A Deep Learning Framework for Land Use Land Cover Change Forecasting in the Brazilian Amazon

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Introduction & Motivation

Anticipating land use dynamics (LULC) in tropical biomes remains a non-trivial task, with direct implications for policy-centered downstream applications, such as **REDD+ carbon projects and environmental monitoring**.

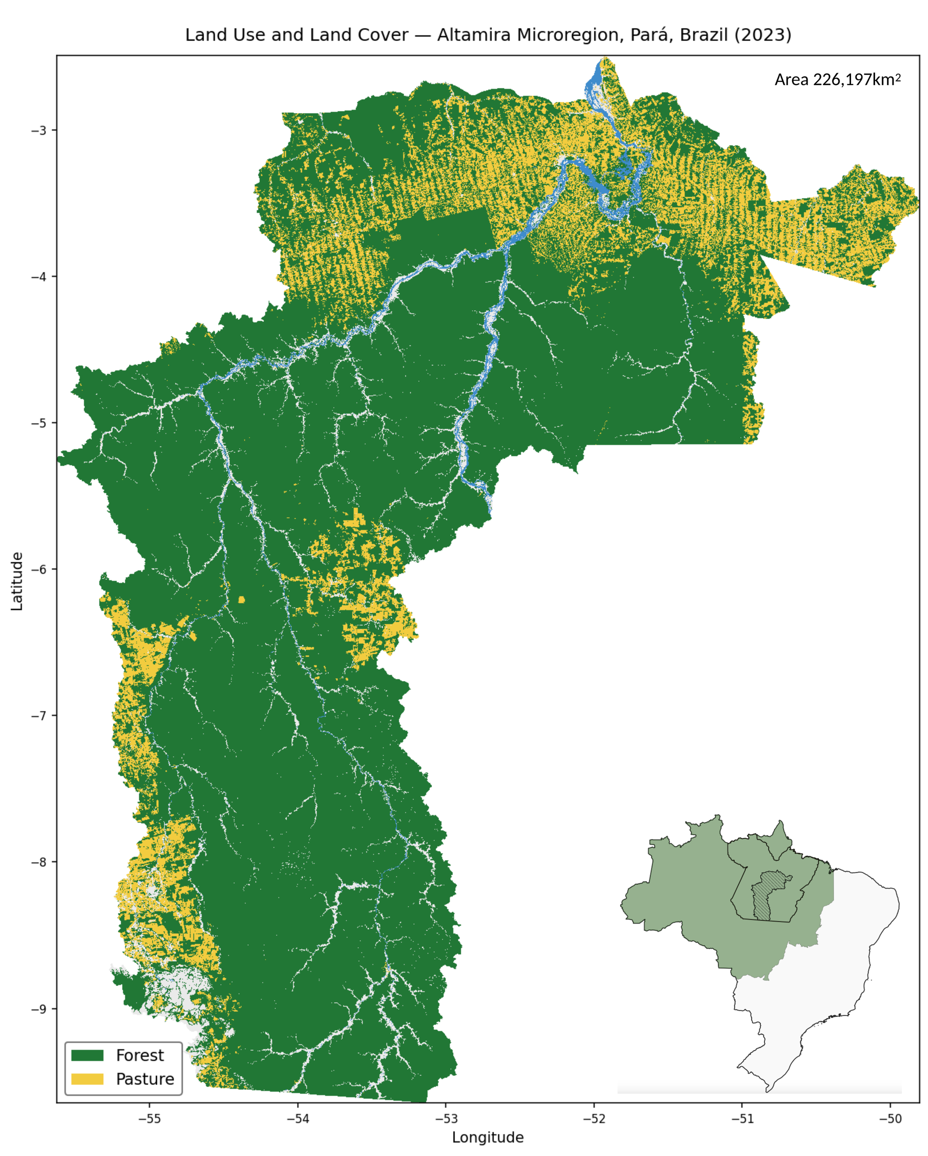
Pasture expansion is the single **largest driver of forest loss in the Brazilian Amazon**, a phenomenon largely driven by **economic incentives and land tenure configuration**[1].

