Specific Comments

Line 1: This introductory sentence and overall beginning of the paper could be more inviting, especially given the well-written abstract and standard of writing in the rest of the manuscript.

Response: We are thankful for the comment. We have updated the first paragraph by adding information on the role of flow for abiotic and biotic processes, as well as on the importance of studying turbulent wakes in shallow flows. Respective references were also added to the reference list.

Original:

Modern science perceives the diversity in fluvial ecosystems in a context of a tight link between spatial heterogeneity in environmental factors and biota. Central to this topic is the flow heterogeneity produced by natural in-stream obstructions such as boulder clusters, log jams, patches of riparian and aquatic vegetation. Flow patterns evolving around these obstructions are conventionally referred to as turbulent wakes (Cimbala et al., 1988; Chen and Jirka, 1995; Takemura and Tanaka, 2007; Zong and Nepf, 2011; Chang and Constantinescu, 2015; Chang et al., 2017, 2020).

Modified:

Flow is the governing factor in rivers, influencing redistribution of energy, materials and living organisms within river networks (Sponseller et al. 2013). Natural obstructions present in rivers such as boulder clusters, wood jams, patches of riparian and aquatic vegetation heterogenize the fluvial environments. Flow patterns evolving around such obstructions are conventionally referred to as turbulent wakes (Cimbala et al., 1988; Chen and Jirka, 1995; Takemura and Tanaka, 2007; Zong and Nepf, 2011; Chang and Constantinescu, 2015; Chang et al., 2017, 2020). Understanding mechanisms behind their formation will help to address the fundamental questions related to river morphology, sediment dynamic, potential impacts on biota and, consequently, for assessment and restoration of rivers (e.g. Gurnell et al., 2012).

Line 55: Tsujimoto (1999), Follett and Nepf (2012) and Chen et al. (2013, W09517) have all observed downstream fine sediment deposition experimentally. In addition, the diversion of the side streams and eventual downstream join may form a half-lemniscate shape, but fine particle deposition in the steady wake region takes a triangular shape (Tsujimoto 1999, Photo 3; Follett and Nepf 2012, Figure 5b and Figure 6).

Response: We added references to the studies that observed particle deposition in the steady wake region in the laboratory conditions. As for the sediment deposition observed by authors on river floodplains, it is difficult to define their form as classical triangular due to higher degree of inhomogeneity in the shape of in-stream objects. Therefore, we specified that on floodplains depositions more often attain longitudinally extended half-lemniscate shape.

Original:

These wakes are characterized by a steady region within which the velocity deficit at the centerline does not change with longitudinal distance. This region promotes deposition of fine sediments which takes a shape of a half-lemniscate with considerable longitudinal spatial scales that define the floodplain's morphology (Figure 1d).

Modified:

This region promotes deposition of particles, which takes a triangular shape as observed in laboratory experiments (Folett and Nepf, 2012 (Figures 5b and 6), Tsujimoto, 1999 (Photo 3)). On river floodplains such depositions of fine sediments more often take a shape of a half-lemniscate with considerable longitudinal extension that defines the floodplain's morphology (Figure 1d).

Line 53/Figure 1: I cannot identify the vortex street in Figure 1b; visually this seems very similar to Figure 1a. Please clearly show the delayed onset of the vortex street as described in Line 53.

Response: We have showed the onset of the vortex street in Figure 1b with arrows. We also clarified in the main text that for this case the onset is delayed.

Line 60: The driftwood aspect (first noticed in Line 118) could be brought out here a bit—otherwise it is difficult to see the difference between "idealized geometries" and the experimental obstructions used.

Response: we explained what is meant with "idealized geometries" here. We also emphasized that natural obstructions such as accumulation of driftwood on river floodplains have inhomogeneous structure, which is difficult to reproduce during experiments.

