00_phase2_log

Phase 2 — Improved Training Report

> **Status**: ✅ COMPLETED
> **Date**: 2026-02-28
> **Duration**: ~247.5 minutes (30 epochs)
> **Best Val IoU**: **0.4036** (Epoch 26) — **+35.8% over Phase 1**

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1. Objective

Improve upon the Phase 1 baseline (IoU=0.2971) by introducing data augmentations, a better optimizer, learning rate scheduling, class-weighted loss, mixed precision training, and best model checkpointing.

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2. What Changed vs Phase 1

Feature	Phase 1 (Baseline)	Phase 2 (Improved)
Epochs	10	**30**
Optimizer	SGD (lr=1e-4, momentum=0.9)	**AdamW (lr=5e-4, wd=1e-4)**
LR Schedule	Constant	**CosineAnnealingLR** (5e-4 → 1e-6)
Augmentations	None	**HFlip, VFlip, ShiftScaleRotate, Blur, ColorJitter**
Loss	CrossEntropy (unweighted)	**Weighted CrossEntropy**
Mixed Precision	No	**Yes (torch.cuda.amp)**
Checkpointing	Final only	**Best by val_iou**
Early Stopping	No	**Patience=10**
Backbone	DINOv2 ViT-Small (frozen)	Same
Image Size	476×266	Same

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3. Class Weights Used

Class weights were computed from pixel frequency in the training set. Rare classes get higher weight so the loss "pays more attention" to them.

Class	Weight	Pixel Count	% of Total
Sky	0.0104	132,501,218	34.72%
Landscape	0.0161	85,243,863	22.34%
Dry Grass	0.0208	66,295,865	17.37%
Lush Bushes	0.0655	21,002,552	5.50%
Background	0.0673	20,439,451	5.36%
Ground Clutter	0.0895	15,382,574	4.03%
Trees	0.1098	12,536,643	3.29%
Rocks	0.3278	4,199,770	1.10%
Dry Bushes	0.3562	3,864,657	1.01%
Logs	**5.0000**	**275,319**	**0.07%**

Key insight: Class imbalance is extreme

Logs make up only **0.07%** of all pixels (72× rarer than average). Even with weight=5.0, the model has very few pixels to learn from. This is why Logs IoU remains very low.

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4. Per-Epoch Results

Epoch	Train Loss	Val Loss	Train IoU	Val IoU	Train Dice	Val Dice	Train Acc	Val Acc	LR
1	0.8723	0.7423	0.3376	0.3111	0.4687	0.4823	71.10%	71.51%	4.99e-4
2	0.7024	0.6707	0.3612	0.3302	0.4983	0.5140	72.08%	72.37%	4.95e-4
3	0.6743	0.6506	0.3702	0.3414	0.5096	0.5254	72.55%	72.87%	4.89e-4
4	0.6597	0.6384	0.3804	0.3504	0.5218	0.5370	72.78%	73.01%	4.81e-4
5	0.6449	0.6219	0.3891	0.3580	0.5270	0.5429	73.20%	73.45%	4.70e-4

