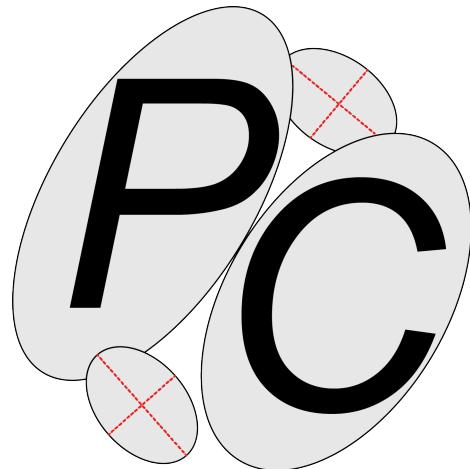

Installing and Running PebbleCounts

Grain-sizing algorithm for gravel-bed river imagery

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1 Introduction

This guide will walk you through the installation and running of PebbleCounts at the command-line. PebbleCounts is a Python based application for the identification and sizing of gravel from either orthorectified, georeferenced (**UTM projected**) images with known resolution or simple non-orthorectified images taken from directly overhead with the image resolution approximated by the camera parameters and shot height. It is a semi-automated program in that edge detection and k-means segmentation are performed automatically, but the user must interactively hand-click the well outlined pebbles and ignore the bad results. For the detailed background and validation (in addition to the suggested use), check out the open-source publication accompanying the algorithm:

Purinton, B. and Bookhagen, B.: Introducing PebbleCounts: a grain-sizing tool for photo surveys of dynamic gravel-bed rivers, *Earth Surf. Dynam.*, 7, 859–877, <https://doi.org/10.5194/esurf-7-859-2019>, 2019.

and cite it if you use the results in your own work.

2 Software Citation

Purinton, Benjamin; Bookhagen, Bodo (2019): PebbleCounts: a Python grain-sizing algorithm for gravel-bed river imagery. V. 1.0. GFZ Data Services. <http://doi.org/10.5880/fidgeo.2019.007>

3 License

GNU General Public License, Version 3, 29 June 2007

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3.1 Disclaimer

PebbleCounts is a free (released under GNU General Public License v3.0) and open-source application written by a geologist / amateur programmer. If you have any problems contact me purinton@uni-potsdam.de

potsdam.de and I can help!

4 Quick note on imagery and running PebbleCounts

Georeferenced ortho-photos should be in a [UTM projection](#), providing the scale in meters. You can use the [gdal](#) command line utilities to [translate rasters between various projections](#). Because PebbleCounts doesn't allow you to save work in the middle of clicking it's recommended that you don't use images covering areas of more than 2 by 2 meters or so. Furthermore, the algorithm is most effective on images of 0.8-1.2 mm/pixel resolution, where a lower cutoff of 20-pixels is appropriate. Resampling can also be accomplished quickly in [gdal](#). For higher resolution (< 0.8 mm/pixel) imagery it's recommended not to go above 1 by 1 meter areas, particularly if there are many < 1 cm pebbles. If you want to cover a larger area simply break the image into smaller parts and process each individually, so you can give yourself a break. If at anytime you want to end the application simply press *CTRL + C*.

4.1 The PebbleCountsAuto Function

In addition to the manual-clicking version of PebbleCounts based on k-means segmentation, we have also developed and included an automated version that has higher uncertainties. We recommend using PebbleCounts in a subset of data to validate larger areas run in PebbleCountsAuto. The description of the automatic algorithm and uncertainties can be found in the publication: <https://doi.org/10.5194/esurf-7-859-2019>. Validation steps using both methods are shown in detail in another publication: <https://doi.org/10.1029/2021JF006260>.

5 Installation

The first step is downloading the GitHub repository somewhere on your computer, and unzipping it. There you will find the Python algorithms (e.g., `PebbleCounts.py`), a folder `example_data` with two example images one orthorectified and the other raw, a jupyter notebook `Read_and_Plot_PebbleCounts_CSV.ipynb` with a tutorial on how to manipulate output grain-size distribution .csv files, and a folder `docs` containing the [full manual](#).

For newcomers to Python, no worries! Installation should be a cinch on most machines. First, you'll want the [Miniconda](#) Python package manager to setup a new Python environment for running the algorithm ([see this good article on Python package management](#)). Download either the 32- or 64-bit Miniconda installer of Python 3.x then follow the instructions (either using the `.exe` file for Windows, `.pkg` for Mac, or `bash installer` for Linux). Add Miniconda to the system `PATH` variable when prompted.

PebbleCounts has a number of important dependencies including [gdal](#) for georeferenced raster manipulation, [openCV](#) for image manipulation and GUI operation, [scikit-image](#) for filtering and measuring, [scikit-learn](#) for k-means segmentation, [shapely](#) for geometry operations, along with a number of standard Python libraries including [numpy](#), [scipy](#), [matplotlib](#), and [tkinter](#).

5.0.1 For Windows

Once you've got [conda](#) commands installed, you can open a command-line terminal and create a conda environment with:

```
conda create --name pebblecounts python=3.6 opencv shapely \
scikit-image scikit-learn numpy gdal scipy matplotlib tk
```

and once installation is complete (and assuming no errors during the install) activate the new environment to run PebbleCounts by:

```
activate pebblecounts
```

Deactivate the environment to exit anytime by:

```
deactivate
```

5.0.2 For Mac and Linux Users

Those using Mac OS or Linux shouldn't have much trouble modifying the above commands slightly (just add a leading [conda](#) to the [activate](#) and [deactivate](#) commands above). Also we need to install [opencv](#) separately from within the virtual environment using the [pip](#) package manager.

Similar to the above, once you have [conda](#) installed we create the virtual environment:

```
conda create --name pebblecounts python=3.6 shapely \
scikit-image scikit-learn numpy gdal scipy matplotlib tk
```

and once installation is complete (and assuming no errors during the install) activate the new environment by:

```
conda activate pebblecounts
```

We've left out the [opencv](#) package which must be installed with the following [pip](#) command in the activated [pebblecounts](#) environment:

```
pip install opencv-python
```

Deactivate the environment to exit anytime by:

```
conda deactivate
```

Issues with opencv on Mac and Linux Note that installing openCV and getting it to function properly can be a pain sometimes, especially in the case of Linux. In that case it is recommended to find some instructions for installing openCV's Python API for your specific Linux operating system [online](#).