Original:

Although in recent years there was evident recognition of the importance of wakes for natural fluvial environments (MacVicar et al. 2009, Bertoldi et al. 2011, Gurnell et al. 2012), there is a general lack of detailed field data on such wakes because most previous numerical and experimental studies were mainly carried out for idealized geometries. Only few such studies included a field component (e.g. Euler et al. 2012).

Modified:

Although in recent years there was evident recognition of the importance of wakes for natural fluvial environments (MacVicar et al. 2009, Bertoldi et al. 2011, Gurnell et al. 2012), there is a general lack of detailed field data on such wakes. Most previous numerical and experimental studies were mainly carried out for idealized geometries with defined characteristics of the obstruction, bed material and channel setup to minimize artefacts related to the scale effects. In contrast, natural obstructions often have inhomogeneous structure (e.g. accumulations of driftwood after floods). Field component was included only in few studies (e.g. Euler et al. 2012, Sukhodolov and Sukhodolova, 2014).

Figure 2a: what is the wooden apparatus? It is not perfectly perpendicular to the sidewalls and obstruction in the photo; would this have influenced the dataset?

Response: it is true that in this photo the lateral structure looks from above non-perpendicular to the sidewalls (we suppose this is what was the questions of a reviewer). This was made on purpose for this photo in order to avoid visual overlap with measurement cross-sections 1-10. During actual measurements the platform was positioned perfectly perpendicular to the side walls and parallel to the predefined cross-sections.

Line 112: What were the relevant survey results that led you to the choice of obstruction diameter?

Response: sentence clarified as follows:

The choice of the diameter of model obstructions was made based on preliminary topographical surveys of riparian vegetation on the floodplain of the Tagliamento River (measurements of vegetation patches diameter with total station, details are not presented in this manuscript and data set but planned to be included in the analysis of these experiments).

Line 114: Do you think this distance was adequate to eliminate entrance effects? Why?

Response: Yes, we think that the distance is adequate to eliminate the entrance effects. The preliminary studies completed with mixing layers with the similar experimental setup on the same river reach (Sukhodolov and Sukhodolova, 2019) show that the riverbed roughness suppresses the lateral growth of a mixing layer at distances around 20h, or about 6 m for this setup. That means that the mixing layers forming at the entrance of the in-stream flume do not grow, but decay at the distances of about 30-40h due to the friction of the riverbed. On the other hand the distance of about 30h is sufficiently long for the bottom boundary layer to be fully developed. Furthermore, the flow entering the flume is already naturally fully developed. We have also mentioned that entrance effects were eliminated in the main text.

Figure 3: Was the channel shallower near the sidewalls, as it appears in photo? If present, how would the bed variation have affected the velocity profile?

Response: The differences in depth across the total span of the in-stream flume were about 5 cm, which is about 10% of average depth. So we expect a slight decrease of flow velocity near the sidewalls, which is more strongly affected by the friction on the walls rather than by depth difference. However, because the walls of the flume were smooth, the sideward boundary layer is quite limited in the lateral extension, which is manifested by the higher degree of lateral homogeneity of flow in the larger portion of the experimental setup.

Line 165: how is high quality defined?

Response: by high quality we mean that measured records had good signal-to-noise ratios and contained no spikes potentially caused by large particles drifted in the proximity and interfering with measuring volume of the devices. We have clarified this also in the main text.

Modified text:

The instantaneous three dimensional velocity vectors were measured during four to ten minute periods to ensure high quality records of 60 to 500 seconds long (good signal-to-noise ratios, absence of artefacts potentially caused by drifted particles in the proximity of device measurement volume).

Line 192: How did you ensure the camera optical axis was perpendicular to the free surface?

The drone sets the camera flat to the horizontal plain in the lowermost position by adjusting its vertical orientation with compass and tilt sensors. The compass and tilt were calibrated for the specific area before the flights. The flights were performed mainly when the effects of wind were small and the drone had no compensatory tilt for hovering when holding the position. The position for drone was selected at the central location of the setup and the height was adjusted to fit the whole length of setup in the view. Because barrel effect of the lens in this drone camera is excluded the camera had no oblique view and no rectification of images was needed on the post-processing. The accuracy was checked by using about 80 check points geo-referenced with a total station.