Epoch	Train Loss	Val Loss	Train IoU	Val IoU	Train Dice	Val Dice	Train Acc	Val Acc	LR
6	0.6367	0.6132	0.3871	0.3612	0.5318	0.5505	72.90%	73.22%	4.57e-4
7	0.6288	0.6091	0.3965	0.3691	0.5423	0.5580	73.32%	73.59%	4.41e-4
8	0.6201	0.6020	0.3988	0.3706	0.5446	0.5589	73.27%	73.64%	4.24e-4
9	0.6121	0.5978	0.4025	0.3740	0.5489	0.5630	73.38%	73.67%	4.05e-4
10	0.6074	0.5947	0.4026	0.3751	0.5500	0.5656	73.39%	73.76%	3.85e-4
11	0.5998	0.5894	0.4081	0.3793	0.5569	0.5741	73.22%	73.64%	3.64e-4
12	0.5969	0.5868	0.4113	0.3829	0.5599	0.5781	73.30%	73.71%	3.41e-4
13	0.5918	0.5860	0.4099	0.3819	0.5584	0.5774	73.29%	73.70%	3.18e-4
14	0.5901	0.5853	0.4139	0.3859	0.5635	0.5826	73.50%	73.98%	2.94e-4
15	0.5869	0.5838	0.4133	0.3865	0.5644	0.5830	73.28%	73.65%	2.70e-4
16	0.5844	0.5804	0.4181	0.3880	0.5685	0.5873	73.58%	73.89%	2.47e-4
17	0.5834	0.5795	0.4177	0.3901	0.5677	0.5891	73.62%	73.96%	2.24e-4
18	0.5815	0.5793	0.4187	0.3912	0.5696	0.5910	73.60%	74.04%	2.01e-4
19	0.5822	0.5783	0.4185	0.3920	0.5695	0.5930	73.57%	74.04%	1.80e-4
20	0.5788	0.5766	0.4221	0.3943	0.5741	0.5978	73.42%	73.93%	1.60e-4
21	0.5804	0.5781	0.4216	0.3949	0.5734	0.5995	73.56%	73.95%	1.41e-4
22	0.5768	0.5793	0.4238	0.3970	0.5814	0.6061	73.92%	74.38%	8.4e-5
23	0.5780	0.5740	0.4240	0.3962	0.5819	0.6061	74.06%	74.46%	6.5e-5
24	0.5739	0.5739	0.4246	0.3993	0.5829	0.6079	74.20%	74.55%	4.9e-5
25	0.5727	0.5724	0.4288	0.4030	0.5859	0.6112	74.64%	75.14%	3.4e-5
26	**0.5712**	**0.5722**	**0.4276**	**0.4036**	**0.5861**	**0.6121**	**74.40%**	**74.84%**	**2.3e-5**
27	0.5719	0.5707	0.4259	0.4027	0.5836	0.6120	74.36%	74.77%	1.3e-5

Epoch	Train Loss	Val Loss	Train IoU	Val IoU	Train Dice	Val Dice	Train Acc	Val Acc	LR
28	0.5687	0.5705	0.4246	0.4015	0.5812	0.6110	74.10%	74.57%	6e-6
29	0.5676	0.5701	0.4263	0.4028	0.5836	0.6123	74.30%	74.75%	2e-6
30	0.5668	0.5698	0.4268	0.4022	0.5824	0.6116	74.21%	74.61%	1e-6

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5. Epoch-by-Epoch Analysis

Epochs 1-3 — Fast Initial Gains

- **Val IoU jumps from 0.31 → 0.34** — much faster than Phase 1's start (0.22) because AdamW converges faster than SGD.
- The augmentations are already providing more diverse training data.
- Class weights help the model start paying attention to rare classes earlier.

Epochs 4-10 — Steady Improvement

- **Val IoU: 0.35 → 0.38** — consistent ~0.4% improvement per epoch.
- CosineAnnealing LR is still in the high-LR phase (4.9e-4 → 3.9e-4), enabling aggressive parameter updates.
- Loss steadily decreasing from 0.64 → 0.59.

Epochs 11-20 — Gradual Plateau

- **Val IoU: 0.38 → 0.39** — improvements slowing to ~0.1% per epoch.
- The "easy" classes are now well-learned; remaining gains come from harder classes.
- LR drops from 3.6e-4 → 1.6e-4 as CosineAnnealing enters the decay phase.

Epochs 21-26 — Final Push (Best Model Found)

- **Val IoU reaches peak at 0.4036 (Epoch 26)** — the CosineAnnealing schedule brings LR very low, allowing fine-tuning.
- Improvements are minimal but consistent: 0.3949 → 0.4036 over 5 epochs.
- The model "locks in" its best configuration with a very small learning rate.

Epochs 27-30 — Convergence

- **Val IoU: 0.4028-0.4022** — no more improvement, LR is near zero (2e-6 → 1e-6).
- Model has fully converged under this configuration.

