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**Comparison of software accuracy to estimate the bed grain size distribution from digital images: A test performed along the Rhine River**

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# 1 **Comparison of software accuracy to estimate the bed grain size** 2 **distribution from digital images: A test performed along the Rhine River**

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## 9 **Abstract**

10 The quantification of the bed grain size distribution (GSD) of river surfaces is primarily  
11 conducted through manual approaches in the field. These methods are time consuming  
12 and not able to accurately represent the spatial diversity of the grain size distribution of  
13 rivers. Recently, several software programmes and procedures have been developed  
14 using semi-automatic and automatic methods to estimate bed GSD from digital imagery.  
15 The purpose of this study is to compare softwares accuracy between reference GSDs and  
16 estimated GSDs using geometric approaches (Basegrain software and a procedure  
17 developed on ImageJ), statistical approaches (Digital Grain Size (DGS) and PebbleCounts  
18 softwares) and a machine learning framework (SediNet). This study evaluates ten digital  
19 images recorded along the Rhine River downstream of the city of Basel. The results  
20 showed that all software programmes considerably underestimated the manually  
21 measured GSDs. Nevertheless, it is possible to significantly improve the estimation of bed  
22 GSD by applying calibration laws. Both DGS and Basegrain softwares are reliable to  
23 estimate the GSD, while the three others softwares are accurate for percentiles equal and

1  
2 24 higher than the  $D_{50}$ . After linear regression correction, the mean NRMSE of percentile  
3  
4 25 errors did not exceed 13% for DGS and Basegrain software, while the others not exceed  
5  
6 26 22% for percentiles coarser than the  $D_{50}$ .  
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9

10 27 **Key words:** bed grain size, digital images, software accuracy, river, Rhine  
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## 13 28 1. Introduction

14  
15  
16 29 Riverbed grain size is a key parameter in geomorphological and ecological studies of  
17 30 rivers. This parameter allows researchers to evaluate physical habitat quality, sediment  
18 31 transport dynamics and restoration action effects. The quantification of the bed grain size  
19 32 distribution (GSD) of river surfaces is mostly conducted through manual approaches in the  
20 33 field, such as Wolman sampling, the paint-and-pick approach or grid sampling (Bunte &  
21 34 Abt, 2001). These methods are time consuming and obtained punctual measurements are  
22 35 not representative of the spatial diversity of a river's grain size distribution (Graham et al.,  
23 36 2010). Currently, new remote sensing methods have been developed to semi-  
24 37 automatically or automatically estimate the bed GSD of bar surfaces. These approaches  
25 38 are divided into two classes: (i) two-dimensional approaches using terrestrial and aerial  
26 39 imagery (Baptista et al., 2012; Chang & Chung, 2012; Chardon et al., 2021; Graham et al.,  
27 40 2005; Lejot et al., 2011; Purinton & Bookhagen, 2019; Rubin, 2004; Strom et al., 2010;  
28 41 Sulaiman et al., 2014; Turley et al., 2017) and (ii) three-dimensional approaches using  
29 42 photogrammetry, laser scanning or LiDAR datasets by estimating roughness as a proxy of  
30 43 bed GSD (Brasington et al., 2012; Chardon et al., 2020; Heritage & Milan, 2009; Vázquez-  
31 44 Tarrío et al., 2017; Woodget et al., 2018). Although the photographic sampling method  
32 45 does not enable the mapping of surface GSD over a large area as usually with a three-  
33 46 dimensional approach, it requires only a simple camera and thus is less costly than the  
34 47 precendently mentionned. Moreover, terrestrial photographic sampling requires fewer  
35 48 preprocessing steps for correcting raw data than three-dimensional approaches, which can

1  
2 49 be difficult and technical (e.g., cleaning and georeferencing of raw point clouds, roughness  
3  
4 50 metric calculation and calibration with the manual field GSD) (Brasington et al., 2012;  
5  
6 51 Heritage & Milan, 2009; Vázquez-Tarrío et al., 2017; Woodget et al., 2018). However, the  
7  
8 52 accuracy of two-dimensional approaches is extremely sensitive to environmental  
9  
10 53 conditions such as sun illumination, the presence of vegetation or biofilms, and sediment  
11  
12 54 petrography or/and mineralogy. In addition, for suhtwo-dimensional approaches, bed  
13  
14 55 sediment structures (burial, overlapping and foreshortening) also influence the accuracy of  
15  
16 56 the obtained results (Graham et al., 2010; Hodge et al., 2009).

17  
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19  
20 57 Two methods were used to estimate the bed GSD from digital images via morphological  
21  
22 58 approaches and statistical approaches (Buscombe, 2013). Morphological approaches use  
23  
24 59 thresholding and segmentation processing to define the outline of each visible particle,  
25  
26 60 while statistical approaches tend to estimate the grain size through image texture analysis  
27  
28 61 from the semi-variance approach (Carbonneau et al., 2004), autocorrelation approach  
29  
30 62 (Warrick et al., 2009), the wavelength approach (Buscombe, 2013) and recently following  
31  
32 63 the k-means approach (Puriton et al., 2019). Deep learning methods were also developed  
33  
34 64 to estimate automatically the GSD using digital images as SediNet (Buscombe, 2020) and  
35  
36 65 GRAINet (Lang et al., 2021). Although Basegrain (morphological approach) and DGS  
37  
38 66 (statistical approach) programs are frequently used to estimate the GSD from digital  
39  
40 67 images, a question still remains: which software provides, using default parameters, the  
41  
42 68 most accurate estimation of bed GSD from digital imagery? The objective of this study is to  
43  
44 69 compare the software accuracy of reference GSDs and estimated GSDs from DGS,  
45  
46 70 Basegrain, SediNet, PebbleCounts software and a procedure using ImageJ. The analysis  
47  
48 71 was based on ten digital images sampled along the Rhine River downstream of the city of  
49  
50 72 Basel.

## 51 73 **2. Methodology**

## 74 2.1 Study area

75 Photographic sampling was performed on the Old Rhine River between the cities of  
76 Kembs and Ottmarsheim over five above-water deposits. The Old Rhine River is a  
77 bypassed and regulated reach in the Alsacian Plain. An instream flow is maintained in the  
78 Old Rhine between 52 and 115 m<sup>3</sup>/s from the Kembs derivation dam, depending on the  
79 natural hydrological regime of the Rhine River (Fig. 1b). Spills occur in the Old Rhine River  
80 when the Rhine River discharge exceeds 1400 m<sup>3</sup>/s in Basel, which is the maximum flow  
81 capacity discharge of the Grand Canal d'Alsace (GCA). The channel bottom of the study  
82 reach is composed mainly of gravel and cobble (Arnaud et al., 2015). The mean slope and  
83 mean width are equal to 0.09% and 100m, respectively (Fig. 1b).

## 84 2.2 Field data collection

85 Photographic sampling was performed on clean substrates without vegetation or a biofilm  
86 to avoid substantial estimation errors induced by these elements (Chardon et al. 2020).  
87 According to the recommendations of Barnard et al. (2007) and Chardon et al. (2020), all  
88 digital images were taken under an umbrella in order to control solar conditions which  
89 could influence GSD estimations (Fig. 1). Moreover, all images were taken using a  
90 telescoping bar and a bubble level to capture sediment patches with a horizontal plane of  
91 view. The camera used was an Olympus TG-4, and the image resolution was equal to 16  
92 MP (4608 x 3456 pixel). A median filter was applied to reduce error in the estimation  
93 resulting from pepper and salt phenomena (Chardon et al., 2020). As recommended by  
94 Chardon et al. (2020), the median-sized filter used in this study was equal to 5% of the  
95 Dmax value measured for each digital image.

