A framework for river connectivity classification using temporal image processing and attention-based neural networks

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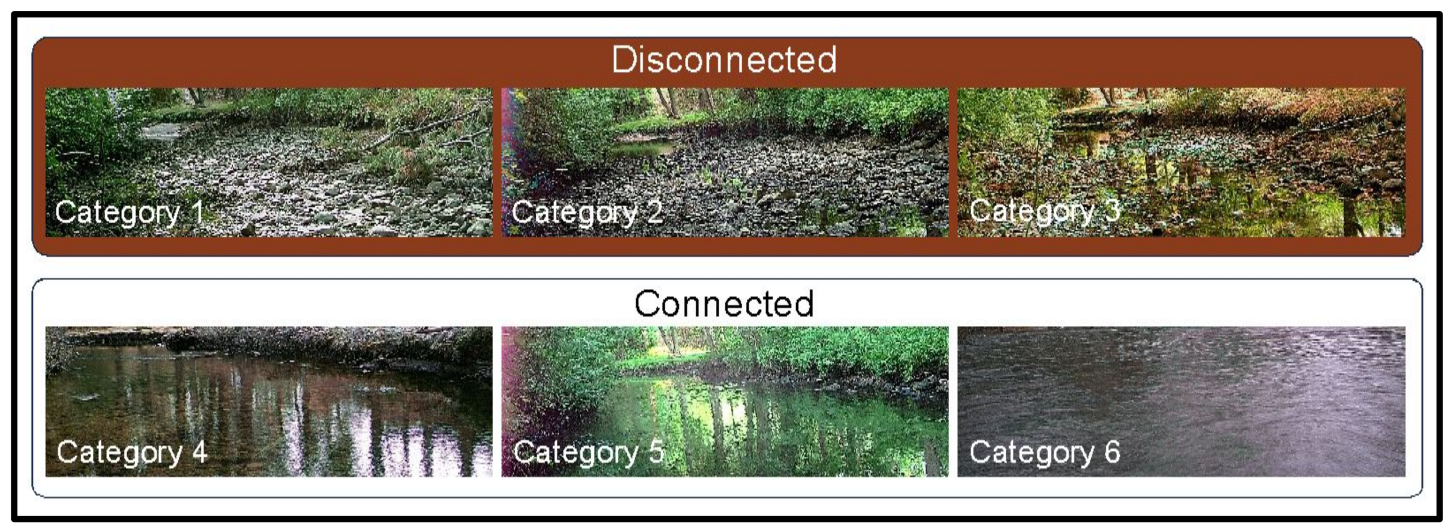
INTRODUCTION

Connected river stream flow is crucial for sensitive aquatic species' survival. Climate change has caused widespread disconnection events in small headwater streams (Zipper et al., 2021), increasing the need for alternative to stream flow gauges. We use an image dataset from Bellucci et al. (2020), where stream ecologists categorized images into six connectivity types. Manual labeling is labor-intensive and exhausting. To improve this, we developed an automated image classification system with a preprocessing pipeline, data augmentation, and machine learning classification, achieving **90% accuracy** on new unseen site images. Our system focuses on two categories: Category 1 (labels 1, 2, 3) and Category 2 (labels 4, 5, 6), shown below:

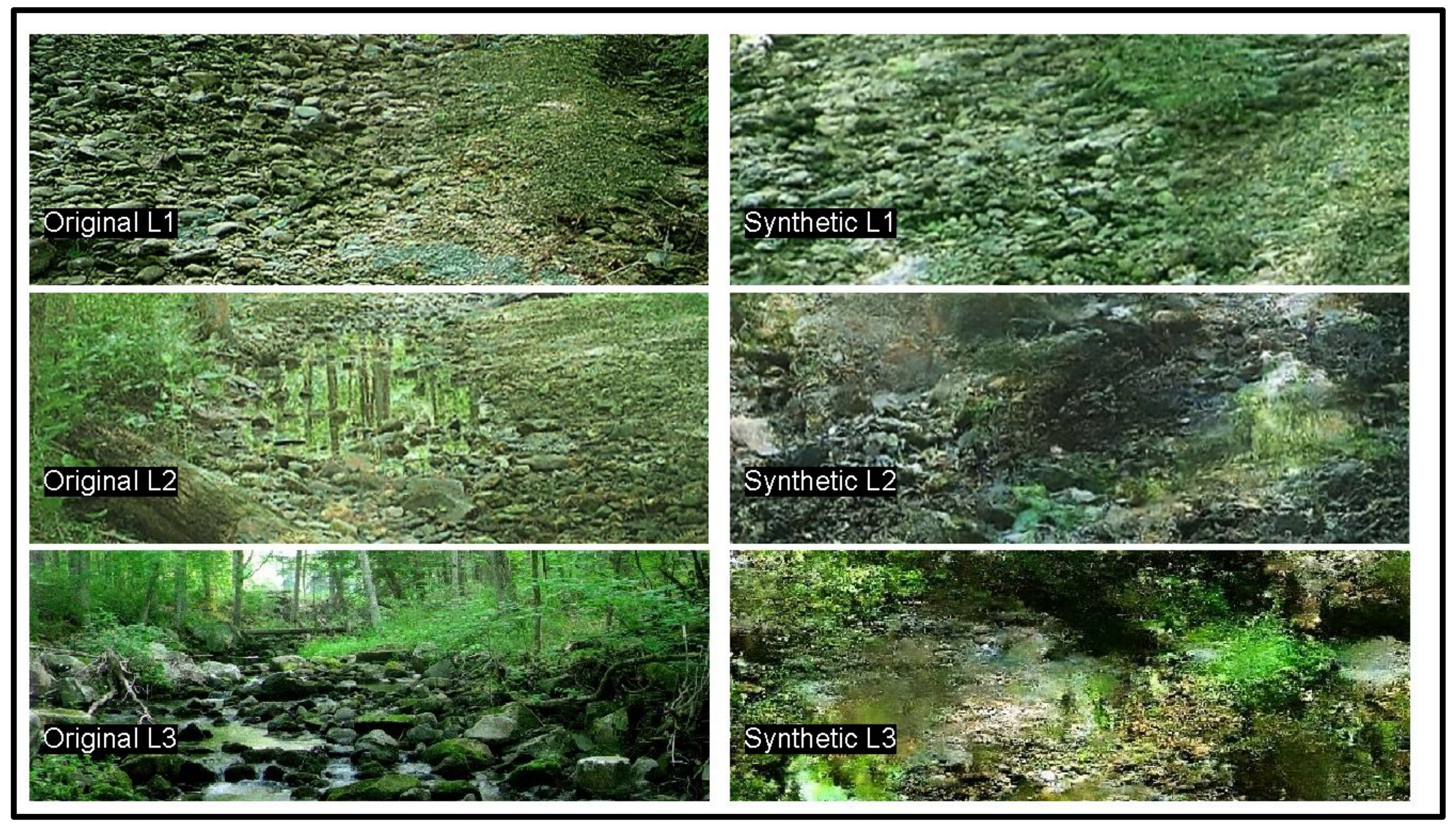


METHODOLOGY

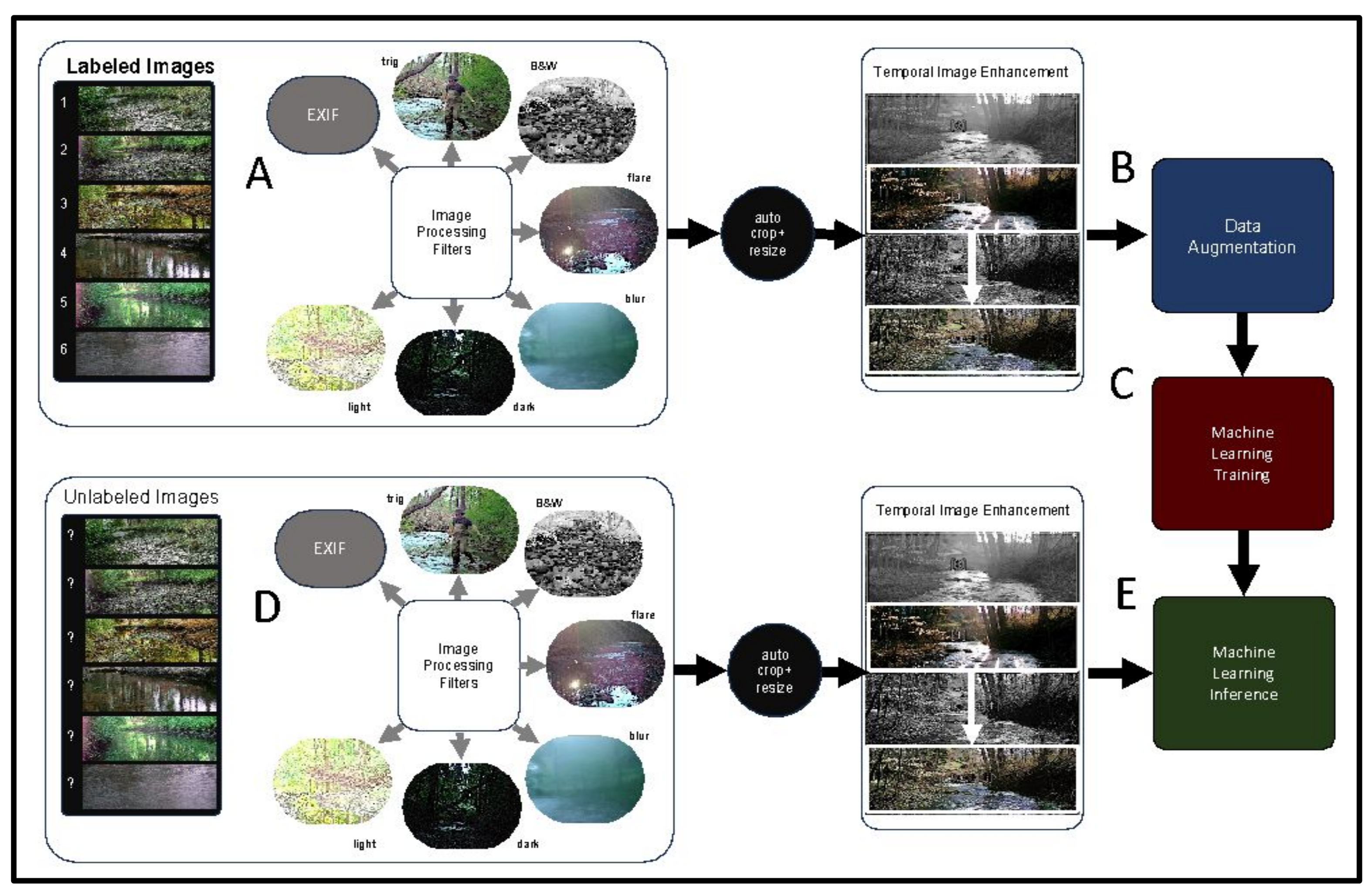
The preprocessing pipeline **filters images** that are over-exposed, under-exposed, black and white, blurred, flared, or triggered by people or animals. The remaining images are enhanced with the temporal enhancement pipeline, auto-cropped, and fed into the machine learning framework. The **temporal enhancement** pipeline groups hourly images with timestamps, applies shadow elimination, converts to YCrCb color space to average brightness, and converts back to the original color. This process enhances classification accuracy by addressing shadows and highlights.