6 Overview

6.1 PebbleCounts: K-means with Manual Selection (KMS)

PebbleCounts using the K-means with Manual Selection (KMS) approach can be summed up in the flow chart shown in Figure 1. To briefly summarize, PebbleCounts pre-processes the image by allowing the user to subset the full scene, then interactively mask shadows (interstices between grains) and color (for instance sand). Following this, PebbleCounts windows the scene at three different scales with the window size determined by the input resolution and expected maximum longest-axis (a-axis) grain size provided by the user. This multi-scale approach allows the algorithm to “burrow” through the grain-size distribution beginning by removing the largest grains and ending on the smallest, with the medium sizes in between. At each window the algorithm filters the image, detects edges, and employs [k-means segmentation](#) to get an approximate cleaned-up mask of potential separate pebbles. The window is then shown with the mask overlain and the user is able to click the **good** looking grains and leave out the **bad** ones (see Figure 6). These grains are then measured via ellipse fitting to retrieve the long- and short-axis and orientation. This process is iterated through each window and the output from the counting is provided as a comma separated value (.csv) file for user manipulation.

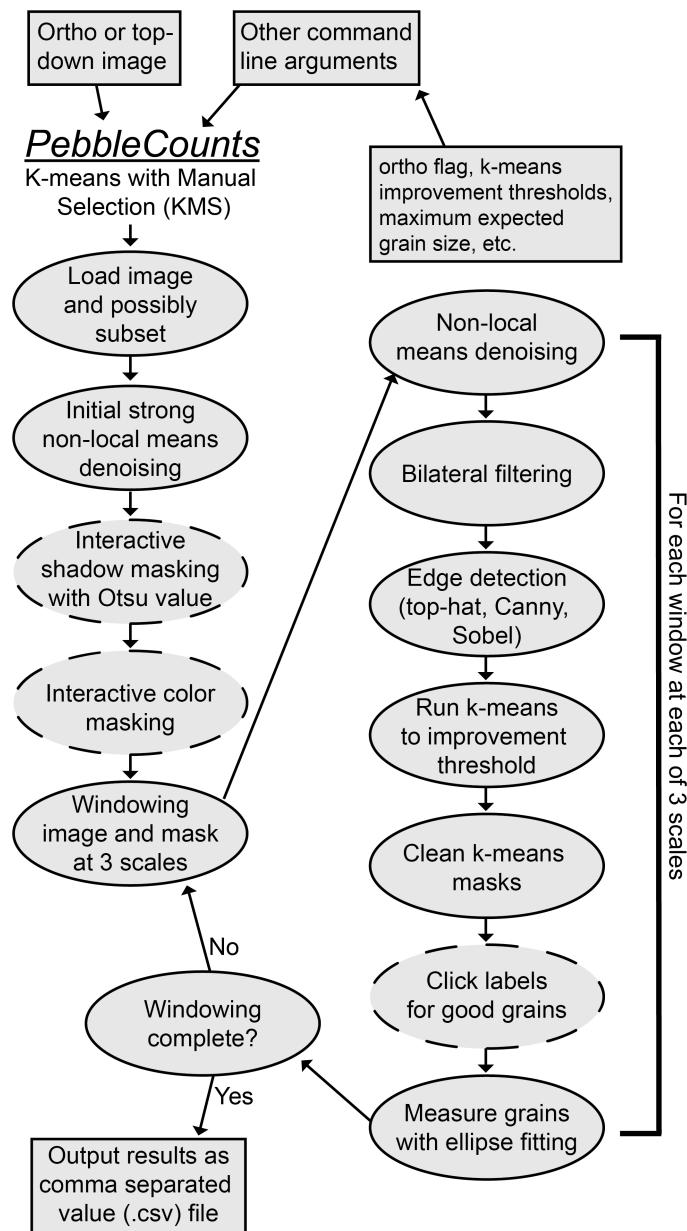


Figure 1: Flowchart of PebbleCounts. The boxes are user supplied input or output from the algorithm. Dashed lines indicate a user input step during processing, either entering and checking values or clicking.

6.1.1 KMS Detailed Processing Steps

Below is an in-depth description of each processing step applied by PebbleCounts. For those wishing to proceed with counting without the full story, go ahead to the **Command-line Options** and then the

Step-by-Step Example sections below! For the nitty-gritty breakdown, follow along:

1. PebbleCounts begins with the input of georeferenced ortho or simple top-down imagery at the command-line along with a number of variable flags. Most of the 20 variables do not need modification, but see their descriptions below to decide.
2. The image is loaded (and possibly subset with a click-and-drag rectangle) and initially denoised with a strong [non-local means denoising](#) filter to smooth color.
3. The [Otsu](#) value for gray-scale thresholding is assessed and the user is asked to supply a percentage of this Otsu value for masking out shadows between grains. The resulting mask is then checked by the user and re-evaluated with a new percentage value, for instance if the value is too high thus causing some of the darker grains to also be masked.
4. The image is displayed and the user can click on a color that should be masked (e.g., uniform colored brown sand or vegetation patches). The masking is accomplished via a narrow range applied to the [HSV](#) color-space around the clicked pixel. The user has the opportunity to accept or reject the additional mask and add more color masks if the full range of interest has not been included. For georeferenced imagery, a binary GeoTiff and a vector polygon shapefile of the sand mask are output at this step. Together, the shadow and color mask provide an initial segmentation of the grains in the image.
5. Following these pre-processing steps, the image and shadow/color mask are windowed at three different scales corresponding to approximately 10, 3, and 2 times the longest expected grain in the image. Each of these windows is passed through steps 6-14.
6. [Non-local means denoising](#) on the [CIELab](#) converted image with the color (chromaticity) filtered but the brightness (luminance) un-altered. This provides a more uniform color for mottled grains.
7. [Bilateral filtering](#) on the CIELab chromaticity bands. This filtering technique reduces noise in an image while preserving high-gradient edges between grains.
8. Edge detection steps applied to the original gray-scale image. This includes [black top-hat](#) and [Sobel](#) filtering, after which a suggested threshold of 90% is applied to only extract the strongest edges, and [Canny](#) edge detection. At each of these steps the associated edge mask is feature-AND ([see textbook by John C. Russ](#)) operated with the shadow/color mask to add additional segmentation details where there is some overlap to definite inter-granular interstices, while avoiding over-segmentation caused by intra-granular noise.
9. Masked pixels are eliminated from the analysis and an $N \times 4$ dimensional vector (N is the number of pixels) is formed with the smoothed CIELab a^* (green-red) and b^* (blue-yellow) chromaticity bands and the X and Y coordinate of the pixel in image space. The chromaticity (a^* and b^*) is rescaled between 0 and 1 and the X and Y is rescaled by a user supplied scaling factor suggested at 0.5. This allows the color information to have a larger influence on clustering in the k-means step, thus avoiding some over-segmentation of larger grains.
10. This $N \times 4$, rescaled vector is passed to the k-means algorithm, which iteratively clusters the

pixels by color and spatial location and checks the overall inertia of the clusters then repeats the clustering with centers shifted until the improvement in subsequent inertia is less than a threshold fractional percentage. This threshold improvement is suggested to be 0.01 for the first, large scale and 0.1 for the medium and fine scale.

