BIVALVE: An imagery-based validation framework for benthic habitat classification from side-scan sonar data

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Abstract

BIVALVE (**B**enthic **I**magery **VAL**idation and **V**isual **E**nhancement) is a methodology and supporting Python-based software toolkit for the development of verified classified benthic maps from photographic ground-truthing data, intended for use in the validation of classified maps generated from side-scan sonar data by machine-learning tools.

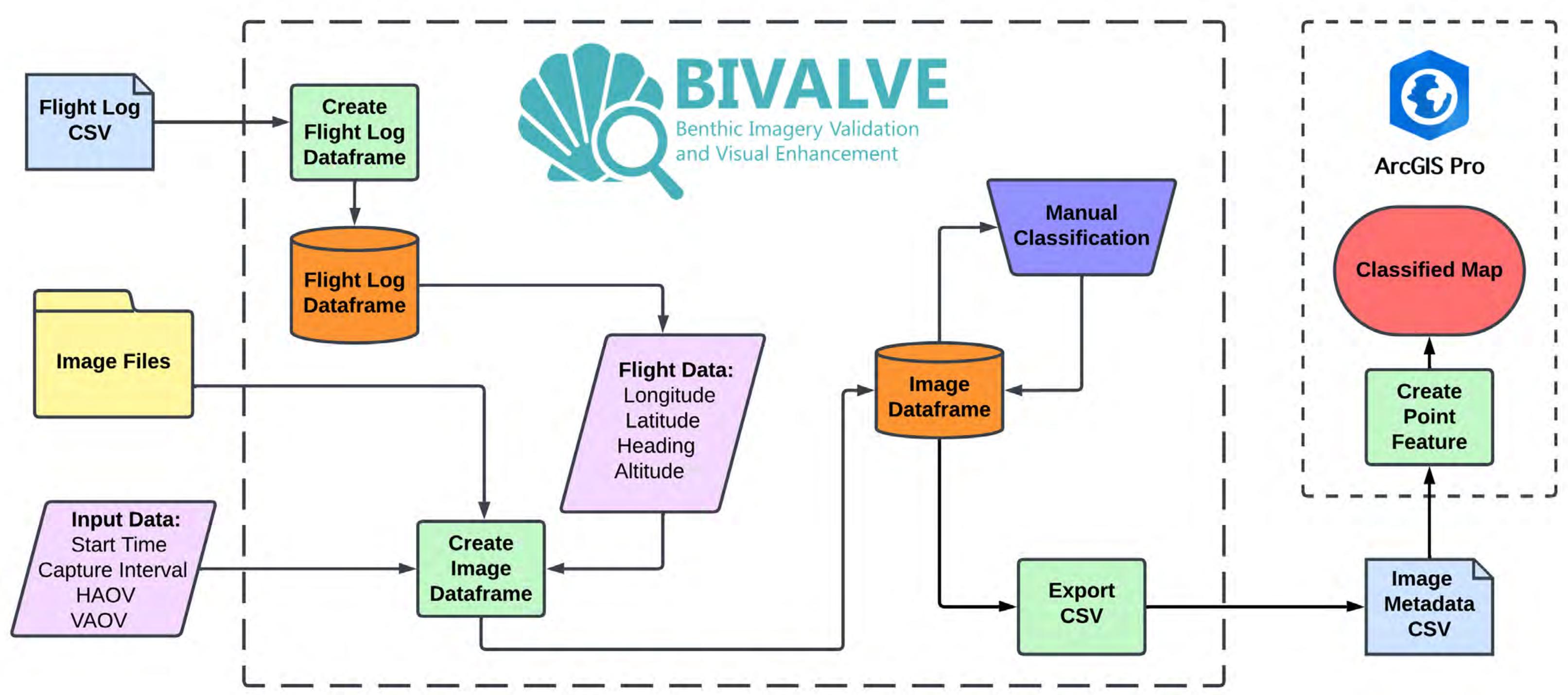

Fig 1. The workflow for developing classified maps from image and AUV flight data using BIVALVE and ArcGIS Pro

Background

- Despite advancements in machine learning (ML), in situ ground-truthing (e.g. grab sampling) remains standard practice for benthic habitat mapping using side-scan sonar
- Developing ML algorithms to the point of autonomy from in situ validation could significantly reduce cost and time required for sonar-based benthic habitat surveys
- Validation tools developed from large, high-density datasets spanning many habitats are critical for assessing accuracy in:
    1. Habitat classification from universal training datasets
    2. Spatial delineation of habitat transition zones

