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Technical Communication

A new sampler for extracting bed material sediment from sand and gravel beds in navigable rivers

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Abstract

Grain-size distributions of bed material sediment in large alluvial rivers are required in various scientific and management applications, but characterizing gravel beds in navigable rivers is hampered by difficulties in sediment extraction. The newly developed and preliminarily tested sampler reported here can extract sediment from a range of riverbeds. The 36 × 23 × 28 cm stainless steel toothed sampler is deployed from and dragged downstream by the weight of a jet boat, and it improves upon previous samplers that are unable to penetrate gravel bed surfaces, have small apertures, and/or cannot retain fine sediment. The presented sampler was used to extract 167 bed material sediment samples of up to 16 kg (dry weight) with an average sample size of ~6 kg from 67 cross-sections spanning 160 river kilometres along the Sacramento River. It was also tested at three sites on a subaerial bar to compare surface, subsurface, and sampler distributions. Sampler penetration is ~5 cm. The device collects individual samples that satisfy the criterion for bed material sediment whereby the largest particle comprises no more than 5% of the total sample mass in gravel and sand beds, except where the degree of surface armouring is large (e.g. armor ratios >> 2) and where more than 10% of bed material sediment is composed of grains larger than 64 mm. When aggregated samples exceed 15 kg, all satisfy the criterion whereby the largest particle comprises no more than 1% of the total sample mass. Samples closely resemble surface size distributions, except where armouring is strong. The sampler should be subject to more rigorous field testing, but many of its current limitations are expected to become negligible with the advent a larger, heavier version of the sampling device. Copyright © 2008 John Wiley & Sons, Ltd.

Keywords: bed material sampling; navigable rivers; aquatic habitat; downstream fining

Introduction

Grain-size distributions of bed material sediment are required in applications ranging from habitat mapping, calibration and validation of sediment transport models, spatially explicit sediment routing, and testing theories of longitudinal and cross-steam sediment sorting. Various methods and samplers have been developed to extract samples from sand bed rivers (e.g. (Ashmore *et al.*, 1989; Queen *et al.*, 1990)). However, characterizing bed material sediment from gravel river beds is hampered by difficulties in sediment extraction.

A number of samplers and sampling methods have been developed to obtain sediment from gravel river beds in wadeable streams (refer to (Bunte and Abt, 2001) for a review). Navigable rivers present a different set of challenges, particularly if the area of interest spans the transition from sand to gravel. In such rivers, a boat-based apparatus is necessary with a sampler capable of penetrating a gravel bed several metres below the water surface. The sampler must have an aperture and volumetric storage large enough to accommodate the coarsest grains in the bed, while limiting the escapement of finest material that is of concern to the researcher or manager.

In the absence of such an apparatus, field scientists and managers generally opt for grid-by-number or random walk counts (Wolman, 1954) and/or bulk sediment samples on exposed river bars (e.g. Rice and Church, 1998) of larger rivers. However, it is not clear whether bar sediments are appropriate for documenting sediment undergoing active processes of sediment transport and sorting in all settings. For example, bars in a degrading fluvial system may represent a relict landform of the river where sediment transport is no longer active. Consequently, bed material grain-size distributions obtained for such inactive subaerial bars and the adjoining subaqueous channel bed may differ for a given cross-section, potentially complicating sediment transport computations or aquatic habitat assessments.

Early work on bed material sediment characterization in navigable rivers suggests the use of dredge-type samplers (e.g. Tennessee Valley Authority *et al.*, 1940). These include clamshell and drag bucket samplers deployed from boats in early surveys of the Mississippi and Missouri Rivers. The former are commonly used for sampling soft beds of sand, silt, and/or clay (Ashmore *et al.*, 1989). Clamshell samplers, such as the Ponar Dredge Sampler (Wildlife Supply Company), are lowered via winch to the bed (aided by weights) in the open position where a spring loaded pin is released causing the metal scoops to bite into the bed. They function well in mixed sand and gravel beds with matrix support, but fail when the spring-loaded scoops close on a clast resulting in sample loss, or when clast-supported beds prevent penetration and trigger the pinch-pin to release upon contact, resulting in no sample. These two factors limit their usage to regions of river downstream of the gravel–sand transition.

