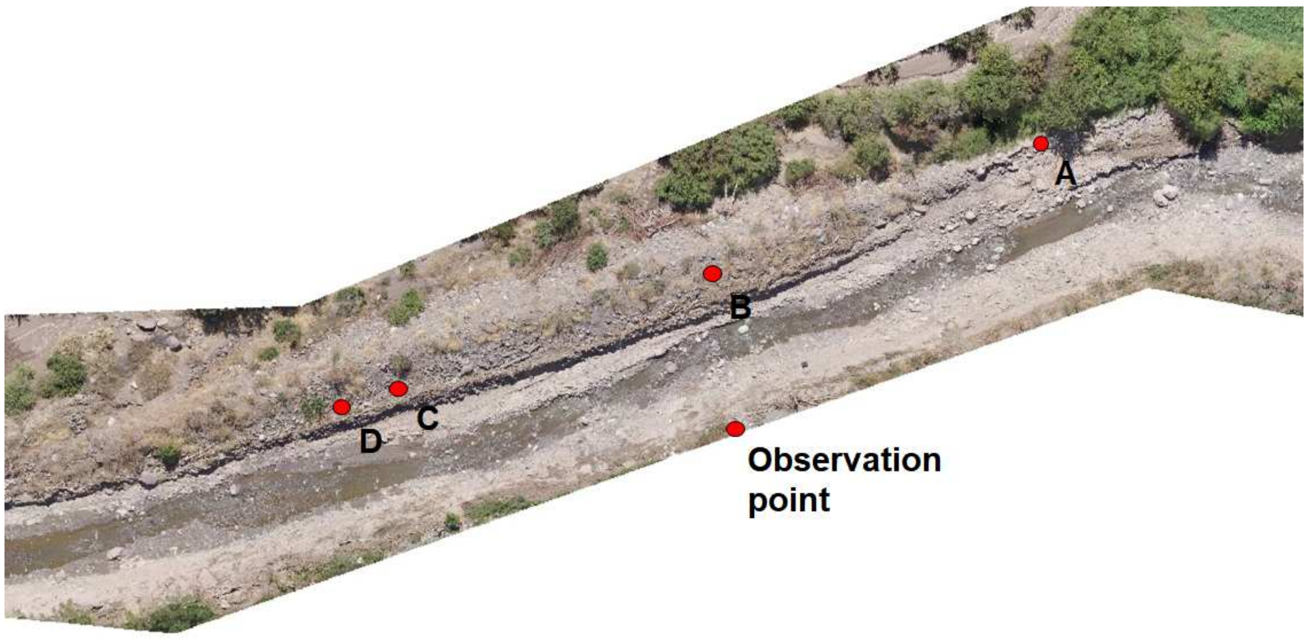

Figure 1: Composite image of the study reach of the Pocuro stream, showing the location of the point from which the video was taken, and the control points used to calculate the flow velocity. The flow is right to left.