## 96 2.3 Image processing

### 97 2.3.1 Manual digitalization

1  
2 98 Following the recommendations of Barnard et al. (2007), the b-axes of 80 to 100 particles  
3  
4 99 were digitized manually from each digital image using a sampling grid to obtain a  
5  
6 100 reference distribution. This step, which was performed using ImageJ software, allows us to  
7  
8  
9 101 achieve a reference GSD.

### 10 11 12 102 2.3.2 DGS software

13  
14  
15 103 The first software used to automatically estimate the grain size of 10 sediment patches  
16  
17 104 was the DGS software developed by Buscombe and implemented in MATLAB (2013). This  
18  
19 105 software is based on a statistical approach using the wavelength method which  
20  
21 106 automatically provides the GSD in grid sampling (Fig. 2). . Batch processing has been  
22  
23  
24 107 proposed to evaluate the GSD of a large number of digital images. No filter was applied,  
25  
26 108 and the totality of the surfaces of the digital images was considered for GSD estimation.

### 27 28 29 30 109 2.3.3 Basegrain software

31  
32  
33 110 The second software used in this study is Basegrain software (Detert and Weitbrecht,  
34  
35 111 2013), which was also developed for MATLAB software (Fig. 3). The approach of  
36  
37 112 Basegrain is based on a morphological method. Five preprocessing steps are available for  
38  
39 113 the user to compute median filter options, the minimal size of a grain area (for watershed  
40  
41 114 algorithm application) and the minimal number of pixels (to determine the minimal area),  
42  
43 115 which is related to grain size (Detert and Weitbrecht, 2013). This study used the default  
44  
45 116 options for each step to decrease the processing time of digital images and to compare the  
46  
47 117 methods between them without to not to favour one method over another. The GSD can  
48  
49 118 be obtained in a grid sampling form.

### 50 51 52 53 54 119 2.3.4 Procedure using ImageJ software

55  
56  
57 120 The method using ImageJ is based on a procedure established by (Sulaiman et al., 2014),  
58  
59 121 which proposed a morphological approach to automatically extract the GSD by areal

1  
2 122 sampling. We slightly changed this protocol as follows: (i) the digital images are  
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4 123 transformed in 8-bit format, (ii) the substrate background algorithm is applied with mobile  
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6 124 windows equal to 50 pixels by default, (iii) an automatic threshold for black and white  
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9 125 transformation is applied, (iv) the watershed algorithm is applied and (v) the b-axis of all  
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11 126 detected particles were determined via automatic measurement (Fig. 5). To compare the  
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13 127 GSD obtained with this method (areal sampling) to the two previous estimations from DGS  
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16 128 and Basegrain software, we collected the b-axis of 60 to 100 particles detected using a  
17  
18 129 grid built with QGIS software.

### 21 130 2.3.5 PebbleCounts software

22  
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24  
25 131 This software was developed in Python language and used initially to estimate the  
26  
27 132 apparent GSD of above-water bar deposits using aerial imagery from a drone (Puriton &  
28  
29 133 Bookhagen., 2019). This software was recently used to estimate the longitudinal bed grain  
30  
31 134 size variations along 100 km of river length of the Toro watershed located in Argentina  
32  
33  
34 135 (Puriton & Bookhagen, 2021). In this study, we used the automatic procedure named as  
35  
36 136 PebbleCountsAuto (AIF) which used edge detection and filter automatically suspect grains  
37  
38 137 (Puriton & Bookhagen., 2019). Same as the procedure in ImageJ software, we collected  
39  
40 138 the b-axis of 60 to 100 particles detected using a grid built with QGIS software from X and  
41  
42  
43 139 Y coordinates provided by the output files of the software.

### 46 140 2.3.6 SediNet software

47  
48  
49 141 This software was based on machine learning framework developed by Buscombe (2019)  
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51 142 using python language. It allows to estimate quantitatively and automatically the  
52  
53 143 measurements from digital images and given percentiles values directly at the output. In  
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55  
56 144 this study, we used the trainer developed only for gravel deposits related to our dataset.

### 59 145 2.4 Estimation of the prediction accuracy



To evaluate and compare the prediction accuracy of each software, we compared percentile values estimated by each automatic processing to the reference distributions. The variation between the predicted and reference values was quantified by two metrics, i.e., the NRMSE (Eq. 1) and NMAE (Eq. 2), which were calculated as follows:

$$NRMSE = \frac{\sqrt{\sum_{i=1}^n (x_i - x)^2}}{x_{mean}} \quad (1)$$

$$NMAE = \frac{\left( \frac{\sum_{i=1}^n |(x_i - x)|}{n} \right)}{x_{mean}} \quad (2)$$

where  $x_i$  is equal to the value of the predicted percentile and  $x$  is the value of the manually measured percentile.  $x_{mean}$  corresponds to the mean value of the percentile manually measured for the digital image dataset.

### 3. Results

#### 3.1 Software accuracy before calibration

Fig. 6 shows that all softwares underestimated all percentiles. The results are quite similar for Basegrain software from  $D_{10}$  to  $D_{50}$ , with a net underestimation of these percentiles (Tab. 1). In contrast, from  $D_{75}$  to  $D_{95}$ , an overestimation occurred using Basegrain (Tab. 1). Globally, for all software programmes, the NRMSE and NMAE decrease according to the increase in the estimated percentile (Fig. 7). However, the values of these parameters differ considerably between the compared software programmes. For DGS software, the maximal NRMSE and NMAE values of percentile errors were equal to 56% and 47%, respectively. For Basegrain software, the maximal NRMSE and NMAE values were equal to 97% and 90%, respectively (Fig. 7). For the ImageJ procedure, the maximal RMSE and

1  
2 166 NMAE values equal 88% and 79%, respectively. For SediNet, the maximal RMSE and  
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4 167 NMAE values equal 67% and 58%, respectively. For PebbleCounts, the maximal RMSE  
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6 168 and NMAE values equal 71% and 59%, respectively.  
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9

### 10 169 3.2 Software accuracy after calibration

11  
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13 170 Significant linear relationships were found between the manually measured and predicted  
14  
15 171 percentiles by DGS and Basegrain software (Tab. 1.) Only significant statistical linear  
16  
17 172 relationships were found from  $D_{75}$  between the predicted and manually measured  
18  
19 173 percentiles by the procedure using ImageJ software (Tab. 1). For SediNet, significant  
20  
21 174 statistical relationships were found for  $D_{10}$ ,  $D_{16}$ ,  $D_{25}$ , and  $D_{84}$ , respectively. Whereas for  
22  
23 175 PebbleCounts, significant relations were found from the  $D_{75}$  (Tab. 1). For the latest, no  
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25 176 relationship was observed for the  $D_{10}$  with a R-square close to 0.  
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30 177 Through the application of linear regressions, a reduction in NRMSE and NMAE occurred  
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32 178 for all percentiles and all procedures between the corrected-predicted percentiles and  
33  
34 179 manually measured percentile due to a high reduction of the previous under-estimation of  
35  
36 180 before correction (Fig. 7; Fig. 8). For DGS software, the maximal NRMSE and NMAE  
37  
38 181 values of percentile errors were equal to 20% and 17%, respectively. For Basegrain  
39  
40 182 software, the maximal RMSE and NMAE values of the percentile errors were equal to 20%  
41  
42 183 and 16%, respectively. For the ImageJ procedure, the maximal RMSE and NMAE values  
43  
44 184 were equal to 40% and 33%, respectively (Fig. 7). For SediNet, the maximal RMSE and  
45  
46 185 NMAE values were equal to 33% and 23%, respectively. Finally, for PebbleCounts, the  
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48 186 maximal RMSE and NMAE values were equal to 38% and 33% excluding the  $D_{10}$ .  
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## 4. Discussion

### 4.1 Comparison of software accuracy

Our results showed that all methods underestimated the GSD with great error in comparison to the reference GSD obtained through the manual approach. This underestimation is explained by an oversegmentation of particles due to petrographic variation (Sime & Ferguson, 2003; Strom et al., 2010; Warrick et al., 2009). To reduce the error estimations, a calibration correction must be applied to improve the GSD estimation, as that proposed by Chardon et al. (2020) (Fig. 7; Fig. 8). Our results show that both DGS and Basegrain are reliable software programmes to estimate the GSD on digital images after linear regression correction (Fig. 8). The maximal value of error estimation was less than 18% (NMAE) after the linear correction (Fig. 7). The other three softwares are also reliable for percentiles estimation coarser than the  $D_{50}$  (Fig. 7). The maximal value of error estimation was equal to 22% (NMAE for SediNet) after linear correction (Fig. 7).