The industry standard bed material sampler in the USA (according to the Federal Interagency Sedimentation Project, FISP), the BM-54, is a variant of the clamshell sampler called a rotating bucket that contains weights for bed penetration, fins for stability, and can be triggered to close on a sample by slackening the line. However, the ~45 kg 'BM-Series' sampler is also unable to penetrate gravel beds because it relies on its downward weight alone. Furthermore, the aperture of the sampler (8 cm × 7 cm) is too small to accommodate relatively coarse (e.g. >32 mm) bed material, making it unsuitable for sampling sediments in gravel-bed rivers.

Drag bucket samplers, although once common for bed material extraction in USA rivers (Tennessee Valley Authority *et al.*, 1940), were never standardized by FISP for use in riverbeds, although they are certified for Government use in sediment sampling sand beds in Canada (Ashmore *et al.*, 1989). These samplers are weighted buckets equipped with a cutting edge that are dragged upstream or downstream by boat. Apparent problems with early bucket designs include poor penetration of the bed, small sample size (less than a few kilogrammes (Church *et al.*, 1987)), and small aperture, none of which posed problems for early sampling excursions in sand-bedded rivers, but which severely limit their use in gravel-bed rivers. The only known variant of a drag bucket sampler appropriate for gravel beds was applied in rivers of Papua New Guinea (Pickup, 1984). However, the so-called Purari sampler, a 35-kg pipe dredge with 15-cm diameter aperture, has an opening too narrow to allow proper characterization of gravel-rich beds and was unable to trap fine sand, silt, and clay in its field tests (Pickup, 1984).

In order to collect grain-size distributions of sand and gravel bed sediments in navigable rivers, I developed a variant of the drag bucket sampler that improves bed penetration and increases sampler aperture to extend its applicability to gravel beds. The sampler is: (1) deployable from small watercraft in 1–15 m deep water; (2) penetrates gravel beds to extract sediments; and (3) obtains relatively large-volume samples and thereby accommodates a large range of grain sizes, decreases sampling efforts over a large geographical area, and limits the escapement of fines. The need for such a sampler is outlined in several prior studies (Church *et al.*, 1987; Billi and Paris, 1992; Edwards and Glysson, 1999).

The New Sampler

The sampler design is loosely based on the Danforth anchor, which contains a rotating bar that, when pulled in the downstream direction, forces the flukes of the anchor into the bed. The 36W × 23H × 26D cm stainless steel toothed Cooper Scooper weighs 29 kg and is deployed from and dragged downstream by the weight of a jet boat, which forces the rotating centre bar (connected to a rope line in the boat) to align the sampler in the downstream direction. This downstream force assisted by lead weights affixed to its butt (Figure 1) causes the teeth to penetrate the bed surface and the sampler mouth to dig into the bed. The force of the sampler penetrating and sticking into the bed can be felt on the rope line held by a person in the boat (much as an anchor locks a boat's position). Upon penetration, the line operator lets out slack and the boat motors to the spot above the embedded sampler. The sampler is lifted vertically by the line operator maintaining the sediment in the sampler and hoisted to the water surface via a system of pulleys. The Cooper Scooper is then clipped into a winch and boom assembly by which it is brought aboard and emptied by hand. Sampler operation on a sand and gravel bed in subaqueous conditions can be viewed in a supplementary video (Supporting Material).

Field Tests

The Cooper Scooper was preliminarily tested in gravel beds at 67 cross-sections (generally three samples across each section) of the Middle and Upper Sacramento River in California, spanning ~160 river kilometres. In the channel, the

