Image2Biomass Prediction

2025-2026 Fall

Background and Aims

The Critical Need:
Accurately estimating pasture biomass is essential for ensuring animal welfare and maintaining soil health.

Limitations of Current Methods:

- **Clip & Weigh**: Accurate but too slow and impossible to scale.
- **Meters**: Plate and capacitance meters are unreliable in variable conditions.
- **Remote Sensing**: Need manual validation and cannot separate species' biomass.

Impact:
Enable farmers to make smarter grazing choices and drive the agriculture industry toward more sustainable and productive systems.

Related works

Advanced Vision Backbones

- **Vision Transformers** (ViT): Shifted from standard CNNs to Transformer-based architectures for better global context understanding.
- **SigLIP** (Sigmoid Loss for Language Image Pre-training): A state-of-the-art multimodal model (Zhai et al., 2023) that outperforms standard CLIP in image-text understanding, offering robust feature extraction for complex pasture textures.

Transfer Learning & Datasets

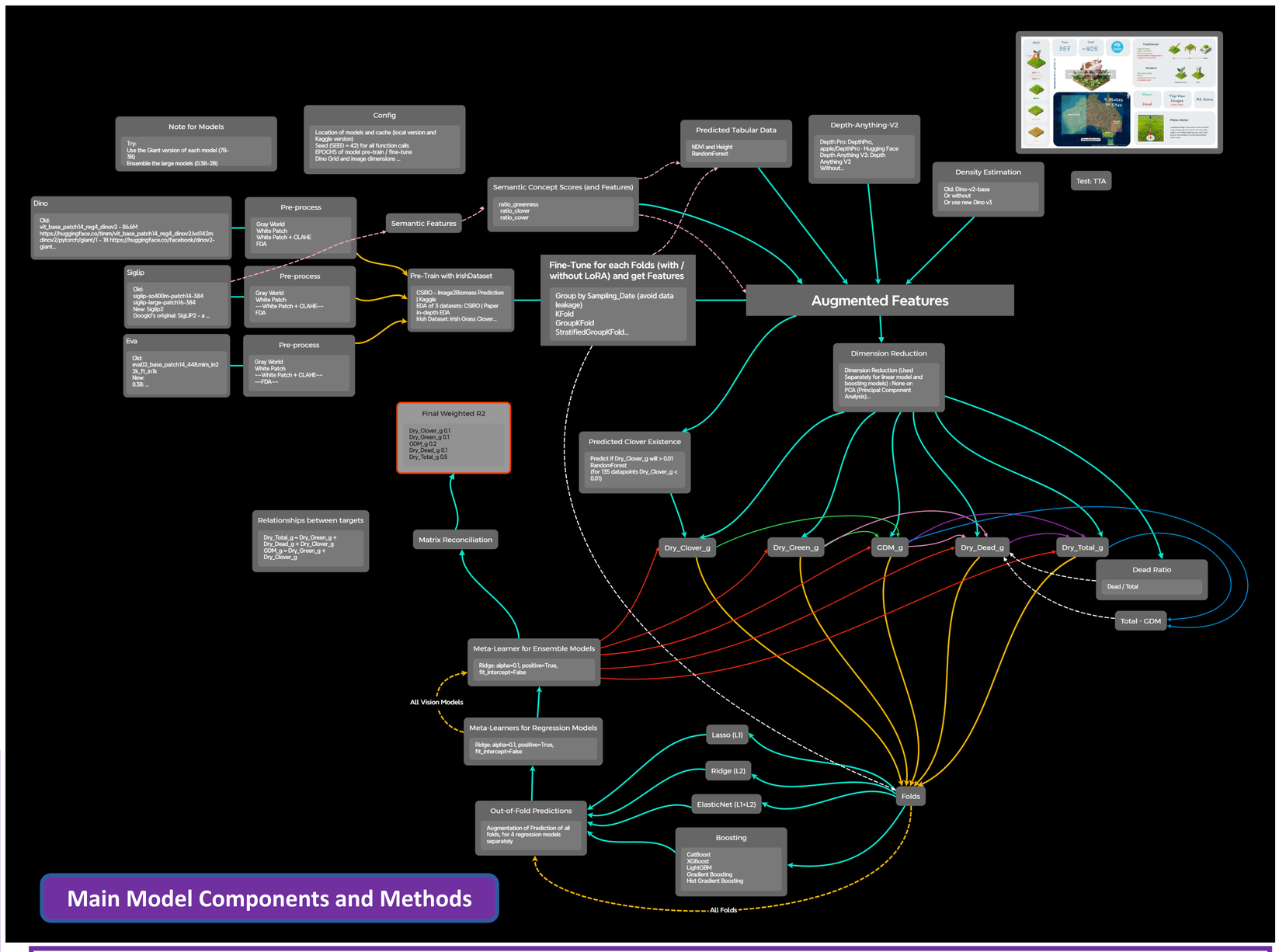
- **Data Scarcity**: Accurate biomass prediction is often limited by small, region-specific datasets.
- **Domain Adaptation**: Utilizing external datasets like the Irish Grass Clover Dataset (VistaMilk/Hennessy et al.) for pre-training has proven effective in learning generalizable features (e.g., distinguishing clover from grass) before fine-tuning on local Australian pastures.