### 4.2 Software advantages and limitations

Each software presents advantages and limitations. For DGS software, the GSD was obtained quickly, and no extra preprocessing step than a median filter application was necessary. Nevertheless, this software is similar to a “black box” with no means to see the detected particles and perform error localization in digital images, which does not allow to evaluate which parameter primarily influences the particle detection. This means that there is no possible way to change the software parameters. The same limitation occurs for SediNet due to the deep learning method used. For PebbleCounts software, the advantage is that only one parameter required from the user before computation and the results of the grain identification are visible in a new window. On the other hand, Basegrain software allows you to view the detected particles and spatial errors but also allows operator intervention to modify or delete the detected particle outlines. However, in some

1  
2 215 cases, numerous visual checks may be necessary during the preprocessing steps (n=5) to  
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4 216 obtain satisfying results. In our cases, to be consistent with the idea of quick and easy data  
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6 217 processing, no calibration steps were implemented, and the GSD being estimated by the  
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8 218 automatic object detection tool of Basegrain. For the ImageJ procedure, the main limitation  
9  
10 219 is the application of step 3, which consists of applying an automatic threshold for black and  
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12 220 white transformation that is necessary for the application of the watershed algorithm.  
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14 221 Because pixel color values differ between each digital image, it is very difficult to find a  
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16 222 single threshold for a set of digital images. In addition the several manual preprocessing  
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18 223 steps of this procedure increase the processing time (Fig.5), which may be problematic for  
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20 224 large datasets.  
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#### 26 225 4.3 Future research avenues 27

28  
29 226 The main advantage of using terrestrial digital images rather than aerial images or three-  
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31 227 dimensional techniques (photogrammetric or LiDAR data) is the low required material cost.  
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33 228 It is also a less time-consuming post-processing approach as most of the measurement  
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35 229 errors could be avoided during the field data collection (vegetation, biofilm, sun, etc.), and  
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37 230 less specific technical knowledge than three-dimensional approaches are needed. Thus,  
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39 231 this method could be easily used by river managers to quickly estimate the bed GSD on  
40  
41 232 both clean above and underwater bars for the planning step of river restoration projects,  
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43 233 evaluate natural changes or integrate bed GSD spatial distribution in numerical  
44  
45 234 hydrosedimentary models. However, questions still remain: what is the best sampling  
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47 235 procedure to integrate the spatio-temporal variability of the GSD? Because digital images  
48  
49 236 allows to estimate the local bed grain size quickly, how to estimate the GSD from this  
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51 237 sampling procedure at a larger spatial scale, similar to aerial or three-dimensional  
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53 238 approaches? Is this approach is a compromise between quantity and quality? More  
54  
55 239 studies have to be conducted in this topic to determine a robust sampling protocol using  
56  
57 240 digital images. Each of these sampling protocols should be guided by (i) the main objective  
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2 241 of the study, (ii) the sampling effort and (iii) the precision, which must be consistent with  
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4 242 the final use of the data.  
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## 7 243 **5. Conclusion**

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11 244 The purpose of this study was to evaluate and compare the accuracy of GSD estimations  
12  
13 245 from ten digital images recorded on the Rhine River using five software programmes.  
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15 246 Results showed that all software programmes underestimated manually measured GSDs.  
16  
17 247 However, after linear regression correction, the NMAE decreased and did not exceed 18%  
18  
19 248 for the DGS and Basegrain software for all percentiles. For the three other softwares, the  
20  
21 249 estimation is reliable for percentiles higher than the  $D_{50}$  with a NMAE below 22%. This  
22  
23 250 study shows that it is possible to estimate the bed GSD of clean substrates in a precise  
24  
25 251 manner using DGS and Basegrain softwares for the entire distribution and the three other  
26  
27 252 softwares for percentiles equal and higher than the  $D_{50}$ . However, a calibration step must  
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30  
31 253 be applied in all cases.  
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## 35 254 **ACKNOWLEDGMENTS**

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38 255 None  
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## 44 257 **Conflict of Interest**

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78  
9 265 **REFERENCES**

10  
11  
12 266 Arnaud, F., Piégay, H., Schmitt, L., Rollet, A. J., Ferrier, V., & Béal, D. (2015). Historical  
13  
14 267 geomorphic analysis (1932–2011) of a by-passed river reach in process-based  
15  
16 restoration perspectives: The Old Rhine downstream of the Kembs diversion dam  
17 268 (France, Germany). *Geomorphology*, 236, 163–177.

18  
19 269  
20  
21 270 <https://doi.org/10.1016/j.geomorph.2015.02.009>

22  
23  
24  
25 271 Baptista, P., Cunha, T. R., Gama, C., & Bernardes, C. (2012). A new and practical method  
26  
27 272 to obtain grain size measurements in sandy shores based on digital image  
28  
29 273 acquisition and processing. *Sedimentary Geology*, 282, 294–306.

30  
31 274 <https://doi.org/10.1016/j.sedgeo.2012.10.005>

32  
33  
34  
35 275 Barnard, P. L., Rubin, D. M., Harney, J., & Mustain, N. (2007). Field test comparison of an  
36  
37 276 autocorrelation technique for determining grain size using a digital ‘beachball’  
38  
39 277 camera versus traditional methods. *Sedimentary Geology*, 201(1–2), 180–195.

40  
41 278 <https://doi.org/10.1016/j.sedgeo.2007.05.016>

42  
43  
44  
45 279 Brasington, J., Vericat, D., & Rychkov, I. (2012). Modeling river bed morphology,  
46  
47 280 roughness, and surface sedimentology using high resolution terrestrial laser  
48  
49 281 scanning: MODELING RIVER BED MORPHOLOGY WITH TLS. *Water Resources*

50  
51 282 *Research*, 48(11). <https://doi.org/10.1029/2012WR012223>

52  
53  
54  
55 283 Bunte, K., & Abt, S. R. (2001). *Sampling surface and subsurface particle-size distributions*  
56  
57 284 *in wadable gravel-and cobble-bed streams for analyses in sediment transport,*  
58  
59 285 *hydraulics, and streambed monitoring* (RMRS-GTR-74; p. RMRS-GTR-74). U.S.