Due to environmental and human-induced shifts in river connectivity, **data augmentation** is often used to prevent model bias toward majority classes. We used horizontal flips and histogram equalization for **basic augmentation.**

For **Diffusion-based** augmentation, we trained a DDM with a dataset balanced by rotations (5° to 30° in 5° increments) and horizontal flips, until it reaches convergences, like below:

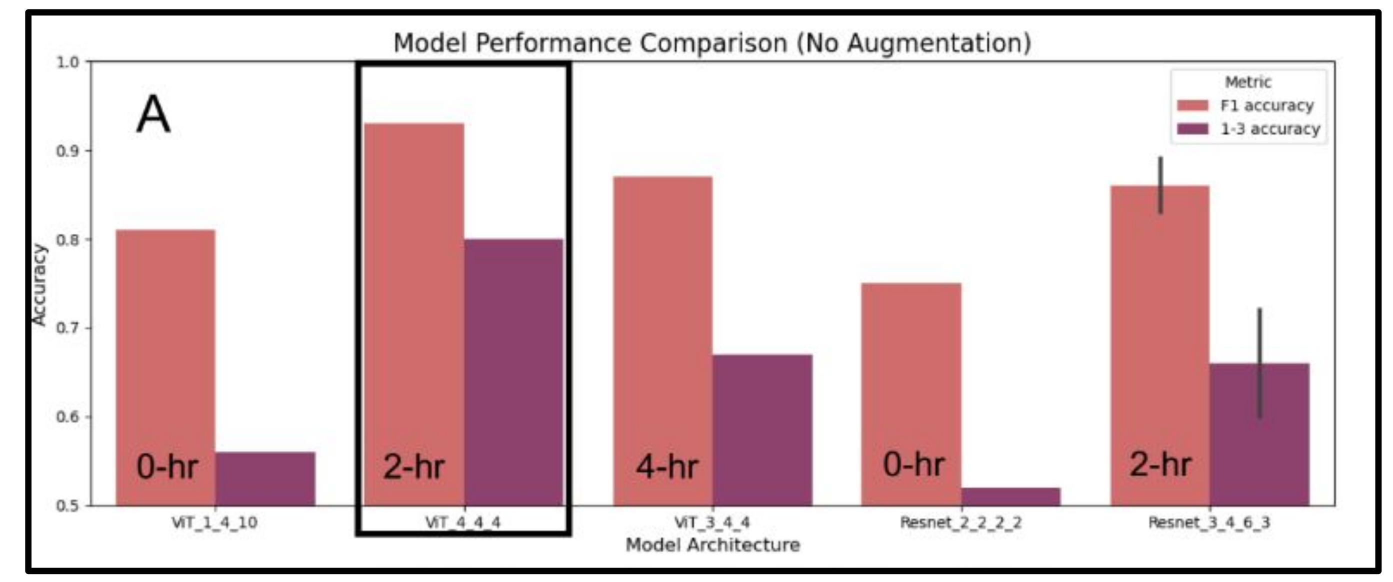


We used deep residual convolutional neural networks **(RESNET)** and vision transformers **(ViT)** for classification. Both methods effectively learn water connectivity patterns but vary in model size, affecting inference practicality. We focused on a small set of hyperparameters to build compact, deployable models on general-purpose computing. Future work aims for CPU-only inference with high accuracy (>90%) for connected and disconnected streams and rivers. Our overall workflow is summarized below.



RESULTS

To create our dataset partitions, we measure the differences between each subset label distribution using absolute or squared differences, optimizing partition sizes and randomly selecting site IDs to ensure a training set without testing set images. We then use the *F1* metric (harmonic mean of precision and recall). Our best model used temporal enhancement without augmentation, as detailed in the chart below.



The best-performing model, ViT_4_4_4, used 2-hour temporal enhancement without augmentation. Basic augmentation reduced overall accuracy but also lowered variance, likely due to insufficient diverse information from histogram equalization. Diffusion-based augmentation also dropped accuracy from 0.87 *F1* to 0.73 *F1*. Better training parameters might improve Diffusion-based augmentation performance, but time constraints limited exploration.

FUTURE DIRECTION

A natural extension to our work is to build models for classes 1-2, 3-4, and 5-6 (3-category problem). There is also future work in exploring alternate cropping strategies that could potentially derive more augmentation for less frequent labels and could work synergistically with our DDM models.

References

- Zipper et al, "Pervasive changes in stream intermittency across the United States." Environmental Research Letters (July 2021)
- Bellucci et al, "A novel method to evaluate stream connectivity using trail cameras," River Research and Application (October 2020)