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Interactive comment on "Rapid and objective characterization of channel morphology in a small, forested stream" *by* Carina Helm et al.

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Dear Associate Editor, and Reviewer 3:

Authors have responded to all comments below in full, with Reviewer 3 comments shown in bold, and responses as regular text. Notable new additions to the paper include sharpening of several methodological components of the manuscript.

REVIEWER 3 COMMENTS

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General comments
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This manuscript presents the results from an investigation to generate a high-resolution orthoimage / topographic survey of c. 3 km of channel that is beneath a forest canopy. The geospatial products are used to extract metrics to characterise channel morphology, which are subsequent used to characterise longitudinal variation in channel morphology and to assess these trends relative to those reported in wider literature. The survey effort is impressive and undoubtably novel in its ambition; I am not aware of a similar survey. However, there are aspects of the methodological description that are unclear. I also think that the authors are overselling the approach as rapid and are not sufficiently critical of how transferable the technique may be to other forested environments (e.g. where canopy densities vary, where launching the UAV from under the canopy may be more challenging, for forested rivers without unvegetated bars etc) and thus a more critical analysis of the technique could be provided. Below, I expand upon these aspects.

The authors are grateful for the constructive comments and detailed review from Reviewer 3. The authors have included text to sharpen several aspects of the methodology. Please see below for detailed responses to further queries.

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Specific comments
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Title. Is the technique really rapid? The survey effort is still considerable from

both a UAV flight and ground control perspective, and there are still some data gaps where total station survey is needed.

Relative to a dense total station survey, the authors considered the acquisition of continuous data to be rapid. As noted in the Discussion, with the RPA we could capture, on daily average, three times more of the channel's length than that covered with a total station full channel survey. However, relative to other approaches (such as an automatic level survey of the channels longitudinal profile, or RPA surveys done at a greater height above ground level), it may not be considered rapid. As this detail cannot be discerned from a short title, the authors accept the comment and have removed "Rapid" from the title for:

Characterization of morphological units in a small, forested stream using close-range RPA imagery.

L9-11. More methodological detail could be provided here; reading the abstract alone I'm not able to decipher what exactly how the imagery were used (orthoimage, DEM etc). Can you give examples of the "variables".

The authors accept this comment, and have incorporated the following text into the abstract:

"From this survey data, relevant cross-sectional variables (hydraulic radius, sediment texture and channel slopes) were extracted from high resolution point clouds and DEMs of the channel, and used to characterize channel unit morphology using a principal component analysis-clustering (PCA-clustering) technique."

L101. More details are needed on the total station control network and associated errors (e.g. closure errors from traverses). How accurate are the control points?

The total station survey was an open survey, as it was not feasible to re-survey the 3 km of channel to the close the traverse. Rather, the open traverses were tied into the benchmarks previously established in the study sections. This has been clarified with the following lines:

"Open survey traverses were tied into the benchmarks previously established in the study sections, and then an affine transformation applied to georeference the points in the XY-plane. The average offset between the benchmark elevations of the local open traverse and their known reference elevations were then used to georeference the points in the Z-plane. Errors were typically 2 cm in the XY-plane, and 1 cm in the Z-plane."

L101L104. How high was the canopy?

At the suggestion of Reviewer 1, we have added more details on the forest characteristics surrounding the channel in the study area section:

"The height of the riparian canopy is variable, between approximately 15 and 40 m."

Were the flight plans pre-planned or was the UAV operated manually? You are arguing that this is a feasible survey approach, so some more details on the logistical / technical challenges would be useful here. If you had a pre-

programmed flight, then could you obtain sufficient GNSS "lock" for navigation?

The flights were conducted manually as due to channel obstacles, and the channel being hidden below the canopy, pre-planning the flights would have been challenging. We have added more text highlighting this with the following lines in section 3.1:

"The RPA survey involved low-level flights (5–15 m above ground level) conducted in tandem with placement of ground control points (GCPs) on the dry exposed bars and checkpoints on both the exposed and submerged bed. Flights were operated manually as channel obstacles such as overhanging vegetation, and the fact that much of the survey was conducted below the canopy, would make pre-planning flights a challenge"

L135. Were any independent total station check points obtained to evaluate the accuracy of the bathymetric correction?