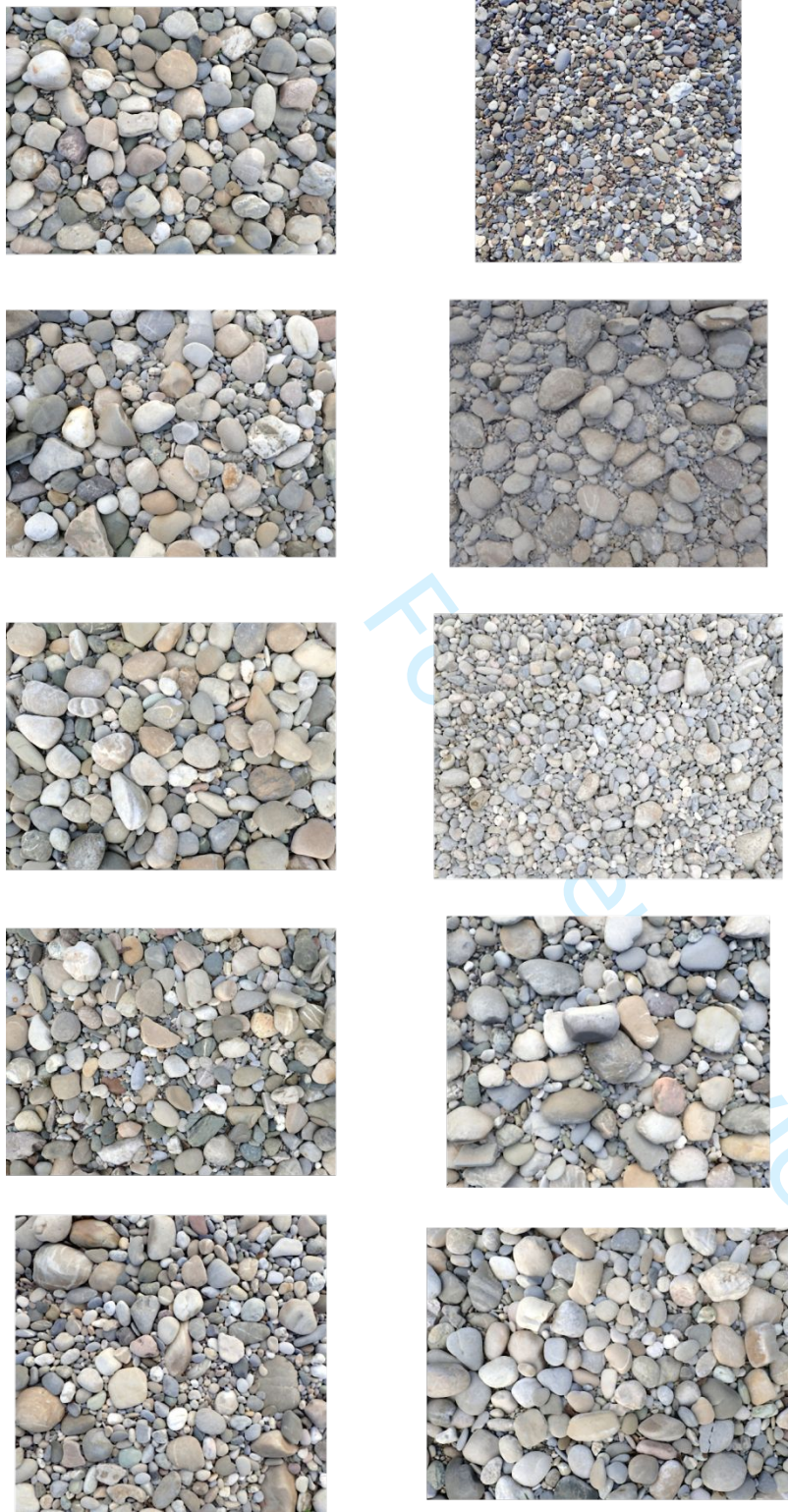
- 1  
2 286 Department of Agriculture, Forest Service, Rocky Mountain Research Station.  
3  
4 287 <https://doi.org/10.2737/RMRS-GTR-74>  
5  
6  
7  
8 288 Buscombe, D., Rubin, D. M., & Warrick, J. A. (2010). A universal approximation of grain  
9  
10 289 size from images of noncohesive sediment: GRAIN SIZE FROM IMAGES OF  
11  
12 290 SEDIMENT. *Journal of Geophysical Research: Earth Surface*, 115(F2).  
13  
14 291 <https://doi.org/10.1029/2009JF001477>  
15  
16  
17  
18 292 Buscombe, Daniel. (2013). Transferable wavelet method for grain-size distribution from  
19  
20 293 images of sediment surfaces and thin sections, and other natural granular patterns.  
21  
22 294 *Sedimentology*, 60(7), 1709–1732. <https://doi.org/10.1111/sed.12049>  
23  
24  
25  
26 295 Buscombe, D. (2019). SediNet: a configurable deep learning model for mixed qualitative  
27  
28 296 and quantitative optical granulometry. *Earth Surface Processes and Landforms* 45  
29  
30 297 (3), 638-651. <https://onlinelibrary.wiley.com/doi/abs/10.1002/esp.4760>  
31  
32  
33  
34 298 Carbonneau, P. E., Lane, S. N., & Bergeron, N. E. (2004). Catchment-scale mapping of  
35  
36 299 surface grain size in gravel bed rivers using airborne digital imagery: MAPPING  
37  
38 300 GRAIN SIZE IN GRAVEL BED RIVERS. *Water Resources Research*, 40(7).  
39  
40 301 <https://doi.org/10.1029/2003WR002759>  
41  
42  
43  
44 302 Chang, F.-J., & Chung, C.-H. (2012). Estimation of riverbed grain-size distribution using  
45  
46 303 image-processing techniques. *Journal of Hydrology*, 440–441, 102–112.  
47  
48 304 <https://doi.org/10.1016/j.jhydrol.2012.03.032>  
49  
50  
51  
52 305 Chardon, V., Schmitt, L., Arnaud, F., Piégay, H., & Clutier, A. (2021). Efficiency and  
53  
54 306 sustainability of gravel augmentation to restore large regulated rivers: Insights from  
55  
56 307 three experiments on the Rhine River (France/Germany). *Geomorphology*, 380,  
57  
58 308 107639. <https://doi.org/10.1016/j.geomorph.2021.107639>  
59  
60

- 1  
2 309 Chardon, V., Schmitt, L., Piégay, H., & Lague, D. (2020). Use of terrestrial photosieving  
3  
4 310 and airborne topographic LiDAR to assess bed grain size in large rivers: A study on  
5  
6 311 the Rhine River. *Earth Surface Processes and Landforms*, 45(10), 2314–2330.  
7  
8  
9 312 <https://doi.org/10.1002/esp.4882>  
10  
11  
12 313 Detert, M., Weitbrecht, V. (2012). Automatic object detection to analyze the geometry of  
13  
14 314 gravel grains – a free stand-alone tool. *River Flow 2012*, R.M. Muños (Ed.), Taylor  
15  
16 & Francis Group, London, ISBN 978-0-415-62129-8, pp. 595-600.  
17 315  
18  
19  
20 316 Graham, D. J., Reid, I., & Rice, S. P. (2005). Automated Sizing of Coarse-Grained  
21  
22 317 Sediments: Image-Processing Procedures. *Mathematical Geology*, 37(1), 1–28.  
23  
24 318 <https://doi.org/10.1007/s11004-005-8745-x>  
25  
26  
27  
28 319 Graham, D. J., Rollet, A. J., Piégay, H., & Rice, S. P. (2010). Maximizing the accuracy of  
29  
30 320 image-based surface sediment sampling techniques. *Water Resources Research*,  
31  
32 321 46(2), 1–15. <https://doi.org/10.1029/2008WR006940>  
33  
34  
35  
36 322 Heritage, G. L., & Milan, D. J. (2009). Terrestrial Laser Scanning of grain roughness in a  
37  
38 323 gravel-bed river. *Geomorphology*, 113(1–2), 4–11.  
39  
40 324 <https://doi.org/10.1016/j.geomorph.2009.03.021>  
41  
42  
43  
44 325 Hodge, R., Brasington, J., & Richards, K. (2009). Analysing laser-scanned digital terrain  
45  
46 326 models of gravel bed surfaces: Linking morphology to sediment transport processes  
47  
48 327 and hydraulics. *Sedimentology*, 56(7), 2024–2043. [https://doi.org/10.1111/j.1365-](https://doi.org/10.1111/j.1365-3091.2009.01068.x)  
49  
50 328 [3091.2009.01068.x](https://doi.org/10.1111/j.1365-3091.2009.01068.x)  
51  
52  
53  
54 329 Lang, N., Irniger, A., Rozniak, A., Hunziker, R., Wegner, J. D., and Schindler, K., (2021).  
55  
56 330 GRAINet: mapping grain size distributions in river beds from UAV images with  
57  
58 331 convolutional neural networks, *Hydrol. Earth Syst. Sci.*, 25, 2567–2597.  
59  
60 332 <https://doi.org/10.5194/hess-25-2567-2021>, 2021.