11. When the improvement threshold is met, the vector is transformed back into image space, maintaining the k-means labels. Each of these labels is then separately selected and cleaned up via a combination of [binary erosion, dilation, removal of small objects, and clearing of border-touching elements](#). Any labels below the lower cutoff value (e.g., 20-pixel b-axis length) are eliminated. The cleaned label masks are then combined into a final potential grain mask.
12. The potential grain mask is now displayed over the original RGB color image and the user is asked to click labels that contain single, well-defined grains. Here it is suggested that any grain mask that contains the majority of the grain (particularly the edges of the grain) is selected, even if the k-means segmentation led to jagged edges and over-segmentation within the grain. This is because the final ellipse fitting ignores these holes and fits to the largest area covered by the mask label.
13. Each of the labels with a user-selected point clicked inside of it is analyzed for [region properties](#) to extract the grain centroid, area, and the following parameters of an ellipse fit to the region: minor and major axis length, area of the ellipse (for providing a misfit value against the area of the grain), and orientation of the ellipse measured from $-\pi/2$ to $\pi/2$ relative to the positive x-axis (orientation=0) in Cartesian coordinates.
14. The clicked regions are then added to the shadow/color mask and the processing is repeated from step 6 on the next window or beginning at the next of the three scales.
15. Following all windowing, the results of each grain are output as a comma separated value text file. The measurements are given in pixel and metric units by multiplying the pixel amounts by the image resolution in meters per pixel. In case of a UTM projected georeferenced image, the UTM X (Easting) and Y (Northing) coordinates of the grain centroid are also provided. Additionally, from the color mask a fractional percentage of the image that was masked by the HSV range is provided in the output file (e.g., the percentage sand) along with the fractional percentage of the image that was not measured (so combined shadows and grains not identified by PebbleCounts).

6.2 PebbleCountsAuto: Automatic with Image Filtering (AIF)

PebbleCountsAuto using the Automatic with Image Filtering (AIF) approach can be summed up in the flow chart shown in Figure 2. To briefly summarize, PebbleCountsAuto pre-processes the image by allowing the user to subset the full scene, then interactively mask shadows (interstices between grains) and color (for instance sand). Following this, the algorithm detects edges, cleans the mask, and filters suspect grains. The remaining grains are then measured via ellipse fitting to retrieve the long- and short-axis and orientation and the output from the counting is provided as a .csv file for user

manipulation.

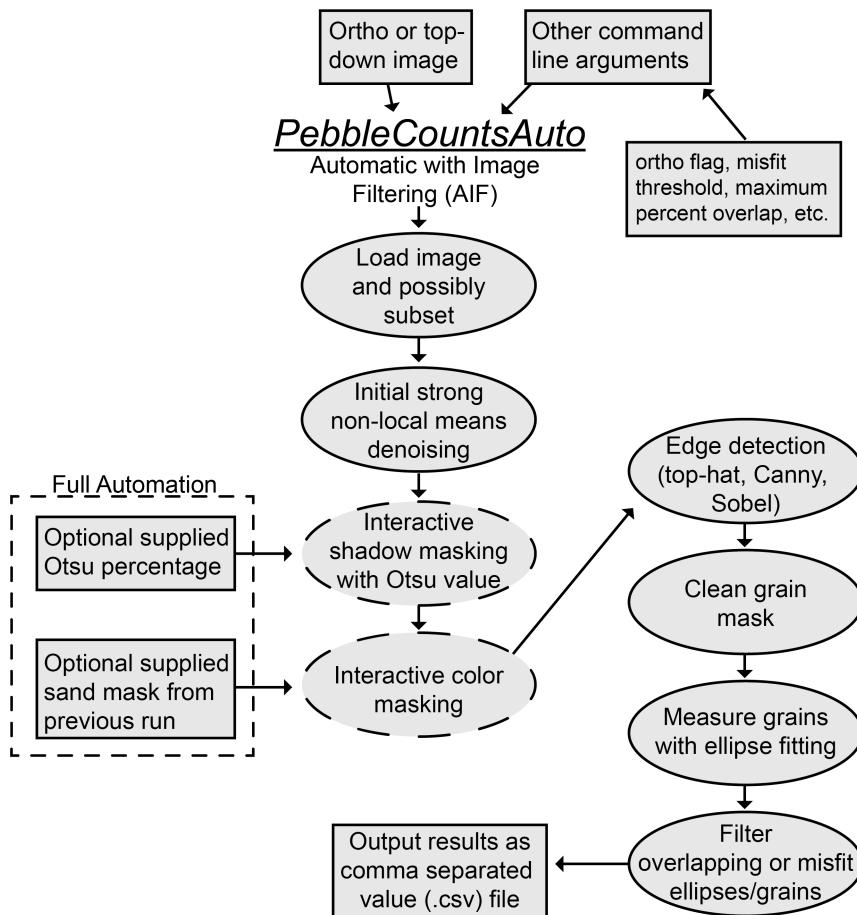


Figure 2: Flowchart of PebbleCountsAuto. The boxes are user supplied input or output from the algorithm. Dashed lines indicate a user input step during processing, either entering and checking values or clicking.

6.2.1 AIF Detailed Processing Steps

Below is an in-depth description of each processing step applied by PebbleCountsAuto:

1. PebbleCountsAuto begins with the input of georeferenced ortho or simple top-down imagery at the command-line along with a number of variable flags. Most of the 15 variables do not need modification, but see their descriptions below to decide.
2. The image is loaded (and possibly subset with a click-and-drag rectangle) and initially denoised with a strong **non-local means denoising** filter to smooth color.
3. The **Otsu** value for gray-scale thresholding is assessed and the user is asked to supply a percentage of this Otsu value for masking out shadows between grains. The resulting mask is then checked

by the user and re-evaluated with a new percentage value, for instance if the value is too high thus causing some of the darker grains to also be masked.