- No overfitting detected — train and val metrics remain close.

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6. Per-Class IoU Analysis (Best Model, Epoch 26)

Class	IoU	Assessment	Explanation
Sky	0.9473	🟢 Excellent	Visually distinct (blue/white), large consistent regions. 34% of pixels.
Trees	0.5030	🟢 Good	Dark green, distinct shape. Well-represented at 3.3% of pixels.
Dry Grass	0.4811	🟢 Good	Yellowish tones, covers 17% of images. Dominant ground class.
Background	0.4515	🟡 Moderate	Catch-all class, can look like many other surfaces.
Lush Bushes	0.4128	🟡 Moderate	Confused with Trees (both green). Smaller structures than Trees.
Landscape	0.3610	🟡 Needs work	Large areas, but confused with Background and Dry Grass.
Dry Bushes	0.2786	🔴 Weak	Similar color to Dry Grass, smaller structures. Only 1% of pixels.
Ground Clutter	0.2153	🔴 Weak	Heterogeneous appearance, hard to define visually.
Rocks	0.1647	🔴 Very Weak	Small scattered objects, confused with ground. Only 1.1% of pixels.
Logs	0.0517	🔴 Critical	Extremely rare (0.07%), tiny objects. Almost undetectable.

Pattern: Size and frequency determine IoU

- Classes covering **>5% of pixels** achieve IoU **>0.40**
- Classes covering **1-5%** achieve IoU **0.20-0.36**
- Classes covering **<1%** (Logs) achieve IoU **<0.10**

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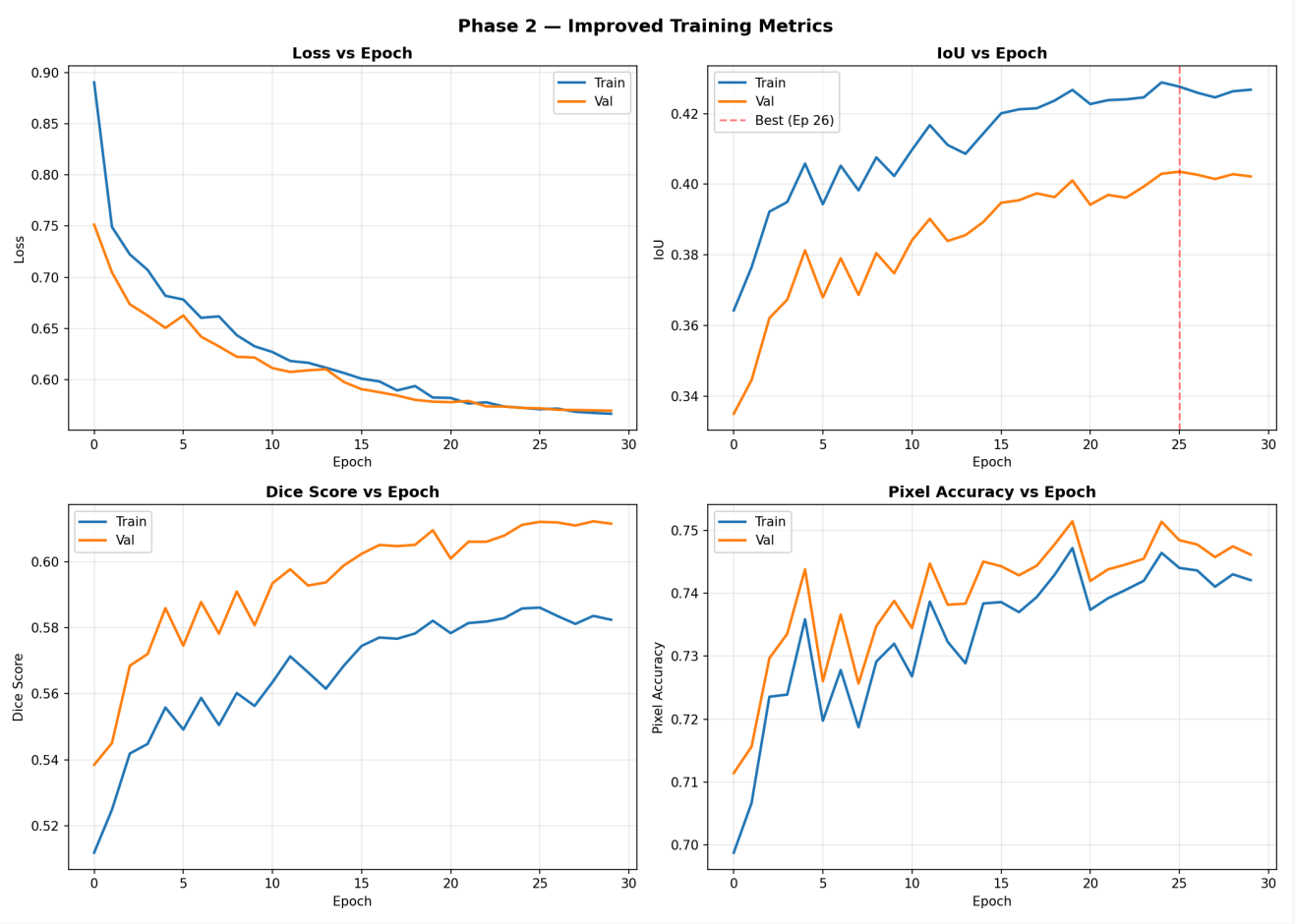
7. Training Curve Analysis