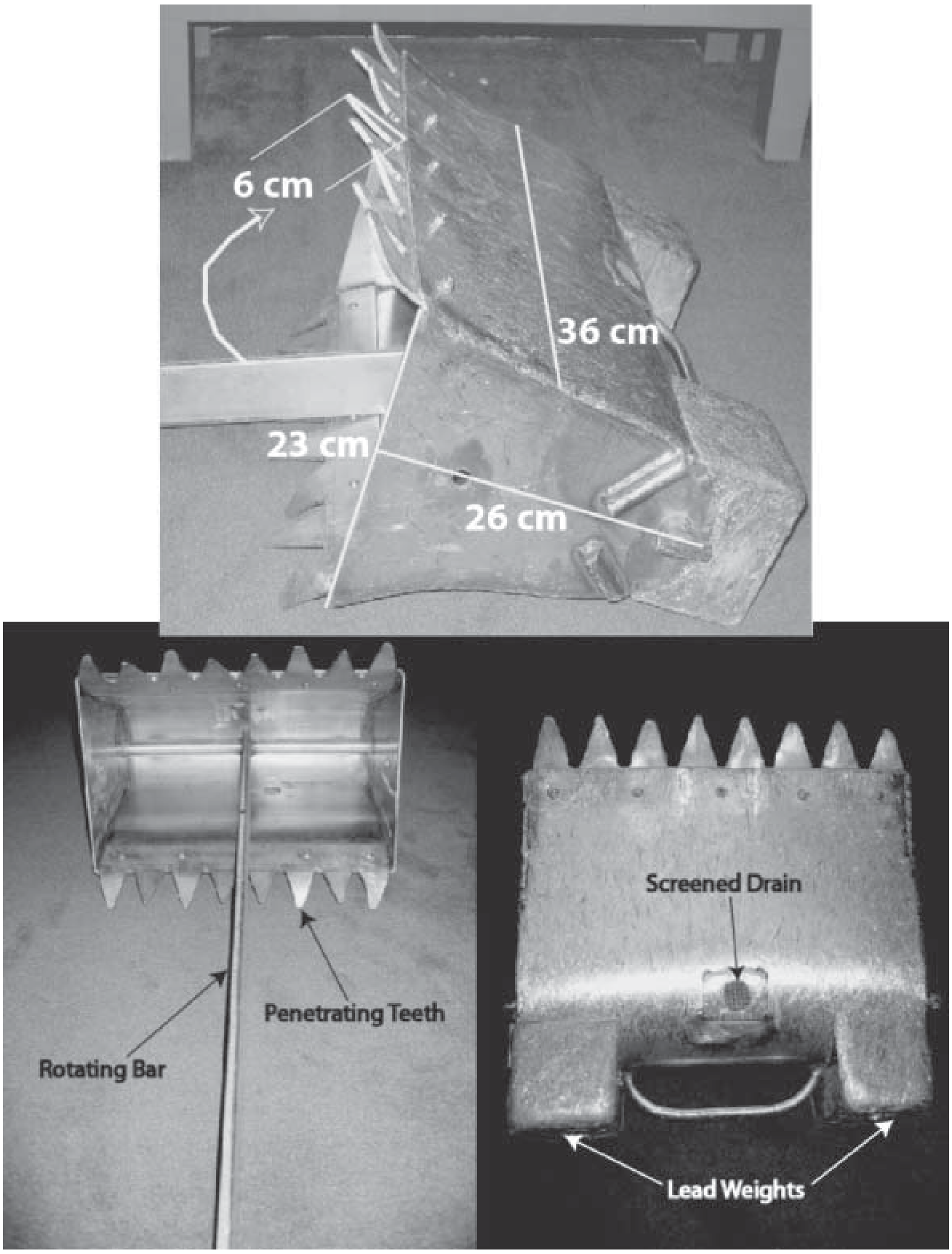

Figure 1. Upper: stainless steel Cooper Scooper dimensions. The rotating bar is 92 cm long. Lower: primary features of the Cooper Scooper.

sampler was deployed from a 6 m North River Osprey inboard flat-bottom jet boat owned and operated by the California Department of Water Resources. Samples were removed from the sampler by hand and bagged for subsequent drying, sieving, and weighing.