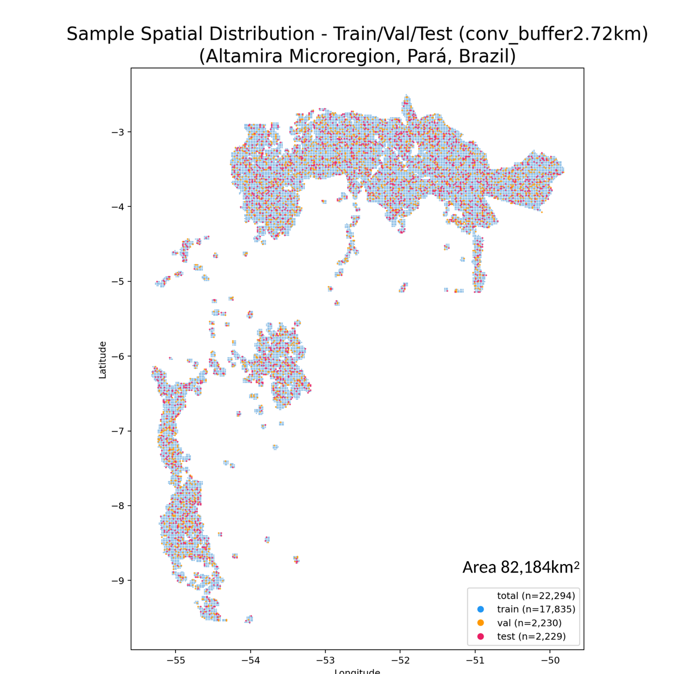
Our study proposes a **multimodal supervised deep learning framework** for both pixel-level (30 m) and patch-level prediction (3,69 km^2) of **forest-to-pasture conversion**, integrating economic and land tenure signals expected to influence land-use decisions.

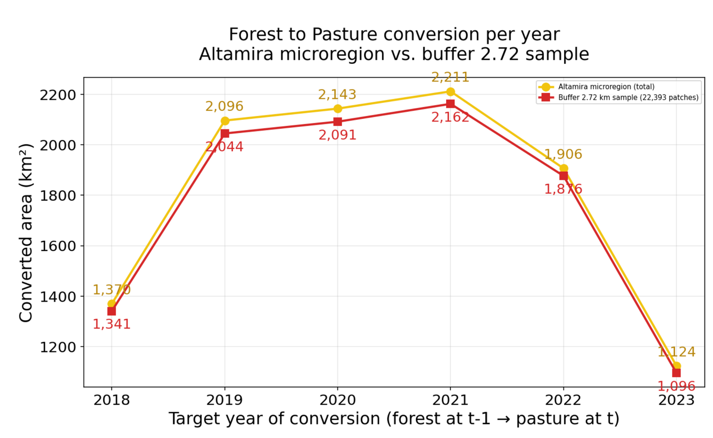
We assess the model's **one-year-ahead** prediction capability.

Study Area

We focus our analysis on the **frontier zone of a carbon sink microregion in Brazil**.