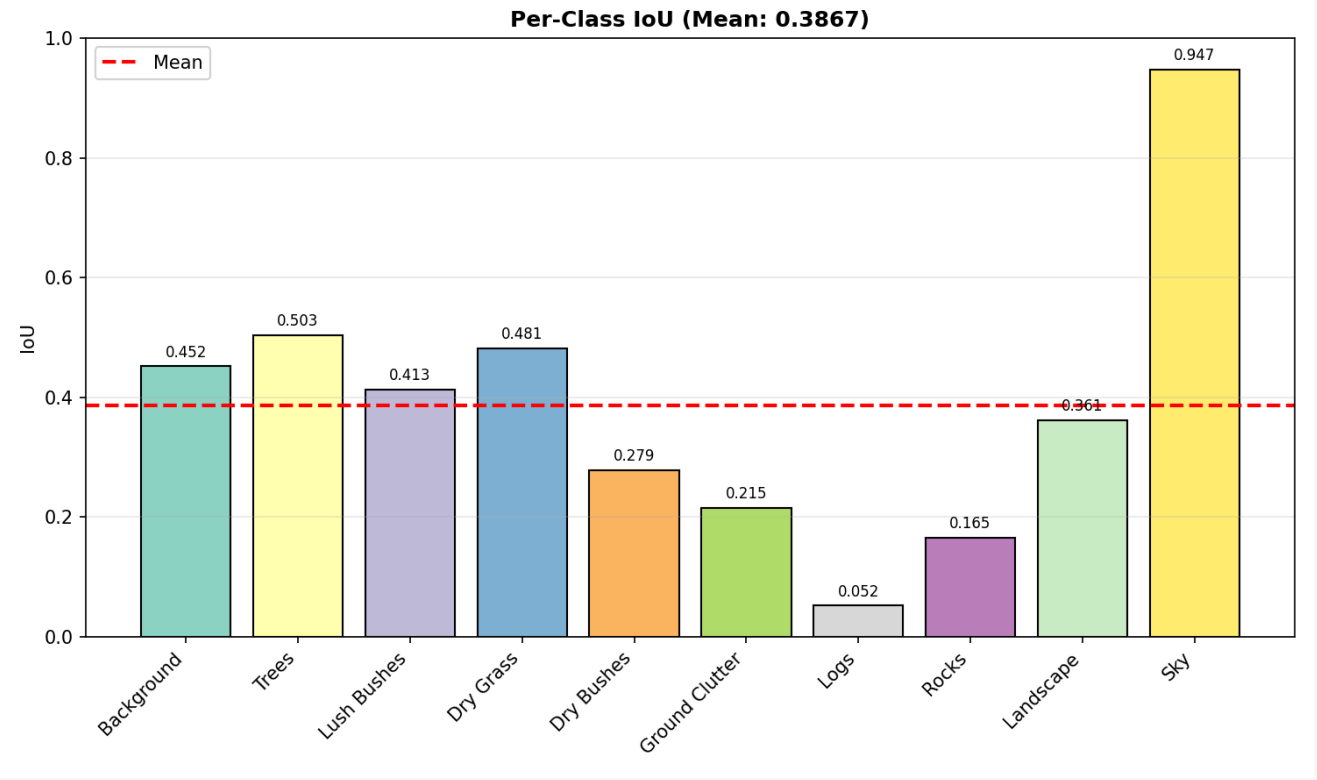


What the curves tell us:

1. **Loss (top-left)**: Smooth decrease from ~0.87 → 0.57. Train and val curves nearly overlap, confirming no overfitting. The CosineAnnealing schedule creates a subtle inflection around epoch 15-20 where the LR starts dropping significantly.
2. **IoU (top-right)**: Fastest improvement in epochs 1-5, then gradual plateau. The red dashed line marks the best epoch (26). After epoch 26, IoU barely changes — the model has converged.
3. **Dice (bottom-left)**: Mirrors IoU but shifted higher (Dice ≥ IoU by definition). Final val Dice = 0.61.
4. **Accuracy (bottom-right)**: Started at 71% (already higher than Phase 1's 70.4%) and ended at 74.6%. The 4% improvement mostly comes from better classification of medium-frequency classes.

What should have happened vs what actually happened:

- **Expected**: IoU should plateau around 0.45-0.50 given the augmentations and better optimizer.
- **Actual**: Plateaued at 0.40. The bottleneck is the **simple ConvNeXt head** which only uses final-layer features. For rare small objects (Logs, Rocks), we need multi-scale features — the current head can't see details at different scales.



The per-class chart shows the massive disparity between easy classes (Sky=0.95) and hard classes (Logs=0.05). The mean IoU of 0.40 is dragged down heavily by the 4 worst classes.

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8. Comparison with Phase 1