As a proxy verification of sampler efficacy for subaqueous beds, the sampler was also tested on a subaerial bar along the Sacramento River, in order to determine which population of sediment the Cooper Scooper collects for varying surface grain-size distributions. For each of three predefined and visually consistent areas of surface grain size, three sets of analyses were performed: (1) a Wolman count of 100 randomly chosen pebbles of surface material; (2) sieve analysis of subsurface grain size (extracted via Cooper Scooper with the surface layer removed); and (3) sieve analysis of a drag sample on the undisturbed bar surface collected via Cooper Scooper. It is worth noting that I conducted 100 pebble Wolman counts at each site, instead of the 400 recommended by Rice and Church (1996), to narrowly limit the area over which I was sampling and thereby remain consistent with the sample area covered by the Cooper Scooper. I sampled down to 2 mm within the area of interest with careful practice (i.e. randomly placing a sharp pen point to the bar surface with eyes averted (Leopold, 1970), spotting the selected grain and collecting it for measurement), in contrast to the findings by Fripp and Diplas (1993) that grains smaller than 15 mm cannot be characterized. There was no apparent bias introduced by using the Cooper Scooper for the subsurface material, as it appears to function similar to a shovel when there is no framework support.

In collecting a subaerial Cooper Scooper sample, a downward normal force was applied to the sampler (in addition to pulling it in the downstream direction), in order to simulate the force from the downstream weight of the boat and the weight of the water over the sampler. Drag distances and penetration depths were also measured for each Cooper Scooper sample. All channel and bar samples were dried and sieved at full phi sizes ranging from 0·063 to 128 mm.

Results

Subaqueous channel field test

I extracted 167 bed material samples of mixed gravel, sand, and fines at each location from regions of the river channel that were formerly inaccessible to bed material samplers. In total, I obtained more than 1 metric ton dry weight (mean sample weight = 6·1 ± 3·7 kg, maximum = 16·2 kg, minimum = 0·1 kg).

Church *et al.* (1987) recommends that the largest grain comprise less than 0·1% of the total sample mass, but suggests a relaxed 1% criterion when particles coarser than 32 mm are present. Only 36% of all the Sacramento River bed material samples and 50% of all section aggregates satisfied the 1% criterion. Given the logistical difficulty of obtaining samples that satisfy the stringent Church *et al.* (1987) criterion, various studies have aimed to limit sampling efforts (e.g. Rice and Haschenburger, 2004; Haschenburger *et al.*, 2007). In challenging sampling conditions (e.g. from a boat), a relaxed criterion for unbiased grain-size estimates is necessary to obtain a sufficient number of samples that span a large study area and there is new encouraging data, suggesting that this is reasonable in matrix-supported beds (Haschenburger *et al.*, 2007). Mosley and Tindale (1985) outlined a criterion wherein the largest particle makes up no more than 5% of the total sample by mass. I adopted this 5% criterion for individual samples and those aggregated for a given cross-section. I also evaluated how much sediment needs to be collected by the Cooper Scooper to satisfy the Church *et al.* (1987) 1% criterion, which is the inverse of determining a priori the volume needed to satisfy the criterion as Church *et al.* (1987) advocate (i.e. in their figure 3.9).

Based on average weights of the largest particles in each grain size class, I computed a representative mass of the largest grain in each sample. For example, the largest particle in grain size class 64–128 mm is assumed to weigh 250 g. According to this method, the largest grain in 77% of all samples extracted using the Cooper Scooper made up ≤5% of the total sample dry weight. The remaining samples (23%) were either small in dry weight (<5 kg), very coarse (containing a population of grains >128 mm), or both. Thus the tested version of the Cooper Scooper systematically retrieved satisfactory (for the 5% criterion) samples when >5 kg of bed material is extracted from beds that contain sediments <128 mm. In addition, when samples from each cross-section were combined, 93% of aggregate samples were satisfactory according to the 5% criterion. Sediments from the remaining 7% of cross-sections were relatively coarse (containing a high proportion of sediment larger than 32 mm).

It is encouraging that all section aggregates with dry mass greater than 15 kg (containing no particles coarser than 128 mm) meet the 1% criterion. This suggests a data collection strategy appropriate for obtaining bed material samples that satisfy the 1% criterion in the tested river could be based on three samples across a section or three replicate samples at a single location each consisting of at least 5 kg of sediment, a fraction of the sample size recommended by Church *et al.* (1987) to satisfy their criteria.