Modified text:

The optical axis of the camera was perpendicular to the water surface (positioned via compass and tilt sensors).

Line 204: Does the 1 cm threshold describe the fluctuations of water stage over time, or space? The variation of the free surface in Figure 5 seems to show 2 cm magnitude variation of the free surface—please clarify.

Response: we have clarified that fluctuations of water stage should not exceed a 2 cm threshold over time.

Modified text:

The hydraulic conditions for the period in which the experiments were conducted were relatively stable and measurements were postponed when fluctuations of the water stage over time exceeded a 2 cm threshold.

Technical Corrections

Line 35: approximately less than or equal to 0.2

Response: corrected

Line 36: therefore (not thereby)

Response: corrected

Line 36: prototype does not quite work here-perhaps type, class, regime?

Response: “flow prototype” was replaced with “flow pattern”

Line 37: consistent use of “the” in the list items

Response: corrected, “the” was deleted in the list items

Lines 40-45: Rominger and Nepf (2011) may be appropriate for the sentence ending in …vertical axes of rotation. This paper has a good example of 2D circulations such as those described.

Response: thank you for the suggestion, we added the reference.

Line 45: The sentence beginning with “Besides…” is confusing. Specifically describing the “features that are typical for shallow wakes behind bluff bodies” would help, e.g. “In addition to the occurrence of a von Kármán vortex street…”

Response: we corrected sentence beginning with “Besides…” as follows:

In addition to the occurrence of a von Kármán vortex street typical for shallow wakes behind bluff bodies, these wakes exhibit additionally a so-called “bleeding flow” - the flow through the structures.

Lines 47-49: This sentence is also vague. Do you mean relatively weaker vortices compared to solid obstructions of the same size? Please be as specific as possible in this section so readers who are not familiar with patch hydrodynamics can understand your later work.

Response: we have modified the current paragraph to make it clearer for the broad audience not familiar with specifics of patch hydrodynamic. Particularly, we highlighted that porous structure of natural obstructions in rivers (vegetation and woody debris) affect flow patterns behind them. The updated paragraph is given below after the next comment.

Line 53: The sentence starting with “These wakes are characterized…” is confusing in light of the list in the previous sentence. Is a steady wake present even in 1c? If a vortex street is present “similar to that behind a solid body” (Zong and Nepf 2011 F10b) then why would a steady wake be present? If a steady wake is present in both 1c and 1b, then how do these classifications differ?

Response: We have clarified that steady wake is present in the figure 1b. We have also introduced a definition of a steady wake in the text.

Modified:

Natural rivers are characterized by presence of porous obstructions such as woody debris or patches of riparian/aquatic vegetation. Consequently, porosity affects structure and dynamics of wakes formed behind these obstructions. In addition to the occurrence of a von Kármán vortex street typical for shallow wakes behind bluff bodies, these wakes also exhibit a so-called “bleeding flow” - the flow through the structures (Cimbala et al., 1988; Chen and Jirka, 1995). Relationships between the volume of solid fraction of the obstruction (Φ) and flow pattern formed downstream were studied in the laboratory experiments by Zong and Nepf (2011) and numerical experiments of Chang and Constantinescu (2015). Three flow patterns for assemblages of emerging vertical cylinders were identified: (1) no vortex street associated with the porous obstruction ($\Phi < 0.05$, Figure 1a), (2) steady wake followed by vortex street ($\Phi < 0.15$, Figure 1b), and (3) vortex street similar to that behind a solid body ($\Phi > 0.15$,