Yes independent total station check points were obtained for the evaluating the bathymetric correction. See our response to the previous comment where we have clarified that we did have submerged checkpoints. In addition, we have added the following text:

"A minimum of ten GCPs were placed along dry exposed bars in each of the 80 channel segments to provide precise image georeferencing, with additional points positioned on the dry exposed bars and below the water surface in order to serve as independent checkpoints, to assess the accuracy of the model outputs. All GCPs and checkpoints were surveyed with a Leica TPS 1100 total station."

The errors are further highlighted in Fig. 4.

L141. Insufficient detail is given on the photo-sieving technique and how images were acquired from 2 m above ground level. If topographic roughness was calculated then were the multiple images acquired to generate a point cloud using SfM? How was the point cloud georeferenced? What was the ground sampling distance to sample 0.0025 cm roughness (smallest sample on figure 3; this seems VERY small). Are the units correct here?

The authors accept this comment. We have clarified how the sample sites were photoseived, and how the point clouds were extracted, with the lines below:

"Each roughness sampling site was approximately 1 m2 and imagery was captured for photo-sieving by hovering the RPA approximately 2 m above ground level. Using an in-house photo-sieving program based in Matlab (Matlab, 2017), the grain size distributions of each training site were determined. The program loads the image, prompts the user to scale the image, and then overlays a grid with 50 nodes prompting the user to measure the B-axis of grains falling below a grid node. Point clouds for each sample site were then extracted from the georeferenced point cloud that was developed for the study section that they fell within. A linear model then was then fit between each sample's D50 (Fig. 3) and their mean roughness value."

The authors thank the reviewer for noticing the error in the x-axis units for Fig 3. Initially the units were in m, but the figure has been updated so that they are in cm.

Figure 5. It would be interesting to see elevation values for the raster. Why are bathymetry and elevation not mosaiced together (perhaps it is the legend labelling that makes this unclear)? For SA5, what explains the abrupt change in

bathymetry value (shown as a vertical line) in approximately the middle of the reach?

The intention of Fig. 5 was to show the relative coverage between the RPA survey and total station surveys. Elevations vary from around sea level at the mouth of Carnation Creek to about 140 m.a.s.l at SA9. This wide range in elevations would require each SA have its own colour bar to effectively be able to visualize patterns in elevation. Therefore, the terrain of the bed was instead shown as a hillshade layer to show patterns in bed texture without resulting in a busy figure that may take away from the Figure's purpose: to show the coverage with the RPA relative to the total station surveyed boundaries. Instead, Figure 9 was included which shows patterns in elevation along a section of the channel.

Fig. 4 in the manuscript shows that the majority of the approximatley 1700 checkpoint errors were on the cm scale, indicating situations such as that observed in SA5 are outliers in the larger survey effort. Visual inspection of the point cloud reveals that this area, which is characterized as having dense low-lying vegetation on the fringe of a new survey section, had a lower density of points, suggesting there may be issues with the DEM produced. It should be noted that a strength of the PCA is that it highlights patterns in a dataset, and not potentially noisy areas as in SA5. In other words, although in the 3 km of channel there may be some anomalous values from poorly aligned sections, these "outliers" should not affect the general trend identified by the PCA . Text has been added to the manuscript highlighting these points in the following sections.

In the "Utility of sub-canopy RPA surveys for small, forested streams" section, we have clarified our sentence on image capture difficulties with:

"In addition to bank vegetation causing obstructions, submerged areas with poor texture and low-hanging branches (predominantly from riparian deciduous species) occasionally led to flight difficulties that prevented sufficient collection of imagery for photo-stitching."

In the "Assessment of classification approach" section, we added:

"Another advantage of the PCA is that it highlights the trends present in a dataset, rather than focussing on specific features. For example, anomalous areas where imagery may have had stitching issues due to poor coverage would likely appear as noise, thereby having a minimal influence on the PCA."

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