

Quantifying Land Cover Change in Dryland Environments using AI and Remote Sensing Data

Dr John Toth

Program: MSc by Research

Supervisors: Dr Arjan Gosal, Prof Duncan Quincey

Period of Study: 24 months on a part-time basis. End Aug 2026

Dryland Biomes

(Terrestrial Ecoregions of the World, Olson et al. 2001)

Biome 2. Tropical and Subtropical Dry Broadleaf Forests.

Biome 7. Tropical and Subtropical Grasslands, Savannas, and Shrublands.

Biome 8. Temperate Grasslands, Savannas, and Shrublands.

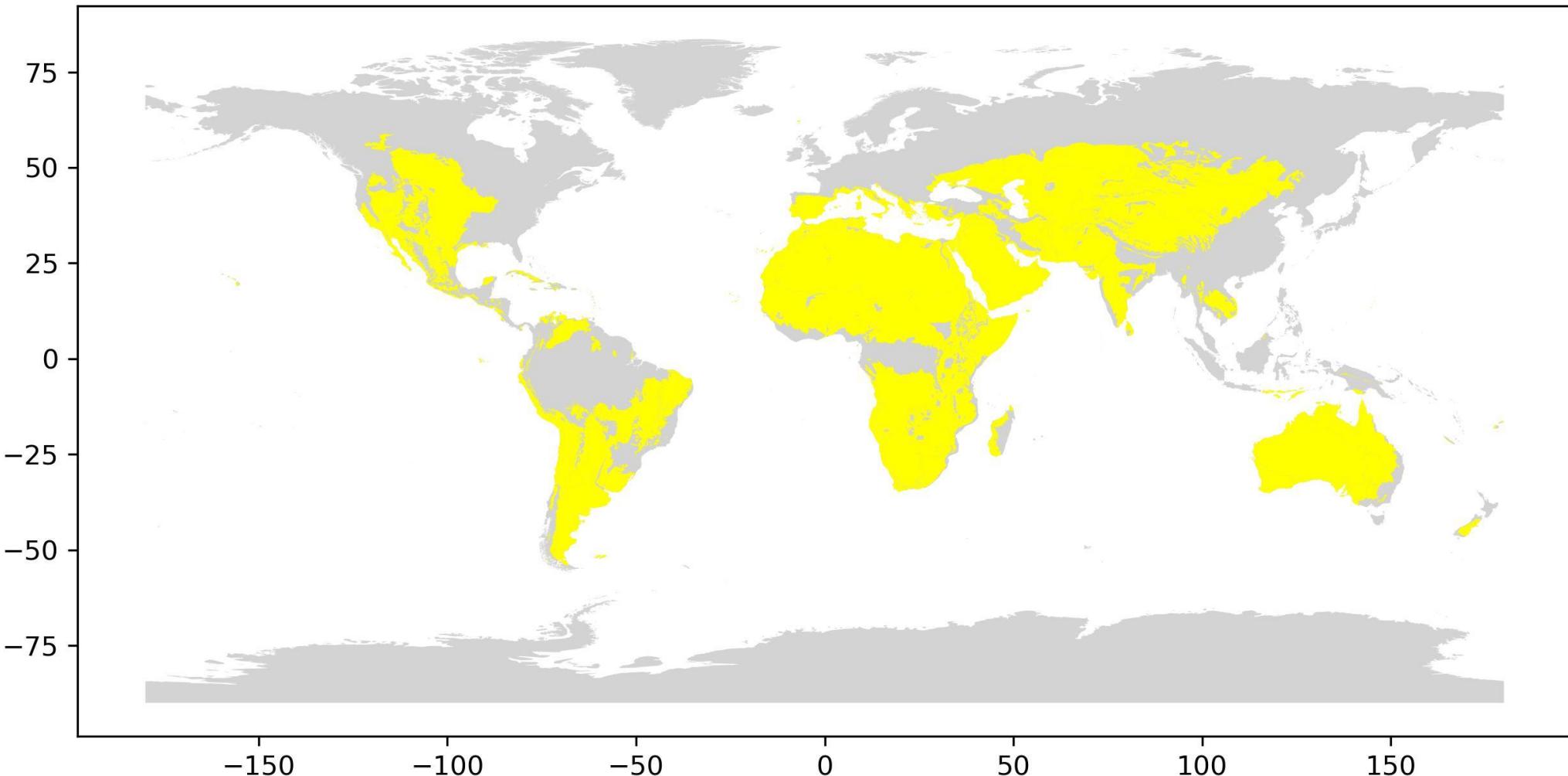
Biome 10. Montane Grasslands and Shrublands.