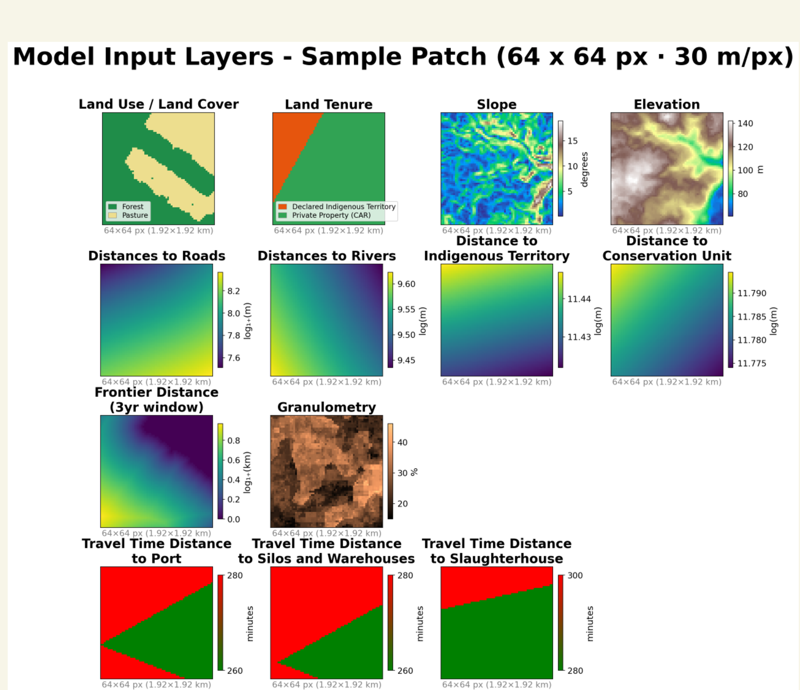


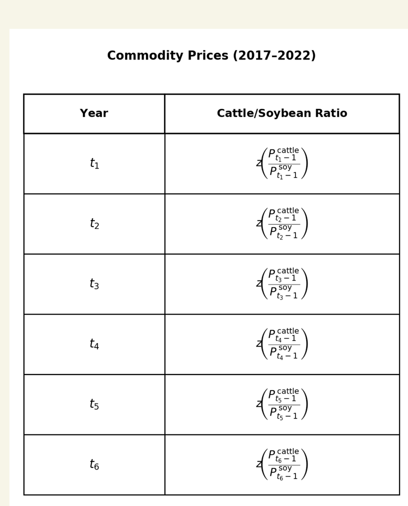




Data & Preprocessing

Our analysis is based on the LULC MapBiomas Brasil dataset, complemented by land tenure data from Imaflora and soil granulometry (MapBiomas). Cattle and Soy prices are collected from Brazil's National Supply Company(CONAB).
After preprocessing, we generate a set of input layers per pixel: distance to roads (SAD/Imazon), distance to rivers (MapBiomas), distance to Protected Territories (Imaflora), and travel time to the agricultural commodity network (OSRM). For each input year *t*, we compute a 3-year conversion frontier distance. Elevation and slope were derived from ANADEM's digital terrain model.



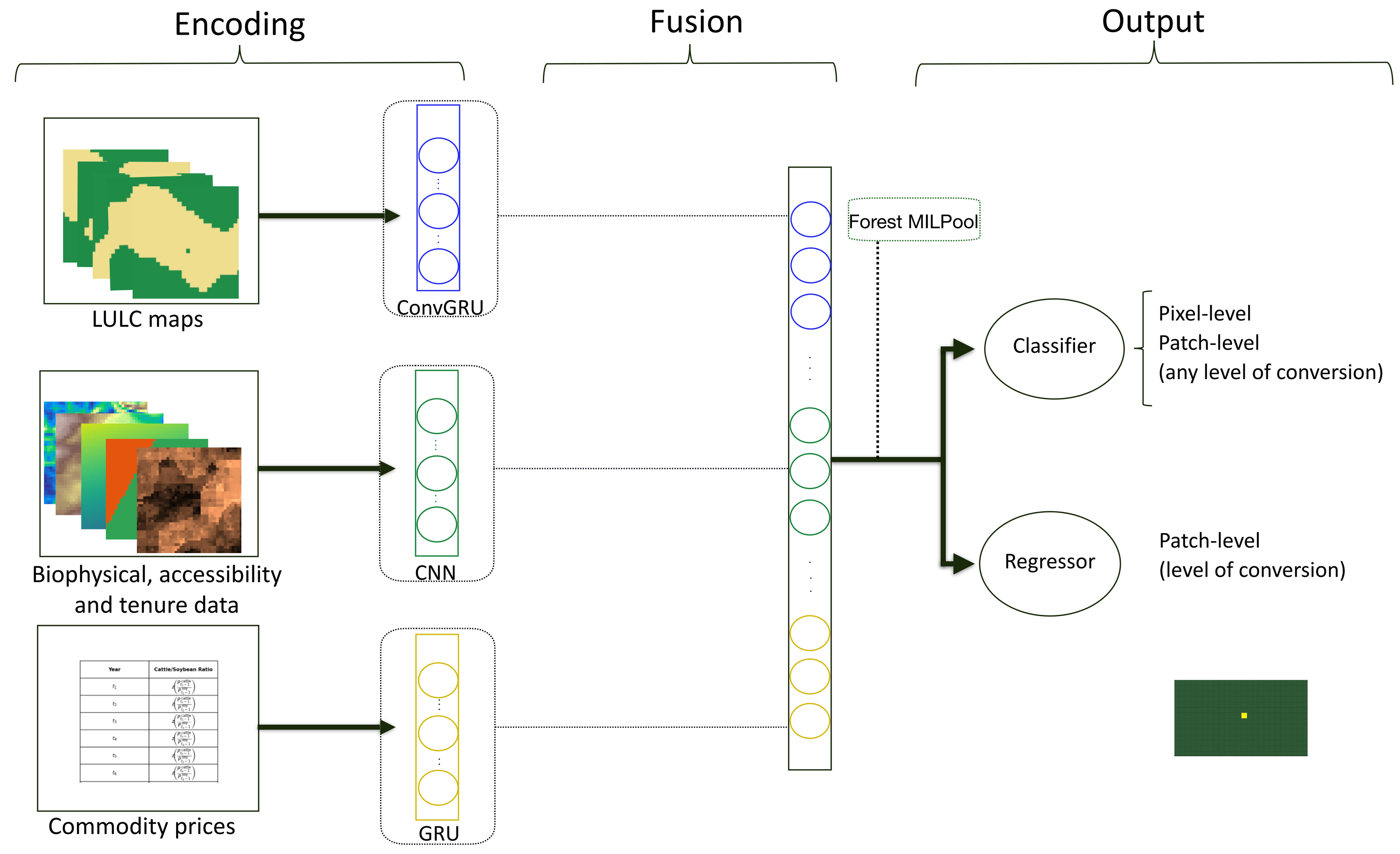

Commodity Prices (2017-2022)