- 1  
2 333 Lejot, J., Piégay, H., Hunter, P. David., Moulin, B., & Gagnage, M. (2011). Utilisation de la  
3  
4 334 télédétection pour la caractérisation des corridors fluviaux: Exemples d'applications  
5  
6 335 et enjeux actuels. *Géomorphologie : relief, processus, environnement*, 17(2), 157–  
7  
8 336 172. <https://doi.org/10.4000/geomorphologie.9362>  
9  
10  
11  
12 337 Purinton, B., & Bookhagen, B. (2019). Introducing PebbleCounts: A grain-sizing tool for  
13  
14 338 photo surveys of dynamic gravel-bed rivers. *Earth Surface Dynamics*, 7(3), 859–  
15  
16 339 877. <https://doi.org/10.5194/esurf-7-859-2019>  
17  
18  
19  
20 340 Purinton, B., & Bookhagen, B. (2021). Tracking downstream variability in large grain-size  
21  
22 341 distributions in the south-central Andes. *Journal of Geophysical Research: Earth*  
23  
24 342 *Surface*, 126, e2021JF006260. <https://doi.org/10.1029/2021JF006260>  
25  
26  
27  
28 343 Rubin, D. M. (2004). A Simple Autocorrelation Algorithm for Determining Grain Size from  
29  
30 344 Digital Images of Sediment. *Journal of Sedimentary Research*, 74(1), 160–165.  
31  
32 345 <https://doi.org/10.1306/052203740160>  
33  
34  
35  
36 346 Sime, L. C., & Ferguson, R. I. (2003). Information on Grain Sizes in Gravel-Bed Rivers by  
37  
38 347 Automated Image Analysis. *Journal of Sedimentary Research*, 73(4), 630–636.  
39  
40 348 <https://doi.org/10.1306/112102730630>  
41  
42  
43  
44 349 Strom, K. B., Kuhns, R. D., & Lucas, H. J. (2010). Comparison of Automated Image-Based  
45  
46 350 Grain Sizing to Standard Pebble-Count Methods. *Journal of Hydraulic Engineering*,  
47  
48 351 136(8), 461–473. [https://doi.org/10.1061/\(ASCE\)HY.1943-7900.0000198](https://doi.org/10.1061/(ASCE)HY.1943-7900.0000198)  
49  
50  
51  
52 352 Sulaiman, M. S., Sinnakaudan, S. K., Ng, S. F., & Strom, K. (2014). Application of  
53  
54 353 automated grain sizing technique (AGS) for bed load samples at Rasil River: A case  
55  
56 354 study for supply limited channel. *CATENA*, 121, 330–343.  
57  
58 355 <https://doi.org/10.1016/j.catena.2014.05.013>  
59  
60

- 1  
2 356 Turley, M. D., Bilotta, G. S., Arbocuite, G., Chadd, R. P., Extence, C. A., & Brazier, R. E.  
3  
4 357 (2017). Quantifying Submerged Deposited Fine Sediments in Rivers and Streams  
5  
6 358 Using Digital Image Analysis: Quantifying fine sediment in rivers and streams using  
7  
8 359 DIA. *River Research and Applications*, 33(10), 1585–1595.  
9  
10 <https://doi.org/10.1002/rra.3073>  
11 360  
12  
13  
14 361 Vázquez-Tarrío, D., Borgniet, L., Liébault, F., & Recking, A. (2017). Using UAS optical  
15  
16 362 imagery and SfM photogrammetry to characterize the surface grain size of gravel  
17  
18 363 bars in a braided river (Vénéon River, French Alps). *Geomorphology*, 285, 94–105.  
19  
20 <https://doi.org/10.1016/j.geomorph.2017.01.039>  
21 364  
22  
23  
24 365 Warrick, J. A., Rubin, D. M., Ruggiero, P., Harney, J. N., Draut, A. E., & Buscombe, D.  
25  
26 366 (2009). Cobble cam: Grain-size measurements of sand to boulder from digital  
27  
28 367 photographs and autocorrelation analyses. *Earth Surface Processes and*  
29  
30 368 *Landforms*, 34(13), 1811–1821. <https://doi.org/10.1002/esp.1877>  
31  
32  
33  
34 369 Woodget, A. S., Fyffe, C., & Carbonneau, P. E. (2018). From manned to unmanned  
35  
36 370 aircraft: Adapting airborne particle size mapping methodologies to the  
37  
38 371 characteristics of sUAS and SfM. *Earth Surface Processes and Landforms*, 43(4),  
39  
40 372 857–870. <https://doi.org/10.1002/esp.4285>  
41  
42  
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378 Fig. 1: Set of sediments deposits studied (n=10). A median filter was applied before  
379 analysis following the recommendations of Chardon et al., (2020).