4. The image is displayed and the user can click on a color that should be masked (e.g., uniform colored brown sand or vegetation patches). The masking is accomplished via a narrow range applied to the [HSV](#) color-space around the clicked pixel. The user has the opportunity to accept or reject the additional mask and add more color masks if the full range of interest has not been included. For georeferenced imagery, a binary GeoTiff and a vector polygon shapefile of the sand mask are output at this step. Together, the shadow and color mask provide an initial segmentation of the grains in the image.
5. Following these pre-processing steps, edge detection steps are applied to the original gray-scale image. This includes [black top-hat](#) and [Sobel](#) filtering, after which a suggested threshold of 90% is applied to only extract the strongest edges, and [Canny](#) edge detection. At each of these steps the associated edge mask is feature-AND ([see textbook by John C. Russ](#)) operated with the shadow/color mask to add additional segmentation details where there is some overlap to definite inter-granular interstices, while avoiding over segmentation caused by intra-granular noise.
6. The resulting potential grain labels are cleaned up via a combination of [binary erosion](#), [dilation](#), [removal of small objects](#), and [clearing of border-touching elements](#). Any labels below the lower cutoff value (e.g., 20-pixel b-axis length) are eliminated.
7. Each of the remaining labels are analyzed for [region properties](#) to extract the grain centroid, area, and the following parameters of an ellipse fit to the region: minor and major axis length, area of the ellipse (for providing a misfit value against the area of the grain), and orientation of the ellipse measured from -pi/2 to pi/2 relative to the positive x-axis (orientation=0) in Cartesian coordinates.
8. The grains are then filtered to remove suspect grains in a three step process, where a yes answer to any step eliminates the grain:
 - (A) Does the centroid fall within another ellipse?
 - (B) Does the ellipse overlap with any neighboring ellipses above some threshold? (15% works well)
 - (C) Is the percent misfit (ellipse area vs. grain-mask area) above some threshold? (30% works well)
9. Following filtering, the results of each grain are output as a comma separated value text file. The measurements are given in pixel and metric units by multiplying the pixel amounts by the image resolution in meters per pixel. In case of a UTM projected georeferenced image, the UTM X (Easting) and Y (Northing) coordinates of the grain centroid are also provided. Additionally, from the color mask a fractional percentage of the image that was masked by the HSV range is provided

in the output file (e.g., the percentage sand) along with the fractional percentage of the image that was not measured (so combined shadows and grains not identified by PebbleCountsAuto).

7 Command-line Programs and Variables

Great you've got it installed! Hopefully that is, we're about to find out! The first step to running the software is navigating to the directory where the three scripts live. On Windows that might look like:

```
cd C:\Users\YourName\PebbleCounts
```

Just replace everything after `cd` with the path on your computer to the downloaded `PebbleCounts` folder.

7.1 Calculate Camera Resolution

First off, if the imagery you intend to use is not orthorectified and georeferenced you'll want to calculate the approximate ground resolution of the photos in millimeters per pixel. To do so you can run the script `calculate_camera_resolution.py` at the command line. Parameters to be provided can be listed with `python calculate_camera_resolution.py -h`. Here they all are:

```
usage: calculate_camera_resolution.py [-h] [-focal FOCAL] [-height HEIGHT]
                                      [-sensorHW SENSORHW [SENSORHW ...]]
                                      [-imageHW IMAGEHW [IMAGEHW ...]]
```

optional arguments:

<code>-h, --help</code>	show this help message and exit
<code>-focal FOCAL</code>	Camera focal length in millimeters
<code>-height HEIGHT</code>	Photo capture height in meters
<code>-sensorHW SENSORHW [SENSORHW ...]</code>	The height and width of the internal camera sensor in millimeters
<code>-imageHW IMAGEHW [IMAGEHW ...]</code>	The height and width of the photography in pixels

7.1.1 Example Use

Let's say I have a photo that I took from a height of 1.5 meters at a camera focal length of 35 mm. The camera has a `sensor size` of 15 by 26 mm and was shot at 24 MP resolution, providing a 4000 pixel high by 6000 pixel wide picture. My command would look like this:

```
python calculate_camera_resolution.py -focal 35 -height 1.5 -sensorHW 15 26 -imageHW \
4000 6000
```

And the output printed to the screen would be:

```
Focal length 35.00 mm; Shot from 1.50 m; Sensor size (15.00, 26.00) mm; Image size \
(4000, 6000) pixels:

The field of view is 0.64 by 1.11 m

approximate (x,y) resolution in mm/pixel = (0.1607, 0.1857)
average resolution in mm/pixel = 0.1732
```

And I could then pass this resolution (0.1732) to the `PebbleCounts.py` script.

Note on Shot Height: If you aren't sure exactly what height the image was shot from, use an approximate value. Even for differences of up to 1 m in shot height the ground resolution for most cameras will change by less than 0.2 mm, and thus have a negligible effect on the resulting grain sizes measured.

7.2 PebbleCounts (KMS)

The code can be run from the command-line with

```
python PebbleCounts.py ...
```