Biome 12. Mediterranean Forests, Woodlands, and Scrub.

Biome 13. Deserts and Xeric Shrublands.

Drylands - Biome

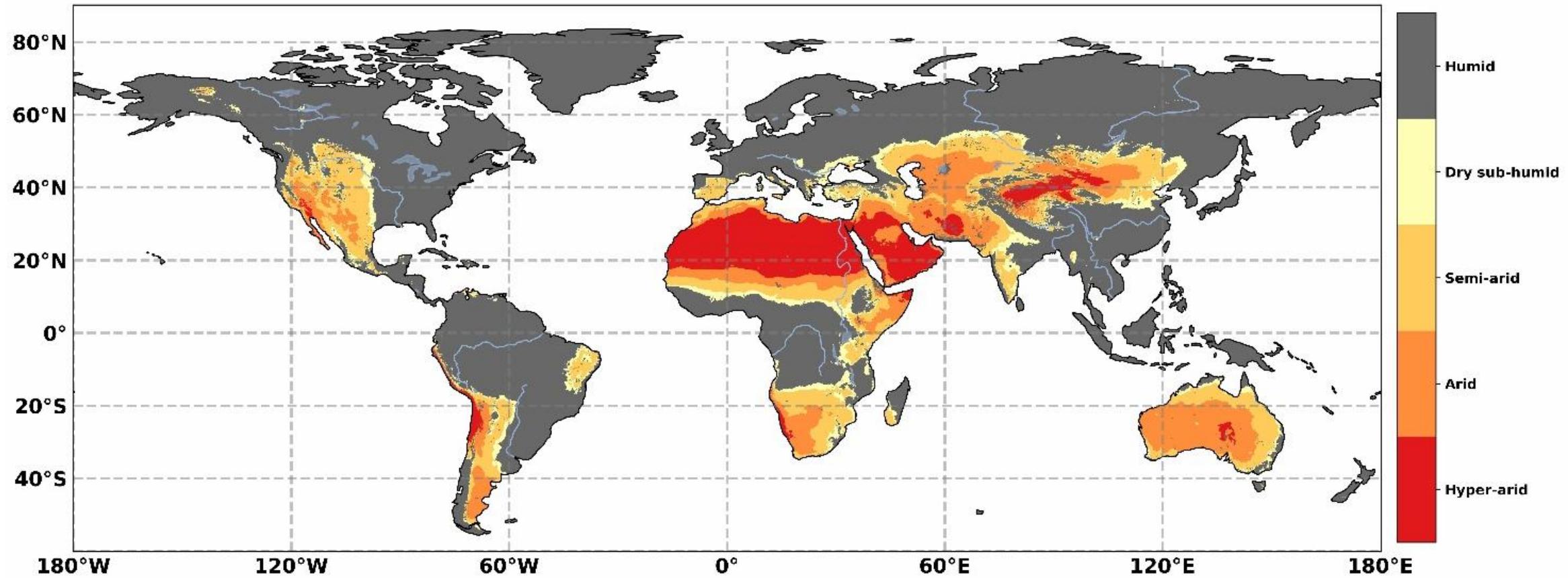
Global Dryland Biomes



A large geographical area characterized by its specific climate and the types of plants and animals that live there. From Terrestrial Ecosystems of the World (WWF, Olson et al. 2001).

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Drylands - Aridity Index



Ratio of annual precipitation to potential evapotranspiration; Hyper-Arid < 0.05, Arid = 0.05-0.2, Semiarid = 0.2-0.5, Dry Subhumid = 0.5-0.65. Arid regions receive less than 250 mm of precipitation per year. Semi-Arid regions receive 250-500 mm per year (Dryland regions of the world, Shukla *et al.* 2019).