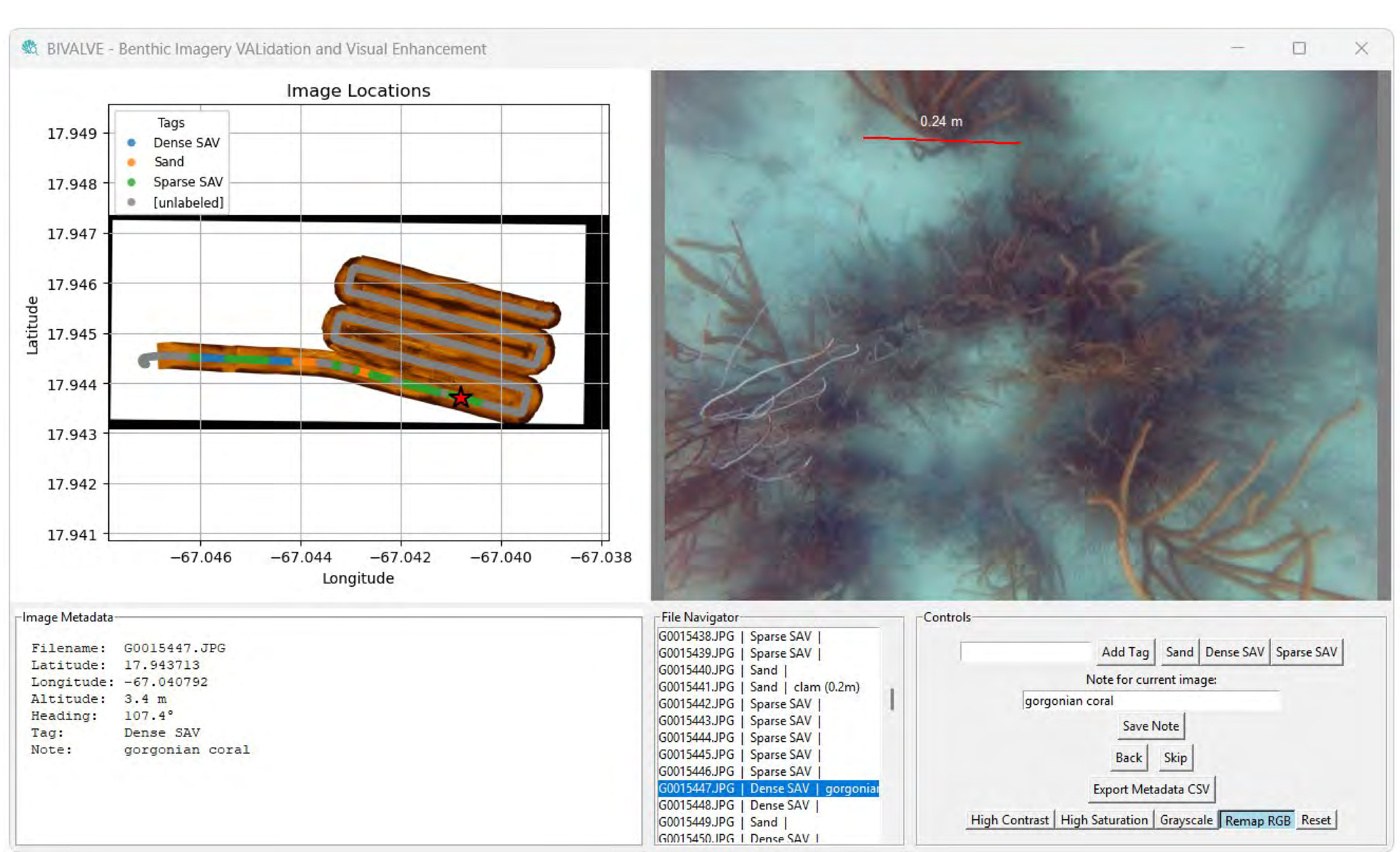

Fig 2. The BIVALVE GUI, shown midway through the classification process for the La Parguera Nature Reserve dataset.

Methodology

Data Collection:

- Simultaneous sonar and photo data via AUV-mounted camera

Metadata Derivation and Application:

- Positional data for each image (latitude, longitude, heading, and altitude) is derived through interpolation of AUV flight log data and stored in internal metadata table

Expert Classification:

- Human analyst generates and assigns class tags to each image in dataset using BIVALVE GUI
- GUI features including distance measurement tool, live map display, and Histogram Equalization (HE) filter assist in classification process