Parameters to be provided can be listed with `python PebbleCounts.py -h`. Here they all are:

```
usage: PebbleCounts.py [-h] [-im IM] [-ortho ORTHO]
                       [-input_resolution INPUT_RESOLUTION] [-subset SUBSET]
                       [-sand_mask SAND_MASK] [-otsu_threshold OTSU_THRESHOLD]
                       [-maxGS MAXGS] [-cutoff CUTOFF]
                       [-min_sz_factors MIN_SZ_FACTORS [MIN_SZ_FACTORS ...]]
                       [-win_sz_factors WIN_SZ_FACTORS [WIN_SZ_FACTORS ...]]
                       [-improvement_ths IMPROVEMENT_THS [IMPROVEMENT_THS ...]]
                       [-coordinate_scales COORDINATE_SCALES [COORDINATE_SCALES...]]
                       [-overlaps OVERLAPS [OVERLAPS ...]]
                       [-first_nl_denoise FIRST_NL_DENOISE]
                       [-nl_means_chroma_filts NL_MEANS_CHROMA_FILTS \
NL_MEANS_CHROMA_FILTS ...]
                       [-bilat_filt_szs BILAT_FILT_SZS [BILAT_FILT_SZS ...]]
                       [-tophat_th TOPHAT_TH] [-sobel_th SOBEL_TH]
                       [-canny_sig CANNY_SIG] [-resize RESIZE]

optional arguments:
-h, --help            show this help message and exit
-im IM               The image to use including the path to folder and
                     extension.
-ortho ORTHO          'y' if geo-referenced ortho-image, 'n' if not. Supply
                     input resolution if 'n'.
-input_resolution INPUT_RESOLUTION
                     If image is not ortho-image, input the calculated
                     resolution from calculate_camera_resolution.py
```

```

-subset SUBSET      'y' to interactively subset the image, 'n' to use
                    entire image. DEFAULT='n'
-sand_mask SAND_MASK The name with the path to folder and extension to a
                     sand mask GeoTiff if one already exists.
-otsu_threshold OTSU_THRESHOLD
                     Percentage of Otsu value to threshold by. Supplied to
                     skip the interactive thresholding step.
-maxGS MAXGS      Maximum expected longest axis grain size in meters.
                     DEFAULT=0.3
-cutoff CUTOFF     Cutoff factor (minimum b-axis length) in pixels for
                     found pebbles. DEFAULT=20
-min_sz_factors MIN_SZ_FACTORS [MIN_SZ_FACTORS ...]
                     Factors to multiply cutoff value by at each scale.
                     DEFAULT=[50, 5, 1]
-win_sz_factors WIN_SZ_FACTORS [WIN_SZ_FACTORS ...]
                     Factors to multiply maximum grain-size (in pixels) by
                     at each scale. DEFAULT=[10, 3, 2]
-improvement_ths IMPROVEMENT_THS [IMPROVEMENT_THS ...]
                     Improvement threshold values for each window scale
                     that tells k-means when to halt. DEFAULT=[0.01, 0.1,
                     0.1]
-coordinate_scales COORDINATE_SCALES [COORDINATE_SCALES ...]
                     Fraction to scale X/Y coordinates by in k-means.
                     DEFAULT=[0.5, 0.5, 0.5]
-overlaps OVERLAPS [OVERLAPS ...]
                     Fraction of overlap between windows at the different
                     scales. DEFAULT=[0.5, 0.3, 0.1]
-first_nl_denoise FIRST_NL_DENOISE
                     Initial denoising non-local means chromaticity
                     filtering strength. DEFAULT=5
-nl_means_chroma_filts NL_MEANS_CHROMA_FILTS [NL_MEANS_CHROMA_FILTS ...]
                     Non-local means chromaticity filtering strength for
                     the different scales. DEFAULT=[3, 2, 1]
-bilat_filt_szs BILAT_FILT_SZS [BILAT_FILT_SZS ...]
                     Size of bilateral filtering windows for the different
                     scales. DEFAULT=[9, 5, 3]
-tophat_th TOPHAT_TH Top percentile threshold to take from tophat filter
                     for edge detection. DEFAULT=90
-sobel_th SOBEL_TH Top percentile threshold to take from sobel filter for
                     edge detection. DEFAULT=90
-canny_sig CANNY_SIG Canny filtering sigma value for edge detection.
                     DEFAULT=2
-resize RESIZE      Value to resize windows by should be between 0 and 1.
                     DEFAULT=0.8

```

7.3 PebbleCountsAuto (AI)

The code can be run from the command-line with

```
python PebbleCountsAuto.py ...
```

Parameters to be provided can be listed with `python PebbleCountsAuto.py -h`. Here they all are:

```
usage: PebbleCountsAuto.py [-h] [-im IM] [-ortho ORTHO]
                           [-input_resolution INPUT_RESOLUTION]
                           [-subset SUBSET] [-sand_mask SAND_MASK]
                           [-otsu_threshold OTSU_THRESHOLD] [-cutoff CUTOFF]
                           [-percent_overlap PERCENT_OVERLAP]
                           [-misfit_threshold MISFIT_THRESHOLD]
                           [-min_size_threshold MIN_SIZE_THRESHOLD]
                           [-first_nl_denoise FIRST_NL_DENOISE]
                           [-tophat_th TOPHAT_TH] [-sobel_th SOBEL_TH]
                           [-canny_sig CANNY_SIG] [-resize RESIZE]

optional arguments:
  -h, --help            show this help message and exit
  -im IM               The image to use including the path to folder and extension.
  -ortho ORTHO          'y' if geo-referenced ortho-image, 'n' if not. Supply input resolution if 'n'.
  -input_resolution INPUT_RESOLUTION
                        If image is not ortho-image, input the calculated resolution from calculate_camera_resolution.py
  -subset SUBSET         'y' to interactively subset the image, 'n' to use entire image. DEFAULT='n'
  -sand_mask SAND_MASK The name with the path to folder and extension to a sand mask GeoTiff if one already exists.
  -otsu_threshold OTSU_THRESHOLD
                        Percentage of Otsu value to threshold by. Supplied to skip the interactive thresholding step.
  -cutoff CUTOFF         Cutoff factor (minimum b-axis length) in pixels for found pebbles. DEFAULT=20
  -percent_overlap PERCENT_OVERLAP
                        Maximum allowable overlap percentage between neighboring ellipses for filtering suspect grains.
                        DEFAULT=15
  -misfit_threshold MISFIT_THRESHOLD
                        Maximum allowable percentage misfit between ellipse and grain mask for filtering suspect grains.
                        DEFAULT=30
  -min_size_threshold MIN_SIZE_THRESHOLD
                        Minimum area of grain (in pixels) to be considered in count. Used to clean the grain mask. 10 is good for ~1 mm/pixel images, 20 for < 0.8 mm/pixel. DEFAULT=10
  -first_nl_denoise FIRST_NL_DENOISE
                        Initial denoising non-local means chromaticity filtering strength. DEFAULT=5
  -tophat_th TOPHAT_TH   Top percentile threshold to take from tophat filter for edge detection. DEFAULT=90
```

<code>-sobel_th SOBEL_TH</code>	Top percentile threshold to take from sobel filter for edge detection. DEFAULT=90
<code>-canny_sig CANNY_SIG</code>	Canny filtering sigma value for edge detection. DEFAULT=2
<code>-resize RESIZE</code>	Value to resize windows by should be between 0 and 1. DEFAULT=0.8

7.4 Detail On Some PebbleCounts and PebbleCountsAuto Variables

Here's a bit more detail on some of the less obvious inputs to clarify:

- `-subset` allows the user to run or ignore the interactive subsetting step by a click-and-drag rectangle.
- `-sand_mask` allows the user to input a binary GeoTiff sand mask that already exists for the image, as output by a previous run of `PebbleCounts.py` or `PebbleCountsAuto.py`, to skip the interactive step.
- `-otsu_threshold` allows the user to input a percentage of the Otsu value to use for shadow thresholding to skip the interactive step.
- `-resize` controls the pop-up window size for the GUI. If you notice the window is too small to see the grains then use a high value like 0.9, but if the image is partially off-screen you should try lowering the value to around 0.7.
- `-maxGS` is the expected size in meters of longest axis (a-axis) of the largest pebble in the image based on some field knowledge (rounded up to the nearest 0.05 m). This value is used during the windowing to set the appropriate sizes at the three scales in conjunction with the `-win_sz_factors` input.
- `-cutoff` is the algorithm's lower limit on b-axis measurement given in pixels. The default value of 20 is what we found to be reliable for accurate distribution measurement. This value is also used by the `-min_sz_factors` input to cleanup the mask at each of the three window scales.
- `-improvement_ths` is the fractional percentage (from 0-1) that k-means uses to assess convergence and stopping. The default values are probably good here.
- `-coordinate_scales` is the fractional percentage (from 0-1) to scale the x,y coordinates of each pixel compared with the color information in the k-means segmentation. Since we want to allow for anisotropic grains covering large areas if they have semi-uniform color, we want to scale the relative importance of pixel location by approximately 50% of the color, hence the default values of 0.5 at each scale.
- `-nl_means_chroma_filts` is the level of chromaticity filtering to apply during `non-local means denoising`, which should be reduced at each scale. Higher values lead to more smoothing of the image and a cartoonish appearance. The default values should again be good here. The `-first_nl_denoise` does the same filtering on the entire image as a first step and should be

left high (default=5), unless the user notes over-smoothing in the image, in which case lower this value to 2 or 3.

- `-bilat_filt_szs` is the square window size to apply for [bilateral filtering](#), with the aim of further smoothing the image while preserving interstices between the grains. The size of this filter window should be reduced with the windowing scale. The default values are also good here.
- `-tophat_th`, `-sobel_th`, and `-canny_sig` are the [tophat](#) filter percentile threshold, [Sobel](#) filter percentile threshold, and [Canny](#) edge detection smoothing standard deviation. These are the values used on edge detection from the gray-scale image and are probably good at the default value. The same value is used for each scale.

8 PebbleCounts (KMS) Step-by-Step Example

1. Depending on whether you're going to use an ortho or non-ortho image (and default or modified arguments) run one of the following commands (**Note:** While all of the default arguments can be modified at the command line, it is recommended to stick mostly to the default values. In most cases, only the maximum expected grain-size need to be modified for different images given 0.8-1.2 mm/pixel imagery. For < 0.8 mm/pixel resolution imagery, it may be necessary to double the `-min_sz_factors` default values to provide more clean clicking masks.):
 - **Ortho With Default Arguments:** (Be sure to set the `-ortho` flag to `y` and the resolution will be automatically read by [gdal](#))

```
python PebbleCounts.py -im example_data\ortho_resolution_1.2mmPerPix.tif -ortho y
```
 - **Ortho With Modified Arguments:** (Increase maximum expected grain size.)

```
python PebbleCounts.py -im example_data\ortho_resolution_1.2mmPerPix.tif -ortho y \
-maxGS 0.4
```

- **Non-ortho Imagery With Default Arguments:** (Be sure to set the `-ortho` flag to `n` and also provide the `-input_resolution` in mm/pixel, which can be found as in the above section [Calculate Camera Resolution](#).)

```
python PebbleCounts.py -im example_data\nonortho_resolution_0.63mmPerPix.jpg -ortho n \
-input_resolution 0.63
```

- **Non-ortho Imagery With Modified Arguments:** (Decrease maximum expected grain size. Also, since the resolution of this image is < 0.8 mm/pixel, I've doubled the default values for `-min_sz_factors`)

```
python PebbleCounts.py -im example_data\nonorthogonal_resolution_0.63mmPerPix.jpg -ortho n \
    -input_resolution 0.63 -maxGS 0.2 -min_sz_factors 100 10 2
```

2. If you do subset (-subset flag set to non-default *y* value), click and drag a box on the pop-up window and press the *spacebar* to close the window again.
3. Input a percentage (0-100) of the *Otsu* shadow threshold value, then press enter. This will open a pop-up window displaying the image with the Otsu mask in white. On the keyboard press *r* to flash the original un-masked image, *y* to accept the mask and move on, and *n* to close the window and enter a new value (Figure 3). This step is skipped if a value for -otsu_threshold is provided in the initial command.

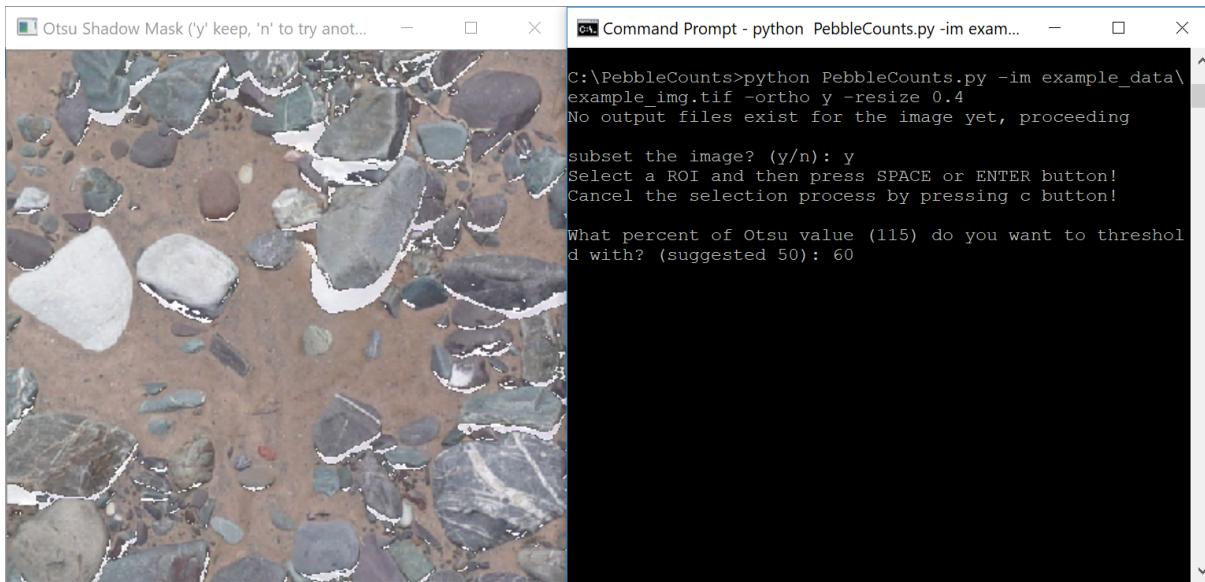


Figure 3: Otsu thresholding of the image with an entered value 0-100. Press *r* to flash the original image, *y* to accept the mask, or *n* to try a different value.