Sediments extracted by the Cooper Scooper span a wide range of grain sizes (Figure 2). A small amount of fines ($D < 0{\cdot}063$ mm) is lost into suspension in the process of lifting the sampler from the bed (evident in underwater video of sampler operation, Supporting Material). However, the presence of fines in many samples (as much as 820 g in one sample of 5·5 kg) indicates that fines get trapped in the interstices of coarser sediments within the sampler and are held there throughout the journey to the water surface. This occurs despite the fact that screens installed on the two side drain holes (Figure 1) have a mesh size of 0·063 mm. It should be noted that the sampler was not designed to retain the finest fractions of the bed material because they are not generally present in large quantities. However, it indicates that the Cooper Scooper could be modified to obtain samples from relatively fine beds for a range of applications.

In its Sacramento River channel field test the Cooper Scooper collected sediment with subtle (and marked) differences in grain size between samples and between cross-sections. For example, Figure 2 shows three texturally distinct

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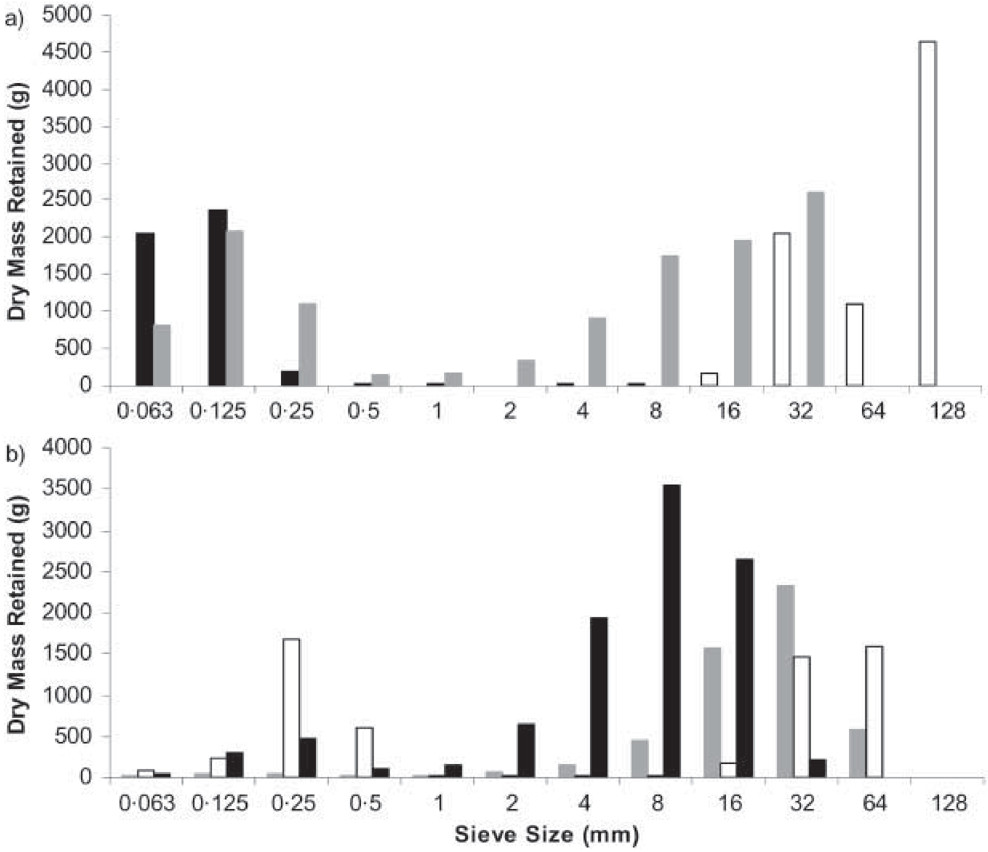

Figure 2. Example grain-size distributions from (a) three sites representing different ends of the grain-size range and (b) three locations within a single cross-section representing cross-stream sorting.

samples extracted from different portions of the river (a) and three samples that form an aggregate from a single cross-section (b).

Subaerial-bar field test

Cooper Scooper samples from the subaerial bar contained dry weight masses equivalent to the largest subaqueous ones (i.e. of ~16, ~15, and ~12 kg, respectively, for the three tested sites). Site 1 was a mixed sand and gravel bed with 20% of the surface covered in material finer than 2 mm. The Cooper Scooper, which penetrated ~5 cm over 1·5 m of drag, obtained samples that are essentially indistinguishable from surface grain size (Figure 3). It is relevant to note that such beds have a high similarity between surface and subsurface grain-size distributions and penetration of the surface layer is not hampered by armouring.