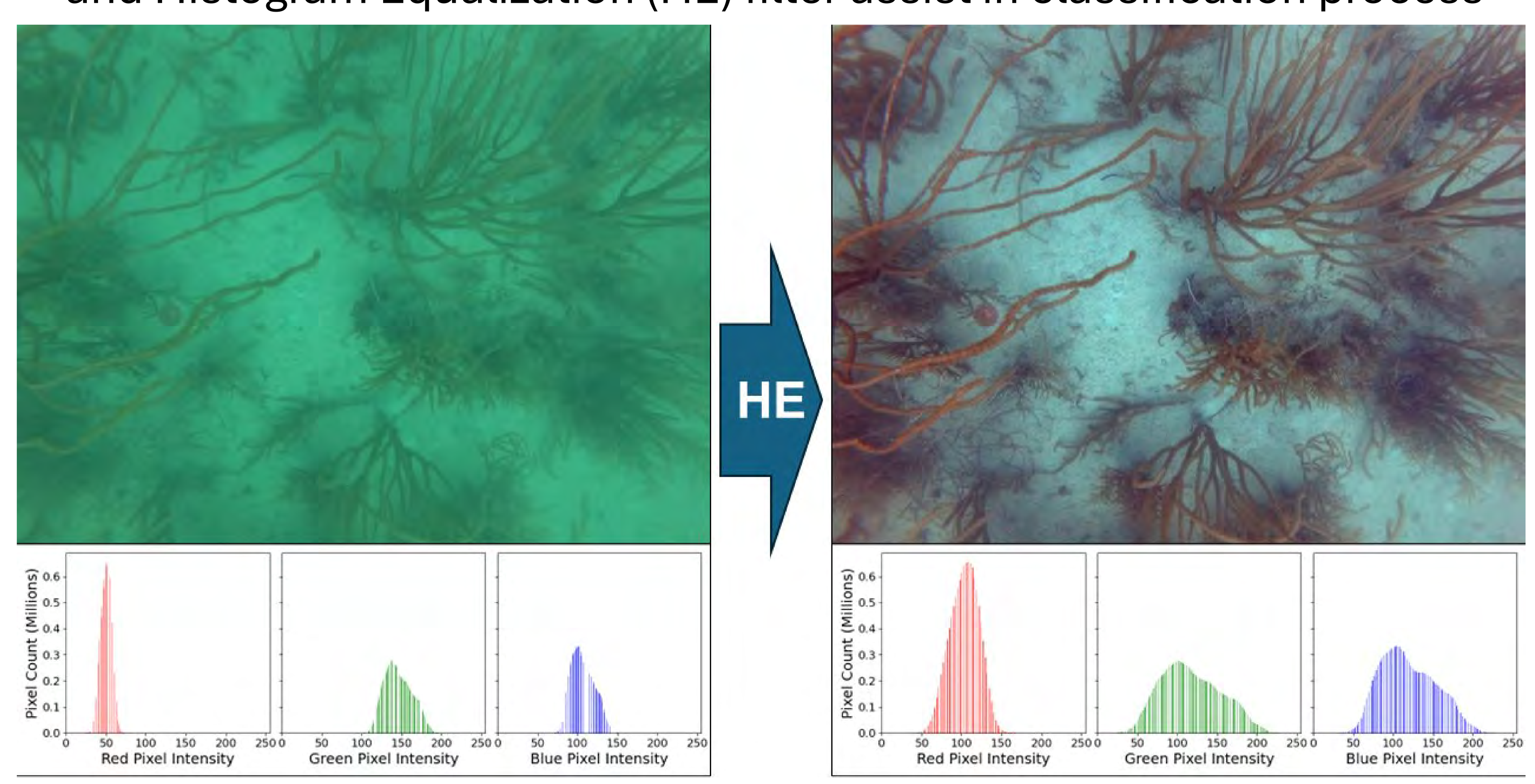

Fig 3. Demonstration of the effect of Histogram Equalization on an image in the dataset. BIVALVE reads the range of pixel intensity values for each color channel, then proportionally redistributes each histogram across the entire intensity range.

Map Generation:

- Metadata table exported as CSV file, imported into ArcGIS Pro, and converted to a classified point feature map using BIVALVE geoprocessing toolkit

Validation:

- Unclassified side-scan sonar imagery processed using SonarWiz and imported into ArcGIS Pro as raster layer
- Individual images containing prominent features are imported as raster layers and compared with side-scan imagery to confirm proper spatial alignment

Data Analysis:

- Classified map generated from side-scan sonar imagery using machine learning-based tool (e.g. SonarClass, SonarWiz Seabed Classification Tool) and imported into ArcGIS Pro as raster layer
- Agreement between validated points (BIVALVE output) and ML-based classified map quantified using statistical methods