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Biome-10. Montane Grasslands and Shrublands

Samples	Data	Model	Device	Epochs	Batch	Time	Loss	Accuracy		F1-score	
					size	min		test	train	macro	weighted
Biome-10											
24494	Sentinel-2	CNN Patch	cpu	500	32	12	0.27	89%	90%	0.68	0.89
24494	Sentinel-2	CNN Patch5	cpu	500	32	15	0.35	88%	88%	0.59	0.87
24878	AlphaEarth	Fully Connected	cpu	500	10	18	0.02	98%	99%	0.93	0.98

Level 1	Biome 2	Biome 7	Biome 8	Biome 10	Biome 12	Biome 13	All
Water [0]	10.7%	10.2%	2.7%	10.5%	0.6%	1.4%	7.3%
Developed [1]	0.9%	0.9%	3.2%	0.5%	3.9%	2.9%	1.7%
Barren [2]	0.4%	1.5%	2.2%	5.1%	0.8%	25.8%	4.7%
Trees [3]	47.4%	26.2%	7.0%	11.4%	52.5%	4.0%	26.0%
Shrub [4]	1.4%	13.8%	2.5%	1.9%	7.5%	23.1%	10.1%
Herb [5]	39.2%	47.5%	82.4%	70.6%	34.7%	42.9%	50.1%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

F1 - scores

For each class:

Precision: true positives / all predicted positives. $TP / (TP + FP)$

Recall: true positives / all actual positives. $TP / (TP + FN)$

$$F1_{\text{class}} = 2 * (\text{Precision} * \text{Recall}) / (\text{Precision} + \text{Recall})$$

F1-macro is straight average of all classes

F1-weighted is average of all classes weighted by number of samples in each class