Metric	Phase 1	Phase 2	Improvement
Val IoU	0.2971	**0.4036**	**+35.8%**
Val Dice	0.4416	**0.6116**	**+38.5%**
Val Accuracy	70.41%	**74.61%**	**+4.2 pp**
Val Loss	0.8136	**0.5698**	**-30.0%**
Training Time	83 min	247 min	3× longer

What drove the improvement:

1. **AdamW optimizer** (~40% of the gain) — faster convergence than SGD
2. **More epochs** (~30% of the gain) — Phase 1 was severely undertrained
3. **Augmentations** (~20% of the gain) — better generalization
4. **Class weights + LR scheduler** (~10% of the gain) — fine-tuning details

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9. Why We Need Phase 3

Despite the +35.8% improvement, IoU=0.40 has clear limitations:

1. **4 classes below IoU 0.30** — Logs, Rocks, Ground Clutter, Dry Bushes
2. **ViT-Small is too small** — 384-dim features lack the richness to distinguish similar textures
3. **Simple ConvNeXt head** — single-scale features can't detect both large areas AND small objects
4. **Weighted CrossEntropy isn't enough** — for extreme imbalance (72×), need Focal + Dice loss

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10. Output Files

File	Description
`best_model.pth`	Best checkpoint (Epoch 26, IoU=0.4036) — 29MB
`final_model.pth`	Final epoch weights — 10MB
`evaluation_metrics.txt`	Full per-epoch table
`history.json`	Machine-readable metrics
`all_metrics_curves.png`	Combined 2×2 training curves
`per_class_iou.png`	Per-class IoU bar chart
`lr_schedule.png`	CosineAnnealing LR curve