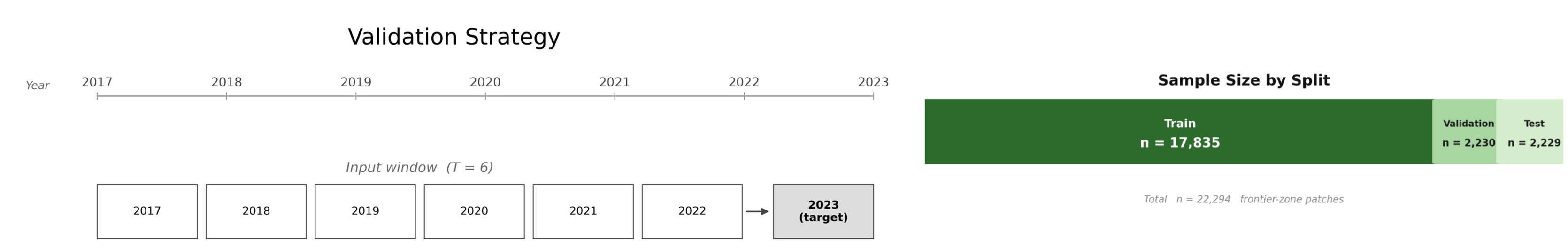
Year	Cattle/Soybean Ratio
t_1	[illegible]
t_2	[illegible]
t_3	[illegible]
t_4	[illegible]
t_5	[illegible]
t_6	[illegible]

Methodology

We implement a modality-specific encoder combining a **Convolutional Neural Network (CNN) and a Gated Recurrent Unit (GRU)**, and concatenate the resulting feature representations in a late-fusion layer for final output.

DL Multimodal Framework



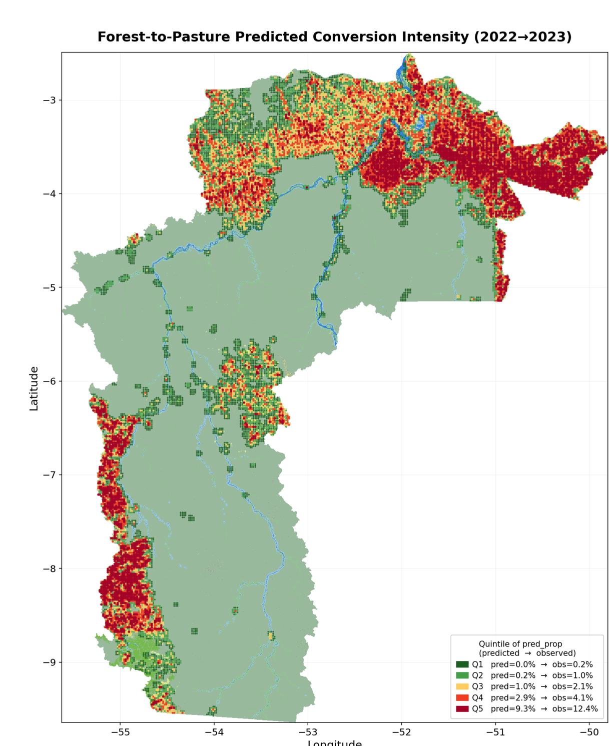


Results

Our final model produces both binary **classification and regression outputs**. We benchmark our preliminary results against studies addressing a similar task (deforestation prediction).

Benchmark

	Pixel-level		Patch-level		
	F1	PR-AUC	F1	PR-AUC	Pearson
Engelmann & Toetzke (2023)[1]	0.263	–	0.608	–	–
Overlan et al. (2025)[2]	–	–	–	–	0.44
Ours	**0.300**	**0.155**	**0.8517**	**0.9247**	**0.5933**



- Areas with the highest predicted conversion intensity (Q5) fall predominantly on **privately occupied public lands** (CAR) (46%) and **settlements** (41%).
- Only 1% of high predicted conversion intensity areas are **Indigenous territories**, reinforcing its **effective protection against forest loss.**

Discussion

Pixel-level LULC forecasting remains a **hard problem for DL**, even with conversion-specific enriched inputs.

At a coarser resolution, such models can be **auxiliary to support allocation of resources with better attribution.**

References

1 Lima Filho, F. L., Bragança, A., & Assunção, J. (2021). Um Novo Modelo de Negócios É Necessário para Aumentar a Produtividade da Pecuária na Amazônia. *Climate Policy Initiative*, (6).
2 Engelmann, T., & Toetzke, M. (2023). Can Deep Learning Help to Forecast Deforestation in the Amazonian Rainforest? Paper presented at the NeurIPS 2023 Workshop: Tackling Climate Change with Machine Learning.
3 Overlan, M. et al. (2025. ForestCast: Forecasting Deforestation Risk at Scale with Deep Learning. (Google Research).

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