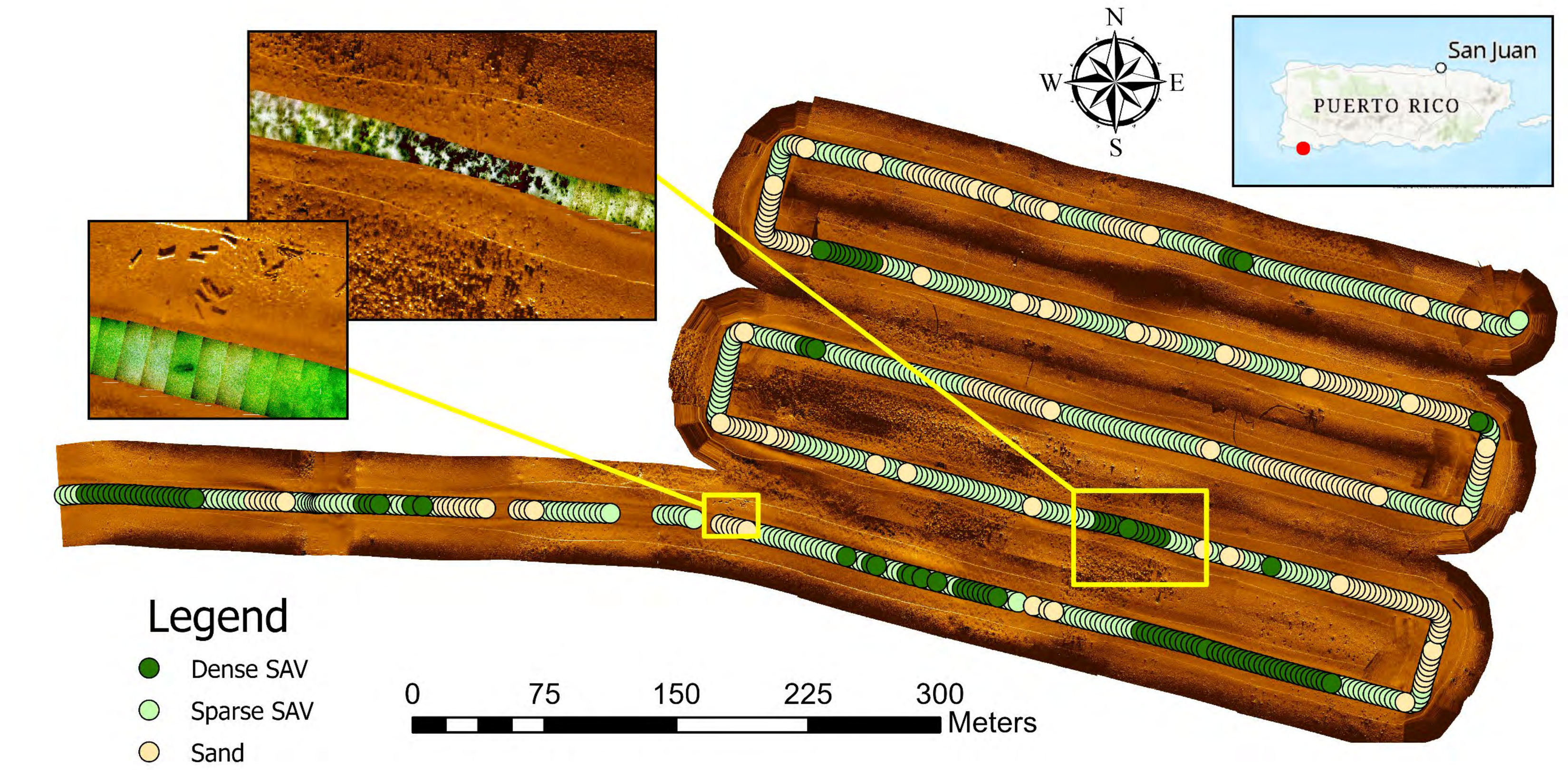

Fig 4. Classified point map superimposed on side-scan imagery data from La Parguera survey. (lower inset) **D**ebris field used as tie point to verify proper synchronization of imagery data. (upper inset) Transition zone shown in both side-scan imagery and imported image files.

Results

- BIVALVE methodology implemented on data from April 2024 survey in La Parguera Nature Reserve, Puerto Rico
- Equipment: REMUS 100 AUV, GoPro Hero7 camera
- 911 images captured within side-scan survey area
- 857 images (94.1% of dataset) classified into one of three categories (Dense SAV, Sparse SAV, and Sand) by a human analyst
- Remaining images we left unclassified due to high turbidity

Discussion and Conclusions

- Statistical analysis approaches:
    1. Hamming Distance – single-value output indicating overall agreement percentage
    2. Confusion Matrix – provides overall accuracy, per-class accuracy, and Kappa statistic (chance-corrected agreement)
    3. Cluster Validation Metrics (Fowlkes-Mallows Index, Adjusted Rand Index) – evaluate quality of clustering results from unsupervised classification processes
- Adjustments made to classification algorithm parameters (texel size, textural indices, etc.) based on results
- Given proper site selection and turbidity conditions, classified validation maps useful in optimizing ML classification algorithms can be generated using the BIVALVE framework
- Large/high-contrast features (e.g. SAV coverage, sand waves) most easily identified
- BIVALVE may not be ideal when features such as sediment grain size and dominant macrofauna are required for classification

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https://github.com/jdidomenico/bivalve