Figure 1c). Steady wake (Figure 1b) often can be observed on natural floodplains. This flow pattern is characterized by a region with steady streamwise velocity, which does not change with longitudinal distance behind the obstruction (e.g. Figure 1b shows a steady wake region with delayed formation of a vortex street). This region promotes deposition of particles, which takes a triangular shape as observed in laboratory experiments (Folett and Nepf, 2012 (figures 5b and 6), Tsujimoto, 1999 (photo 3)). On river floodplains such depositions of fine sediments take a shape of a half-lemniscate with considerable longitudinal extension that defines the floodplain's morphology (Figure 1d). These depositions also support biodiversity and biogeochemical functioning of floodplain ecosystems (e.g. Bätz et al. 2015; Franzis et al. 2011; Mardhiah et al. 2014).

Line 92: bed surface

Response: corrected

Figure 2a: The obstruction in (II) is not visible easily, perhaps you could circle it or reduce transparency/width of the other marker lines; I assume III is a needle weir (not II as listed); please briefly describe operation of the needle weir; white dashed lines are locations of lateral profiles;

Response: we have highlighted location of the obstruction with additional dashed circle. We corrected that "III" is a needle weir. Principle of the needle weir operation was described in the text a follows:

Additional text:

In the right branch of the stream, a needle weir constructed from plastic plates leaned against a wooden frame was installed (Figure 2a). The approach flow velocity in the in-stream flume was regulated by adding or reducing number of plastic plates, which allowed controlling the degree of flow obstruction.

Line 115: isn't n the number of dowels/cm2 and then $a = nd$ =dowels/cm2*cm/dowel?

Response: Here $n = \frac{1}{cm^2}$,

$$a = nd = \frac{1}{cm^2} * cm = \frac{1}{cm},$$

$$\Phi = ad = \frac{1}{cm} * cm = 1.$$

Line 116: Please clarify that this relationship is true for circular cylinder elements only.

Response: respective sentence was corrected as follows:

The density of the dowels within the obstruction models is defined by the number of dowels per unit bed area, n (cm^{-2}), the frontal area per unit volume, a = nd (cm^{-1}) and the average solid volume fraction, $\Phi = n\pi d^2/4 \approx ad$ (for circular cylinder elements) (Zong and Nepf, 2011).

Line 117: "corresponds in the most detail…" please specify that the solid volume fraction is the same "corresponds to cases with equivalent ϕ in Zong and Nepf 2011"

Response: respective sentence was corrected as follows:

This choice corresponds to cases with equivalent Φ examined in the most details as part of the laboratory experiments of Zong and Nepf (2011),…

Figure 3: The arrow showing flow direction does not look perpendicular to the obstruction. Is this a correct representation of flow direction? If so please discuss the flow angle in the text.

Response: We suppose that the reviewer mean the white arrow in the Figure 4a. Here the white arrow is used to help readers visually understand direction of the flow. It does not represent the actual flow angle with regards to the obstruction.

We added respective note to the description of the Figure 4a:

Measuring frame and setup: (a) floatable platform (1 is the lateral platform, 2 is a float, 3 is a deployment mount, 4 is a porous emerged obstruction), white arrow shows flow direction,…

Line 137: Please specify that floats were placed on ends of structure near flume "sides"—I was concerned that float presence may have impacted the flow profile but this isn't the case from F3b

Response: Locations of floats during measurement were specified in the section 3.1. as follows:

During measurements, left side float was placed outside of the flume close to its wall, ensuring that floats will not affect velocity profiles. During measurements both end sides of the platform were stationary fixed to the bottom with the anchoring uprights.

Line 165: four to ten minute periods

Response: corrected as suggested.

Line 207: 'amount of collected data' is vague, please clarify.

Response: we have specified that with amount of collected data we mean number of longitudinal and lateral sampling locations:

The experimental runs were identical in terms of instrumentation and measurement protocols, though differed in the amount of collected data (number of longitudinal and lateral sampling locations, for details see section 3.2).

Line 209: complemented

Response: corrected