Site 2 contained a framework-supported surface layer (i.e. no significant fine material at the surface). The sampler here penetrated ~4·5 cm over 1 m of drag and collected a sample that is noticeably coarser than the surface material at the coarse end of the distribution (Figure 3). This site has a relatively high degree of surface armouring (i.e. with an armour ratio much greater than 2) and a relative abundance (>10%) of bed material sediment larger than 64 mm, both of which affected sample collection. The Cooper Scooper apparently could not dig past the ~10% coverage of large grains and therefore concentrated coarser grains from the surface, resulting in higher fractions for the coarser size classes than those yielded by the surface pebble count at the same site.

Site 3 had mostly framework support at the surface with some finer material (cf. Sites 2 and 3 in Figure 3). The sampler penetrated ~5·5 cm over 1·5 m and extracted a sample with a grain-size distribution that approximates the subsurface at the fine end of the distribution and gradually shifts upward to equal the surface distribution in the >16 mm class. As the surface and subsurface distributions converge for larger grain-size classes, the Cooper Scooper sample is noticeably coarser in the >32 mm class before converging with the other two at grain sizes >64 mm.

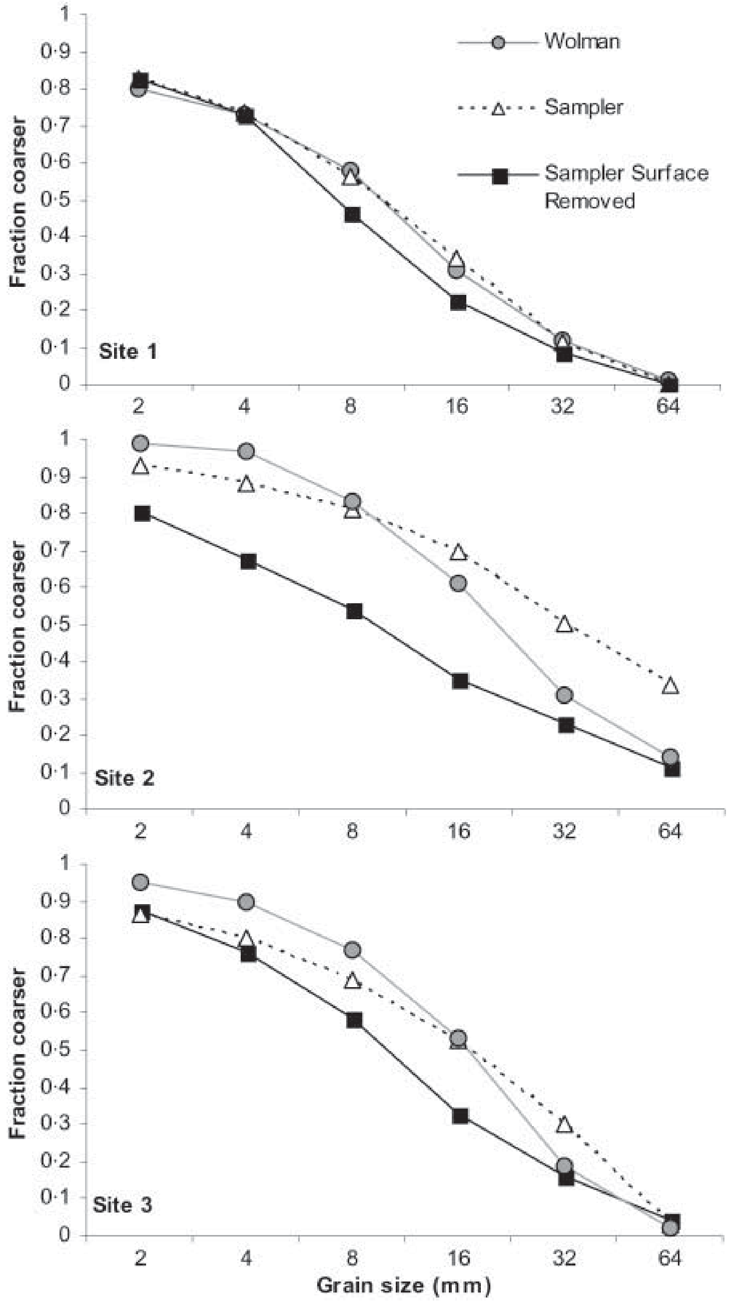

Figure 3. Grain-size distributions from a preliminary field test at three sites on a subaerial bar.