Results

Model Architecture	Configuration Details	Weighted R2 Score
Baselines (CNN)	Pure EfficientNet-B0	0.47
Baselines (ViT)	DINOv2 + Lasso Regressor	0.43
	DINOv2 + ElasticNetCV	0.40
Ensemble V1	Simple Ensemble of 3 ViTs (DINOv2, SigLIP, Eva02)	0.64
Feature Engineering	SigLIP + Semantic Concept Scores	0.66
Proposed Method	**Current Stacking Model (Multi-modal + Chain)**	**0.70**

Key References

Zhai, X., et al. (2023). Sigmoid Loss for Language Image Pre-training. ICCV. (arXiv:2303.15343)
Liao, Q., et al. (2025). CSIRO - Image2Biomass Prediction. Kaggle.
Mahdavikia, A. (2023). Irish Grass Clover Dataset. Kaggle Open Source Dataset.



Main Model Components and Methods

Vision Backbones & Pre-training

- **Backbones**: Utilized State-of-the-Art ViTs: DINOv3, SigLIP2, and Eva-02 for robust feature extraction.
- **Cross-Validation**: Implemented Group-K-Fold (grouped by Sampling Date) to prevent data leakage and ensure temporal robustness.
- **Domain Adaptation**: Pre-trained on the Irish Dataset to align the models with pasture biomass domains before fine-tuning on the target dataset.
- **Preprocessing**: Applied Gray World, White Patch, CLAHE, and FDA to normalize lighting and domain shifts across images.

Feature Engineering & Augmentation

- **Multi-Modal Fusion**: Constructed "Augmented Features" vector by utilizing:
  - **Visual Embeddings**: High-dimensional features from ViT backbones.
  - **Semantic Scores**: Calculated ratios for Greenness, Clover, and Cover.
  - **Tabular Imputation**: Used boosting model to predict and impute missing tabular data (NDVI, Pasture Height).
- **Dimensionality Reduction**: Applied PCA / PLS / GMM to condense the feature space for linear and boosting models separately.

Training

- Utilized a boosting model to predict "Clover Existence" as a mask for output
- Exploited inter-target correlations by training targets in a dependency chain.
- The prediction for Dry Dead Matter is reinforced by a meta-learner that explicitly incorporates derived physical constraints: Dead Ratio (Dead / Total) and Mass Balance (Total - GDM).

Hierarchical Ensemble Strategy (Stacking)

- **Level-1 Models:** A diverse set of regressors trained on the augmented features, including:
  - **Gradient Boosting**: CatBoost, XGBoost, LightGBM.
  - **Linear Regressors**: Lasso (L1), Ridge (L2), ElasticNet.
- **Level-2 Meta-Learner:** A Ridge Regression meta-learner aggregates the Out-of-Fold (OOF) predictions from Level-1 models to generate prediction.

Post-Processing

- Matrix Reconciliation: Applied to ensure predicted sub-components (Clover, Green, Dead) sum logically to the Total Biomass, maximizing Weighted R^2)

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