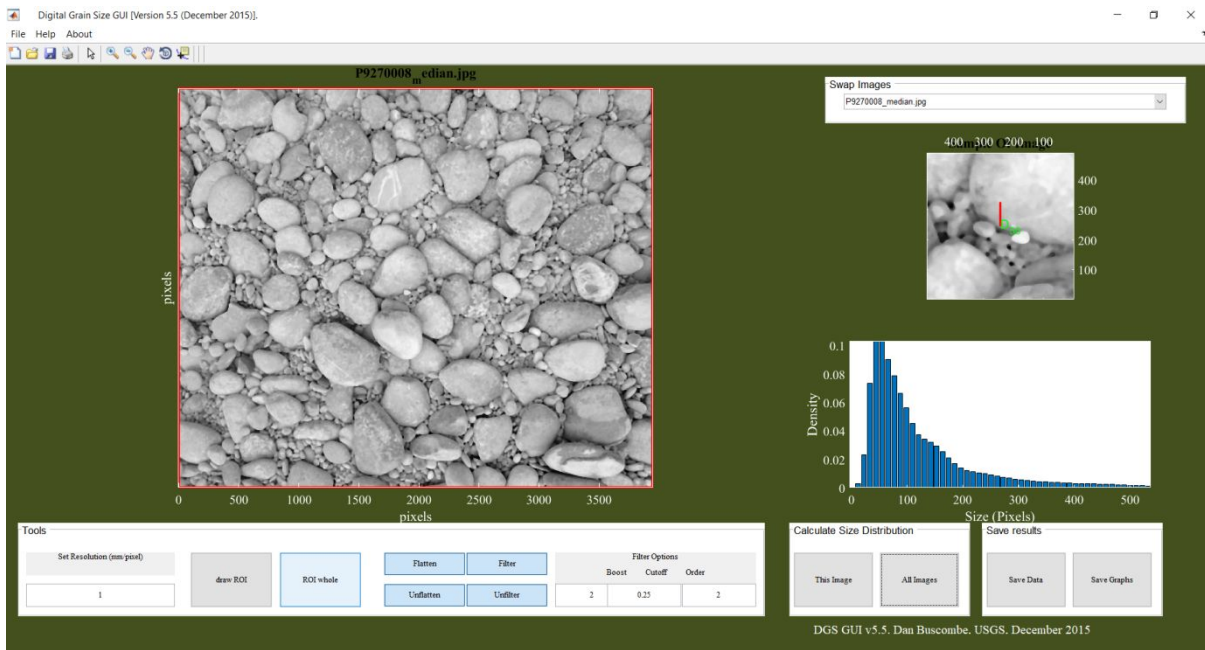
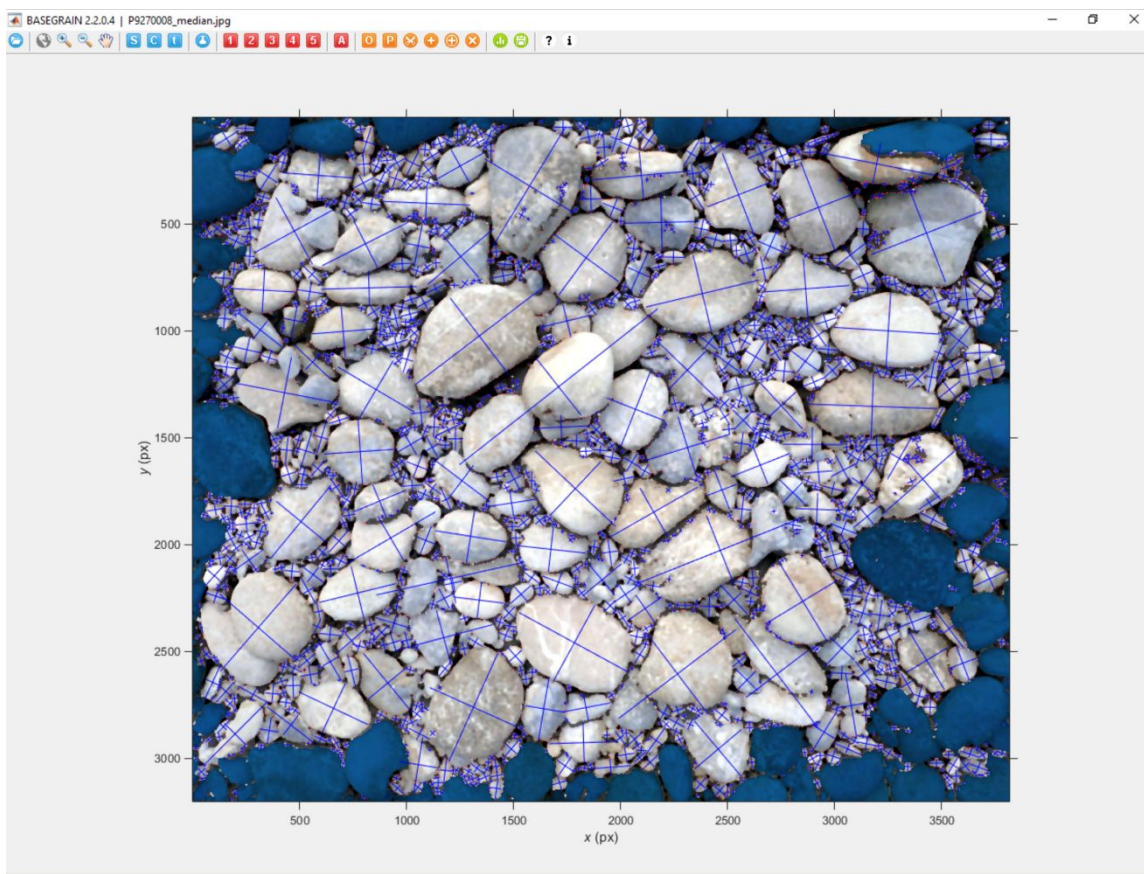


Fig. 2: Example of image processing by DGS software developed by Buscombe (2013).

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392 Fig. 3: Example of image processing by Basegrain software developed by Detert and  
393 Weitbrecht (2013).

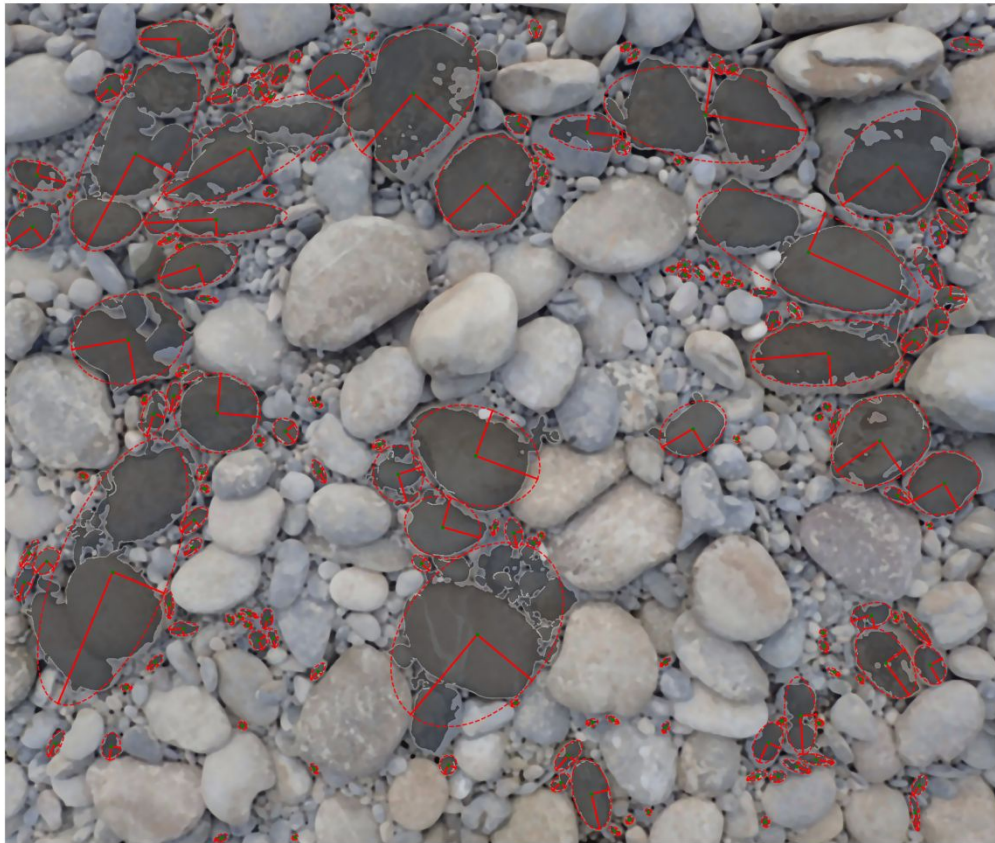


Fig. 4: Example of image processing by PebbleCounts software developed by Puriton & Bookhagen (2019).