These subaerial field tests provide a characterization of which sediment population the Cooper Scooper will extract from varying bed material compositions. In general, where armouring is low and there is matrix support at the surface and in the subsurface, the Cooper Scooper obtains a distribution similar to that of the surface. In such beds, the sampler easily penetrates the surface to access some of the subsurface material, in particular at the fine end of the distribution (e.g. Site 3, Figure 3). These results indicate the relative ease of characterizing matrix-supported beds, which is consistent with recent analysis (Haschenburger *et al.*, 2007).

Where armouring is strong (e.g. where the armour ratio greatly exceeds a value of 2), the sampler is limited by the ratio of its penetration depth to the size of D_{90}, or size of which 90% of the material is finer than (or any characteristic coarse grain size), as well as by its aperture size. For example, the Cooper Scooper sample Site 2, which has an armour ratio of ~4 and a surface $D_{90} > 64$ mm, contains higher fractions of gravel than are present in either surface or subsurface sediments (Figure 3). This arises primarily because the framework-supported surface is not well penetrated by the sampler, which tends to mine out surface grains and concentrate them in the sampler and at its entrance, effectively blocking further passage of sediment. This effect of coarse clast concentration is diminished where armouring is less pronounced, even in coarse beds (e.g. at Site 3 in Figure 3).

Discussion and Conclusion

The new sampler characterized grain-size distributions for large portions of the river for which bed material data were previously unavailable. I have not tested the sensitivity of the data collection to sampler dimensions and features. Instead, I tested preliminarily the sampler's efficacy in obtaining samples from a variety of bed material conditions on submerged beds and verified which population of sediment was collected for various surface grain-size distributions on a subaerial bar. Further, more rigorous field testing is recommended for precise characterization of bed material sediments.

When using a sampler such as this, it is important to know which population of sediments is being sampled, surface or surface and subsurface. Such a distinction is important in various applications such as sediment transport, which increasingly require characterization of the surface layer to compute entrainment (e.g. Parker, 1990). The Cooper Scooper was designed to obtain bulk sediments, but penetration depth is very sensitive to bed material condition. Coarser, armoured beds will limit penetration, as will a framework-supported subsurface. As such, one can never be certain of which population of sediment is being sampled for a given location. However, the subaerial field test provides some guidance in this matter. Penetration depth for samples collected on the three subaerial bar sites averaged 5 cm over a drag distance of ~1·5 m, but these values probably represent a lower bound on actual penetration depths in subaqueous conditions, where there are generally larger forces on the sampler generated by the boat and the weight of water.

Generally, the Cooper Scooper obtains samples more similar to the surface material than the subsurface, but it appears to split the difference on the finer end of the distribution. Quite expectedly, it collects bulk samples (containing both surface and subsurface sediment) in beds with a poorly developed armour layer. The current version of the sampler appears to be subject to bias toward coarse grain sizes where armour ratios are large and D_{90} is relatively large (e.g. Site 2, Figure 3).

The current version of the Cooper Scooper was developed for use along the Sacramento River on the California Department of Water Resources boat. Even though the Sacramento River exhibits a range of conditions (bed state, water depth, etc.), there are undoubtedly conditions that would affect sampling in other systems and the sampler demonstrated herein could be refined accordingly. For example, sampler size and weight could be increased to obtain samples in much coarser and well-armoured beds. Indeed, the Cooper Scooper is effectively limited to beds with material finer than 128 mm due to the height dimension of its aperture (Figure 1) and volumetric limitations. The sampler could also be modified to minimize loss of silt and clay by plugging drain holes, and thereby support aquatic habitat surveys (American Society of Civil Engineers, 1992) and analyses of chemistry and contamination. Based on the preliminary field tests of the Cooper Scooper prototype, I am currently constructing a larger, heavier, and refined version of the Cooper Scooper that will facilitate more rigorous field testing to establish specific criteria for achieving unbiased sample estimates for a particular physical environment (e.g. as suggested by Haschenburger *et al.*, 2007). I expect a larger version of the Cooper Scooper to shift the aforementioned coarse clast concentration to increasingly large values of D_{90}, making it more suitable for well armoured beds.