4. Is there a color you want to mask out in the scene? Maybe the sand is a uniform color distinct from the pebbles. If so, then in the next step enter *y*, which will bring up another pop-up window. With the window active, you can press *q* to close it if you decide not to color mask and *r* to flash the original image (Figure 4). Once you click a point in the window with a color you'd like to mask a second pop-up will open displaying the result of applying a mask to this color. Press *y* to accept the mask or *n* to close it and try another click in the first window (Figure 4). Pressing *y* here will return you to the command prompt where you can finish color masking by entering *n* or adding additional color masks by entering *y*. This step is skipped if a path to a binary sand mask GeoTiff for -sand_mask is provided in the initial command.

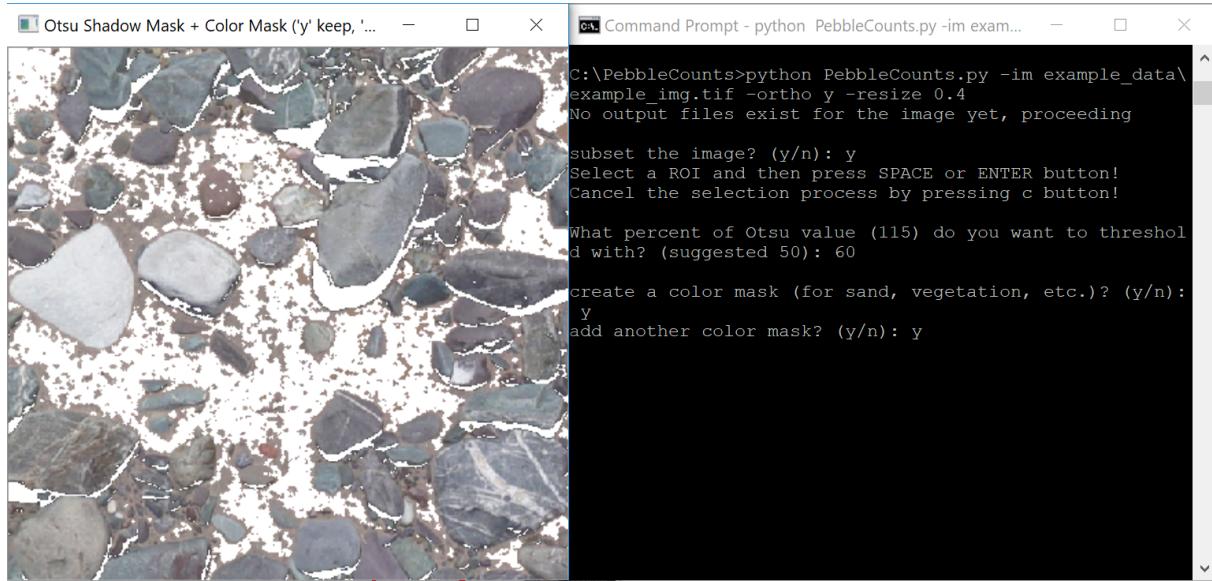


Figure 4: Color masking clicking window. Click on a color you want to mask to open a second window and check it. Press *q* to close window or *r* to flash the original image. Press *y* to accept or *n* to try a different click in the previous window.

5. After these couple interactive steps, PebbleCounts will take over the automated windowing, filtering, edge detection, and k-means segmentation at each window, after which a new window with the mask will open (Figure 5). The command prompt should look something like this:

```
Beginning k-means segmentation
Scale 1 of 3
Window 1 of 1
Non-local means filtering
Bilateral filtering
Black tophat edge detection
Canny edge detection
Sobel edge detection
Running k-means
Current number of clusters: 2, total inertia: 59896.391
Current number of clusters: 3, total inertia: 48804.694
.
Current number of clusters: X, total inertia: XXXX
Cleaning up k-means mask
```



Figure 5: Automated segmentation via edge detection and k-means clustering and pop-up window.

6. After the mask is cleaned a new window will open where you need to click the good looking grains and ignore the bad ones (Figure 6). Left clicking anywhere on the image will produce a black circle at that point, meaning that you've selected all the pixels in this connected region as one grain. A right click anywhere on the image will remove the last click and exchange the black circle for a red one, indicating this area will not be considered (unless of course you add another left click to the region). Overlay the original image to help decide what is and is not a well delineated grain by pressing *r* once to open the image and *r* again to close the image and return to the mask. Once you are satisfied with your clicks press *q* to close the window and automatically move on to the next window and/or scale. The clicked grains will be automatically measured and added to the final output.

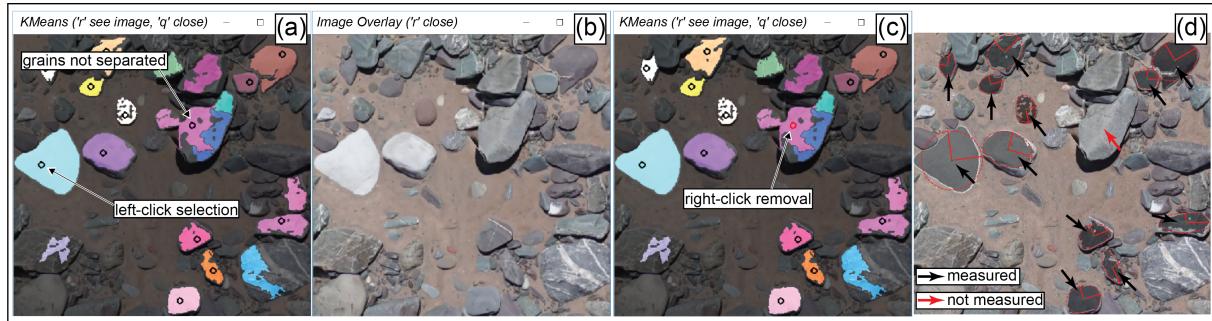


Figure 6: (a) Interactive k-means mask clicking window. A left click adds a pebble region and black circle. Pressing *q* will close the image and continue segmentation on the next window. (b) Pressing *r* opens the original image to check the mask against, *r* again to close the original image. (c) Right click anywhere on the image to remove the last clicked point and replace the black circle with a red one. (d) Shows the final ellipses fit to each of the clicked regions.

7. Repeat the clicking on each window that pops up (see the command window for what number window out of the full number you are on). With a little practice this will go quickly. After the windows are done the results will be saved out and you can repeat from step 1 with another image.