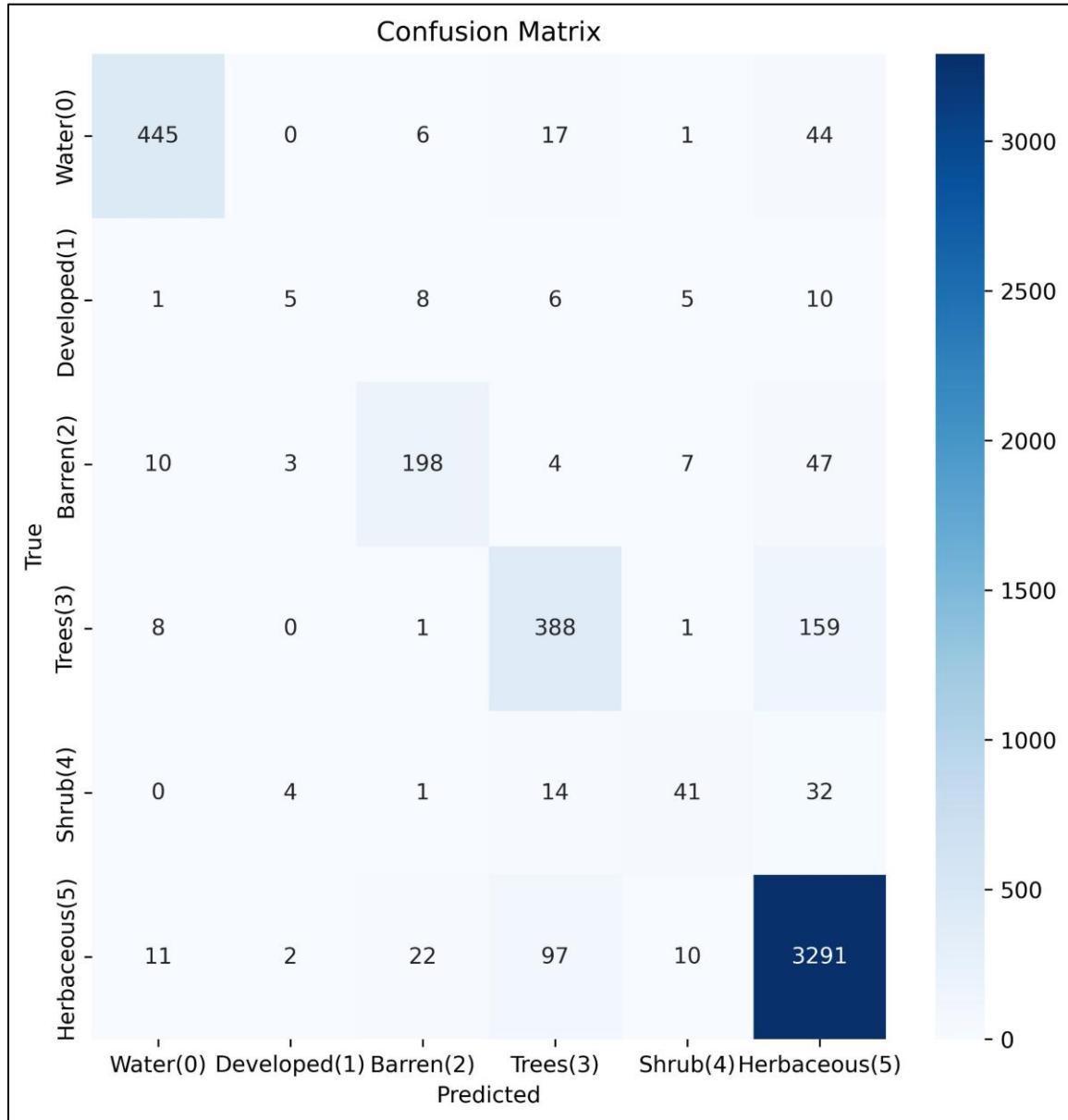
Micro-precision= $tTP / (tTP + tFP)$

Micro-recall = $tTP / (tTP + tFN)$

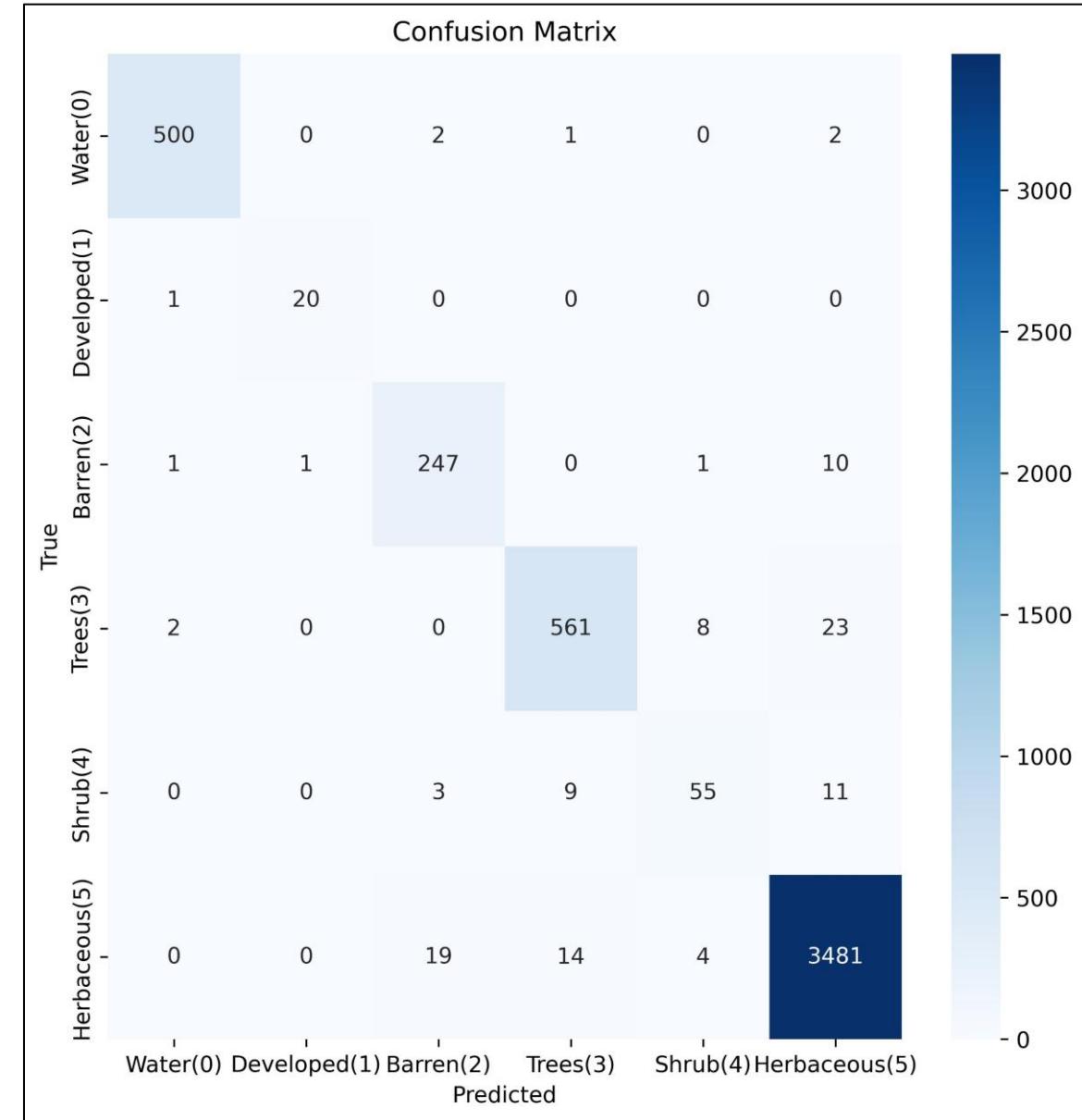
F1-micro = $tTP / (tTP + tFP) = tTP / (tTP + tFN) = \text{Accuracy}$