Preliminary testing suggests the utility of the presented sampler in obtaining bed material grain-size distributions for a range of bed conditions. Such data could be used to assess patterns of downstream fining, to predict sediment transport, and to assess habitat distribution at various scales of interest.

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References

American Society of Civil Engineers. 1992. Sediment and aquatic habitat in river systems. *Journal of Hydraulic Engineering* **118**: 669–687.

Ashmore PE, Yuzyk TR, Herrington R. 1989. Bed material sampling error in sand bed rivers. *Water Resources Research* **25**: 2195–2203.

Billi P, Paris E. 1992. Bed sediment characterization in river engineering problems. In *Erosion and Sediment Transport Monitoring Programmes in River Basins (Proceedings of the Oslo Symposium)*, Bogen J, Walling DE, Day TJ (eds). IAHS Publication 210, International Association of Hydrological Sciences: Wallingford; 11–20.

Bunte K, Abt SR. 2001. *Sampling Surface and Subsurface Particle-size Distributions in Wadable Gravel- and Cobble-bed Streams for Analyses in Sediment Transport, Hydraulics, Streambed Monitoring*. General Technical Report, Rocky Mountain Research Station, Forest Service, U.S. Department of Agriculture: Fort Collins, CO; 428 pp.

Church MA, McLean DG, Wolcott JF. 1987. River bed gravels: sampling and analysis. In *Sediment Transport in Gravel-bed Rivers*, Thorne CR, Bathurst JC, Hey RD (eds). John Wiley and Sons: Chichester; 43–88.

Edwards TK, Glysson GD. 1999. *Field Methods for Measurement of Fluvial Sediment*. Techniques of Water Resources Investigations, U.S. Geological Survey: Reston, VA.

Fripp JB, Diplas P. 1993. Surface sampling in gravel streams. *Journal of Hydraulic Engineering* **119**: 473–490.

Haschenburger JK, Rice SP, Voyde E. 2007. Evaluation of bulk sediment sampling criteria for gravel-bed rivers. *Journal of Sedimentary Research* **77**: 415–423.

Leopold LB. 1970. An improved method for size distribution of stream bed gravel. *Water Resources Research* **6**: 1357–1366.

Mosley MP, Tindale DS. 1985. Sediment variability and bed material sampling in gravel-bed rivers. *Earth Surface Processes and Landforms* **10**: 465–482.

Parker G. 1990. Surface-based bedload transport relation for gravel rivers. *Journal of Hydraulic Research* **28**: 417–436.

Pickup G. 1984. A bed material sampler for use in coarse gravels and armoured riverbeds. *British Geomorphological Research Group Technical Bulletin* **29**: 33–39.

Queen BS, Nordin CF, Rentshchler RE (eds). 1990. *Bed Sediments and Bed Forms in the Lower Mississippi River*. American Society of Civil Engineers: New York; 281–286.

Rice S, Church M. 1996. Sampling surficial fluvial gravels: the precision of size distribution percentile estimates. *Journal of Sedimentary Research* **66**: 654–665.

Rice S, Church M. 1998. Grain size along two gravel-bed rivers: statistical variation, spatial pattern and sedimentary links. *Earth Surface Processes and Landforms* **23**: 345–365.

Rice SP, Haschenburger JK. 2004. A hybrid method for size characterization of coarse subsurface fluvial sediments. *Earth Surface Processes and Landforms* **29**: 373–389.

Tennessee Valley Authority, US Army Corps of Engineers, US Department of Agriculture, US Geological Survey, US Bureau of Reclamation, Iowa Institute of Hydraulic Research. 1940. *Equipment used for Sampling Bed Load and Bed Material*. Report No. 2, Federal Interagency Sedimentation Program: Iowa City, IA; 56 pp.

Wolman MG. 1954. A method of sampling coarse river-bed material. *Transactions, American Geophysical Union* **35**: 951–956.