8.1 An important note on clicking!

As shown in Figure 6, PebbleCounts does not provide a perfect segmentation. Two errors you will commonly note are:

1. Under-segmentation of overlapping grains. Avoid clicking these regions or the resulting ellipse will be fit to many grains.
2. Over-segmentation of single grains. Here it is up to the user to decide which part of the segmented grain (if any) to select. If the mask covers the majority of the grain despite some holes or shrinkage, then it is advisable to select the grain, since the final ellipse will be fit to the full region covered. Even if the center of a grain is entirely missing from the mask, if the ends of the grain are in the same mask then the fit ellipse will approximate the grain well.

9 PebbleCountsAuto (AIF) Step-by-Step Example

The processing of PebbleCountsAuto follows the above steps 1-4, with the option to skip the Otsu and color masking steps using the `-otsu_threshold` and `-sand_mask` command-line variables.

PebbleCountsAuto is otherwise entirely automated. Thus we only provide a few examples of command-line entries for using this algorithm:

- **Ortho With Default Arguments:** (Be sure to set the `-ortho` flag to `y` and the resolution will be automatically read by `gdal`)

```
python PebbleCountsAuto.py -im example_data\ortho_resolution_1.2mmPerPix.tif -ortho y
```

- **Ortho With Modified Arguments:** (Decrease Sobel and Tophat thresholds to provide more edge detection and decrease the misfit threshold to reduce potential bad measurements. Also includes the sand mask generated during the KMS `PebbleCounts.py` run and the Otsu percentage threshold, thus leading to full automation of this run.)

```
python PebbleCountsAuto.py -im example_data\ortho_resolution_1.2mmPerPix.tif -ortho y \
-sand_mask example_data\ortho_resolution_1.2mmPerPix_PebbleCounts_SandMask_TIFF.tif \
-tophat_th 85 -sobel_th 85 -misfit_threshold 20 -otsu_threshold 50
```

- **Non-ortho Imagery With Default Arguments:** (Be sure to set the `-ortho` flag to `n` and also provide the `-input_resolution` in mm/pixel, which can be found as in the above section **Calculate Camera Resolution.**)

```
python PebbleCountsAuto.py -im example_data\nonorthoo_resolution_0.63mmPerPix.jpg \
-ortho n \
-input_resolution 0.63
```

- **Non-ortho Imagery With Modified Arguments:** (Double the default value for `-min_size_threshold` since the resolution is < 0.8 mm/pixel. Also decrease the Sobel and Tophat thresholds to provide more edge detection given the higher resolution.)

```
python PebbleCountsAuto.py -im example_data\nonorthoo_resolution_0.63mmPerPix.jpg \
-ortho n \
-input_resolution 0.63 -min_size_threshold 20 -tophat_th 85 -sobel_th 85
```

10 Output Files

PebbleCounts(Auto) saves out a few outputs in the same folder that the image resides:

- csv: `filename_PebbleCounts(Auto)_CSV.csv`
- label image (georeferenced if original is): `filename_PebbleCounts(Auto)_LABELS.tif`
- figure showing results: `filename_PebbleCounts(Auto)_FIGURE.png`

And if the input is georeferenced imagery:

- binary GeoTiff (input for `-sand_mask` command-line argument): `filename_PebbleCounts_SandMask_TIFF.tif`
- and vector shapefile of the sand mask: `filename_PebbleCounts_SandMask_SHP.shp`

10.1 The CSV File

A detailed example of showing the `PebbleCounts.py` (KMS) and `PebbleCountsAuto.py` (AIF) output .csv files including their contents and how to manipulate them in python is provided in the Jupyter Notebook `Read_and_Plot_PebbleCounts_CSV.ipynb`, which you can view without needing to install anything [HERE](#).

The results .csv contains the parameters used in the PebbleCounts run to generate the file. This may be useful when testing different parameter combinations to keep track of the results.

The results .csv has an entry for each grain (Figure 7) showing the fraction of the scene not measured (combined background shadow and unmeasured grains) the fraction of the scene that was selected by the color mask as background color (e.g., sand) and each grains' characteristics including a- and b-axis of the fit ellipse in pixels and in meters, the area covered by the grain mask in pixels and square meters, the orientation of the fit ellipse measured from $-\pi/2$ to $\pi/2$ relative to the positive x-axis (orientation=0) in cartesian coordinates, the area of the ellipse, and the percent misfit between the ellipse and the grain given by the percentage difference in area. If the input imagery is georeferenced the UTM Northing (Y) and Easting (X) coordinates of the pebble's centroid are provided.

	A	B	C	D	E	F	G	H	I	J	K
1	PebbleCounts Parameters										
2	otsu_threshold	maxGS	cutoff	min_sz_fa	win_sz_fa	improvem	coordinate_overlaps	first_nl_d	nl_means	bilat_filt_s	top
3	50	0.3	20	[50, 5, 1]	[10, 3, 2]	[0.01, 0.1,	[0.5, 0.5, 0	[0.5, 0.3, 0	5	[3, 2, 1]	[9, 5, 3]
4											
5	Image Details										
6	perc. not meas	perc. background color									
7	56.321	22.8574									
8											
9	Pebble Details										
10	UTM X (m)	UTM Y (m)	a (px)	b (px)	a (m)	b (m)	area (px)	area (m ²)	orientatio	ellipse are	perc. diff. are
11	836644.2878	7242473	87.02468	55.85653	0.104462	0.067049	3401	0.0049	-2.30998	3807.286	10.67127
12	836644.5051	7242473	91.02893	55.04593	0.109269	0.066076	3433	0.004947	-2.52788	3924.675	12.5278
13	836644.6023	7242473	46.61951	38.26777	0.055961	0.045936	1288	0.001856	-0.219	1397.333	7.824401
14	836644.5159	7242473	150.841	69.1135	0.181065	0.082962	7258	0.010458	-2.21407	8165.476	11.11357
15	836644.1702	7242473	114.2621	108.5649	0.137157	0.130318	8869	0.012779	-3.00259	9716.069	8.718226
16	836644.8208	7242473	212.117	124.006	0.254619	0.148853	20114	0.028982	-1.52553	20602.38	2.370486

Figure 7: Example .csv file output by algorithms for a georeferenced image. The *perc. not meas.* is the fractional percentage of the image that was either shadows or not measured and *perc. background color* is the fractional percentage of the image that was masked during interactive HSV color selection (e.g., for sand). Also, *perc. diff. area* is the percentage difference in area between the ellipse (*ellipse area (px)*) and grain (*area (px)*), or the approximate misfit of the ellipse.