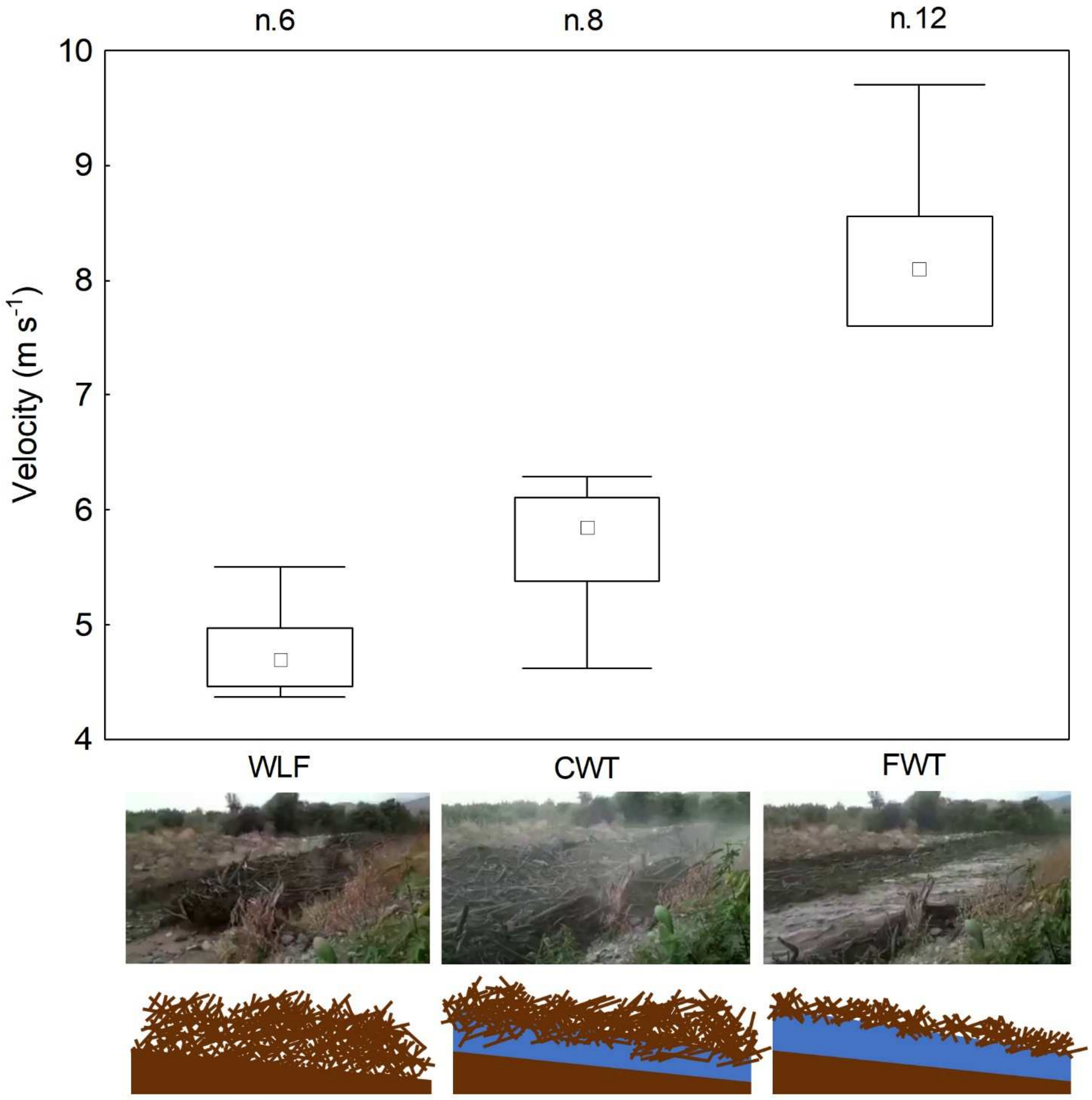

Figure 2: Mean velocity of three different portions of the event: a) in the front of the event, where logs where transported as a dry mass (wood-laden flow; WLF); b) in the middle of the event, where logs were highly congested but clearly floating on water (congested wood transport, CWT); and c) after the passage of the front, where logs were floating on water (floating wood transport, FWT).

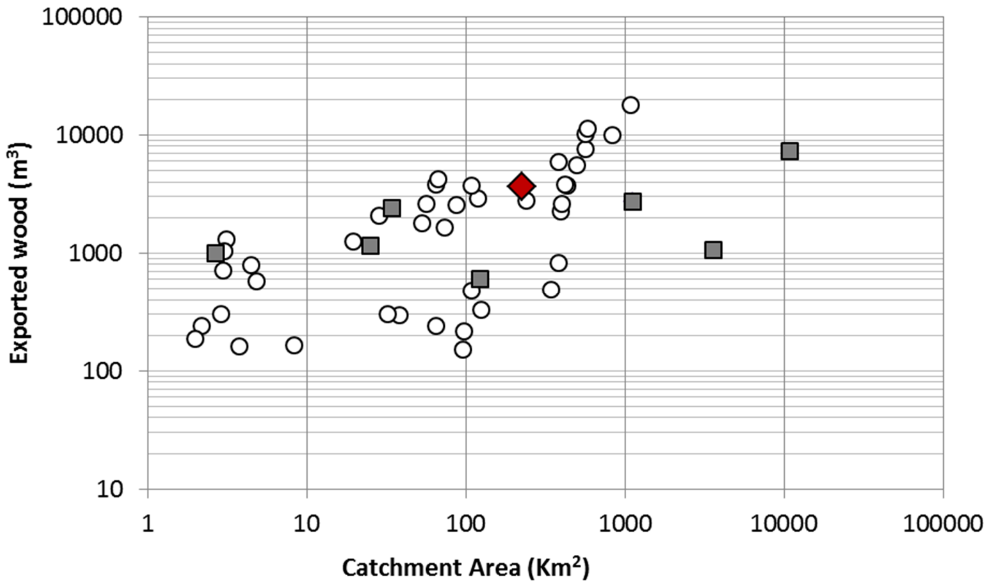

Figure 3: Large wood volume exported from different watersheds by single flood events. The figure is adapted from Ruiz-Villanueva et al. (2016) and include data presented by Steeb et al., (2017; white circles), and by a number of other sources (see Ruiz-Villanueva et al., 2016). The red diamond is the Pouucuro event.