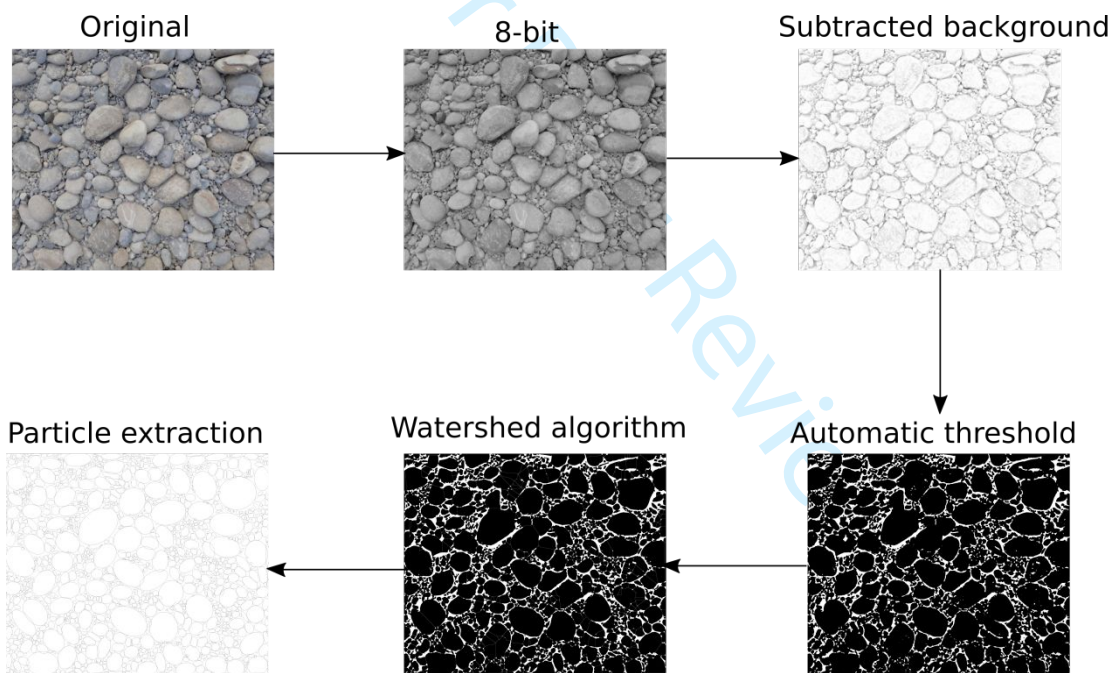


Fig. 5: Example of image processing by ImageJ software and based on the protocol developed by Sulaiman et al. (2014).

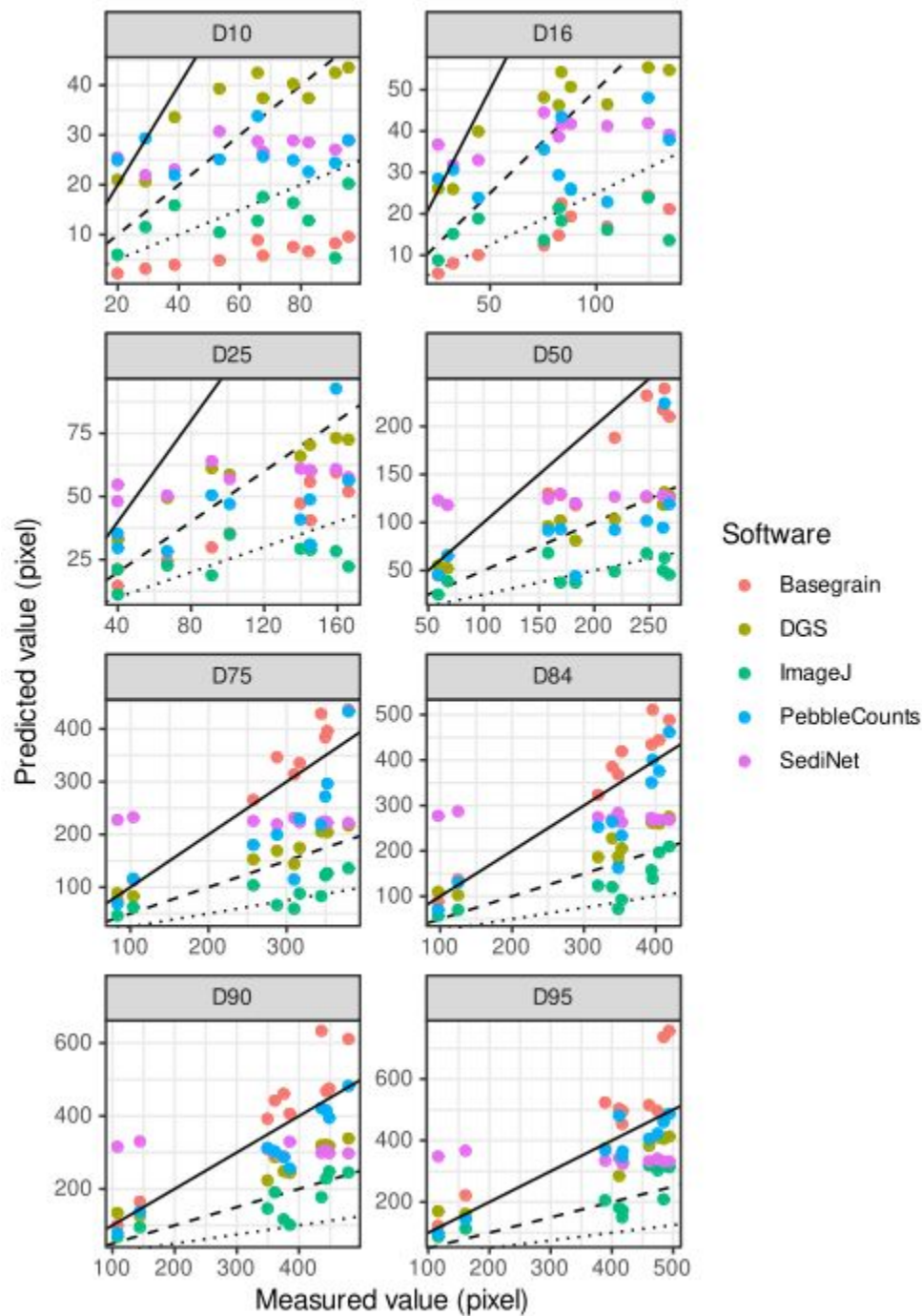
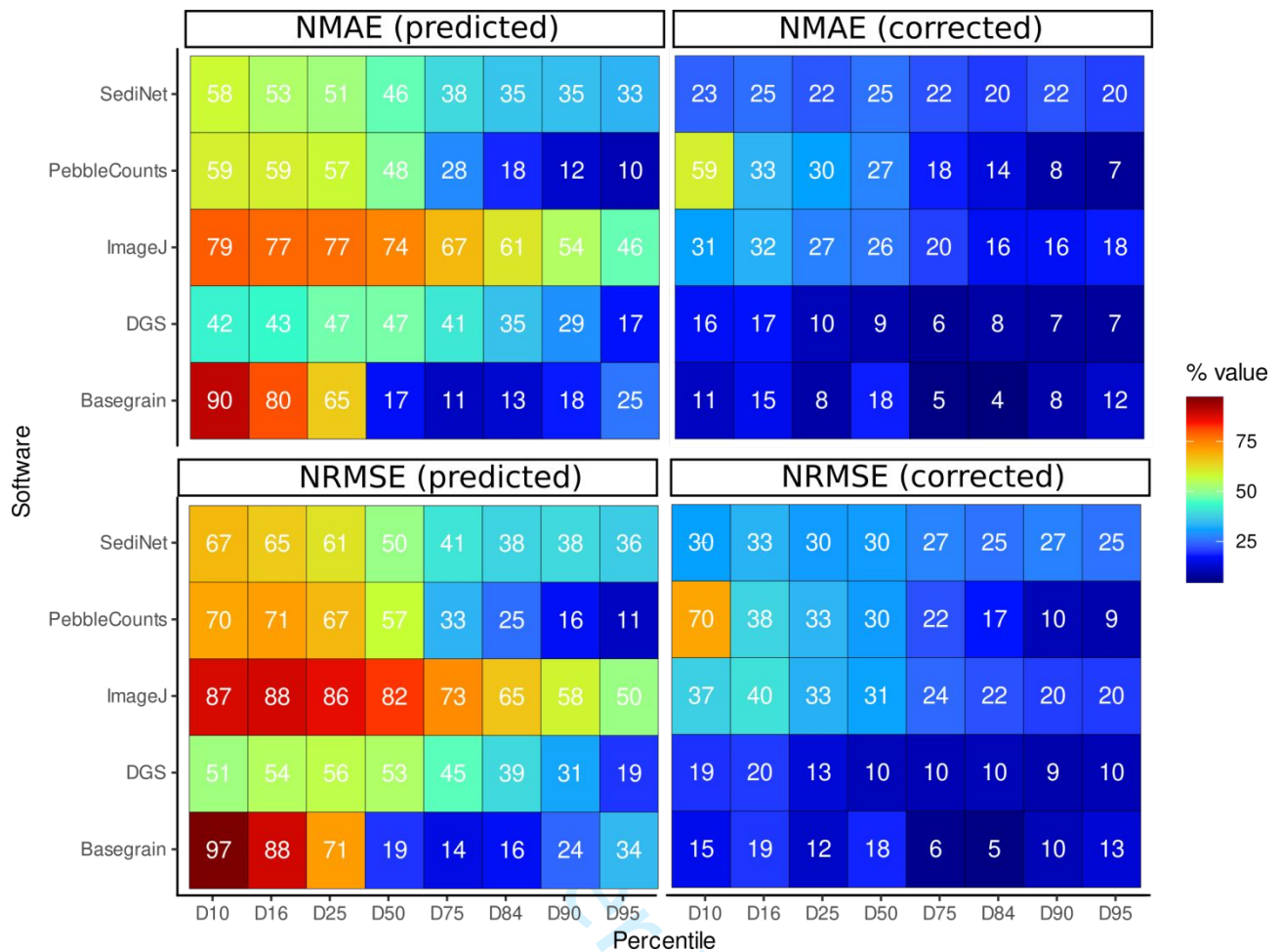


Fig. 6: Predicted percentiles of the GSD for the three methods according to manually measured percentiles before calibration. The black line and dotted black line correspond to the  $y=x$  and  $y = 1.5x$  line equations, respectively. Continuous black line, dashed black line and dotted black line corresponds to  $y=x$  equation,  $y=0.5x$  equation and  $y=0.25x$  equation, respectively.





454 Fig. 7: Values of NRMSE (predicted and corrected) and NMAE (predicted and corrected)  
 455 for each softwares. Predicted and corrected correspond respectively to no calibrated and  
 456 calibrated results after linear regression application.

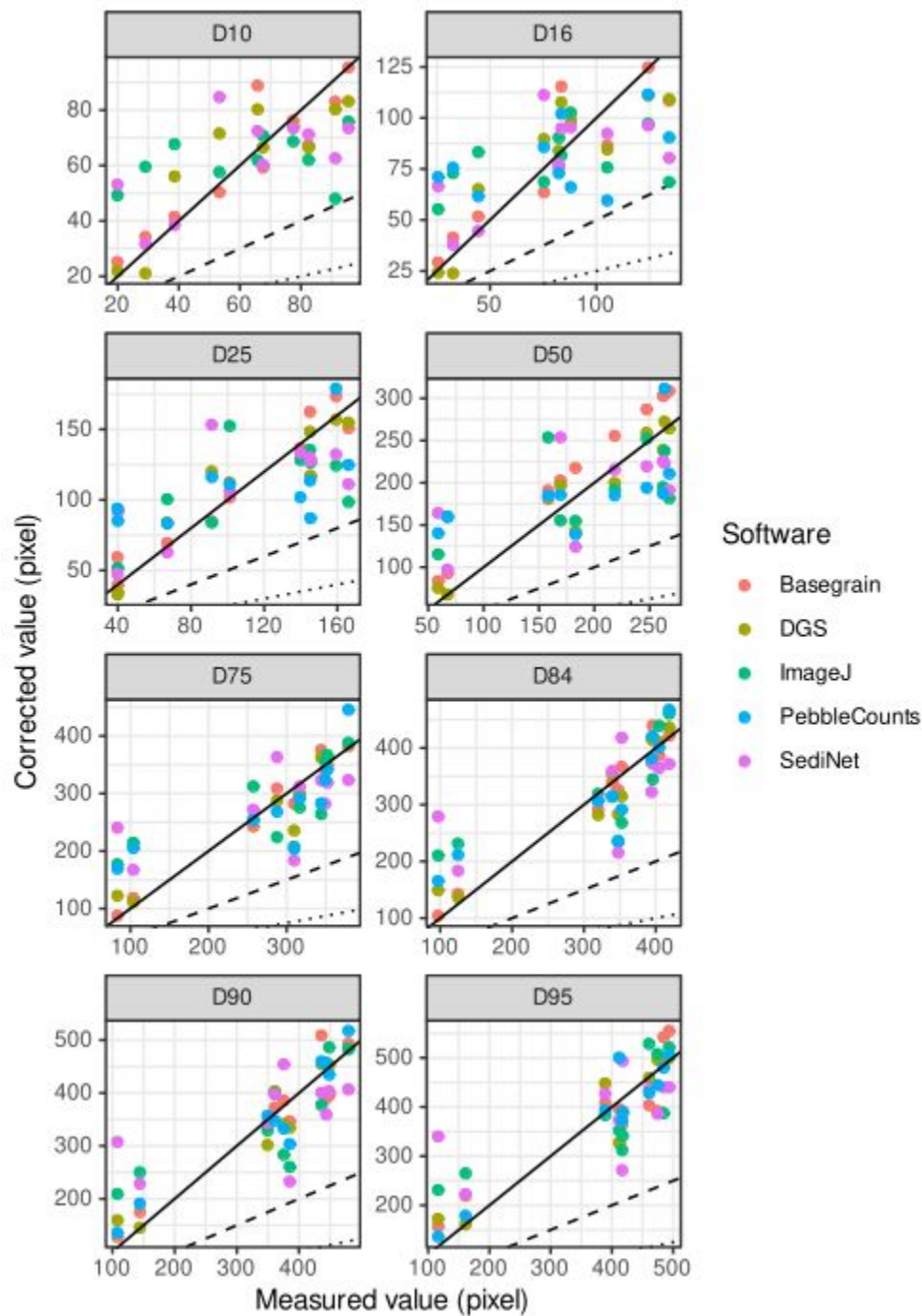


Fig. 8: Predicted percentiles of GSD for the three methods according to manually measured percentiles after calibration. Continuous black line, dashed black line and dotted black line corresponds to  $y=x$  equation,  $y=0.5x$  equation and  $y=0.25x$  equation, respectively.

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Percentile	DGS		Basegrain		ImageJ		PebbleCounts		SediNet	
	R <sup>2</sup>	P-value	R <sup>2</sup>	P-value	R <sup>2</sup>	P-value	R <sup>2</sup>	P-value	R <sup>2</sup>	P-value
D <sub>10</sub>	0.76	0.00096	0.84	0.00018	0.12	0.33	0.04	0.31	0.41	0.047
D <sub>16</sub>	0.79	0.00065	0.80	0.00052	0.15	0.26	0.22	0.17	0.42	0.043
D <sub>25</sub>	0.89	4e-05	0.91	2.2e-05	0.37	0.061	0.35	0.075	0.48	0.026
D <sub>50</sub>	0.92	1e-05	0.94	3.7e-06	0.35	0.07	0.40	0.053	0.40	0.051
D <sub>75</sub>	0.92	1.4e-05	0.97	2.8e-07	0.51	0.02	0.59	0.0087	0.38	0.057
D <sub>84</sub>	0.90	2.4e-05	0.96	5.3e-07	0.57	0.011	0.72	0.0017	0.42	0.042
D <sub>90</sub>	0.92	9.4e-06	0.90	2.6e-05	0.64	0.0054	0.90	2.4e-07	0.36	0.063
D <sub>95</sub>	0.90	2.9e-05	0.84	0.00021	0.63	0.0065	0.92	1.4e-05	0.40	0.052

Tab. 1: R-square values of linear regressions and P-value between grain size percentiles estimated for each software according to grain size percentiles estimated manually.

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