Biome-10. Confusion Matrices

Sentinel-2

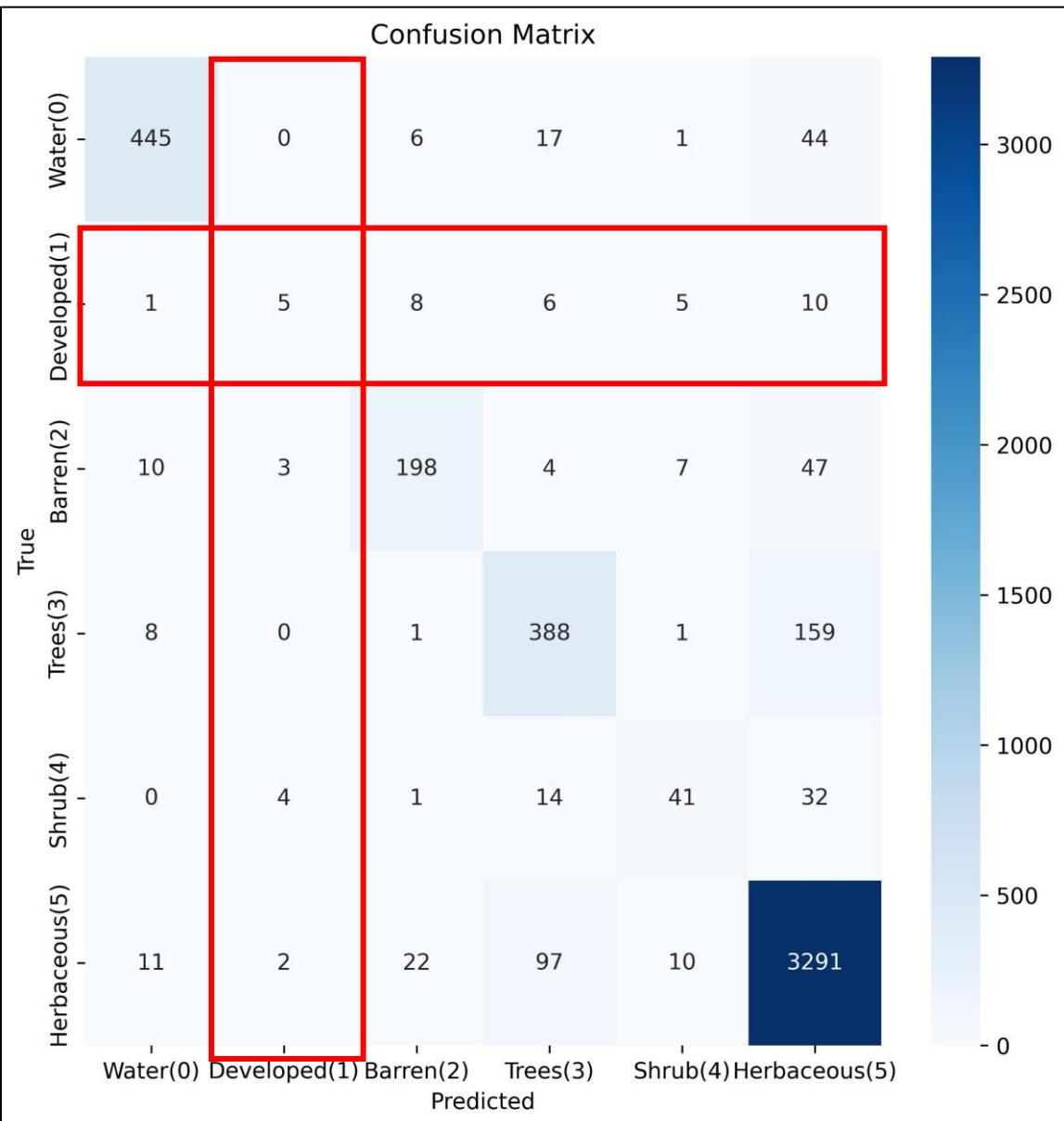


AlphaEarth



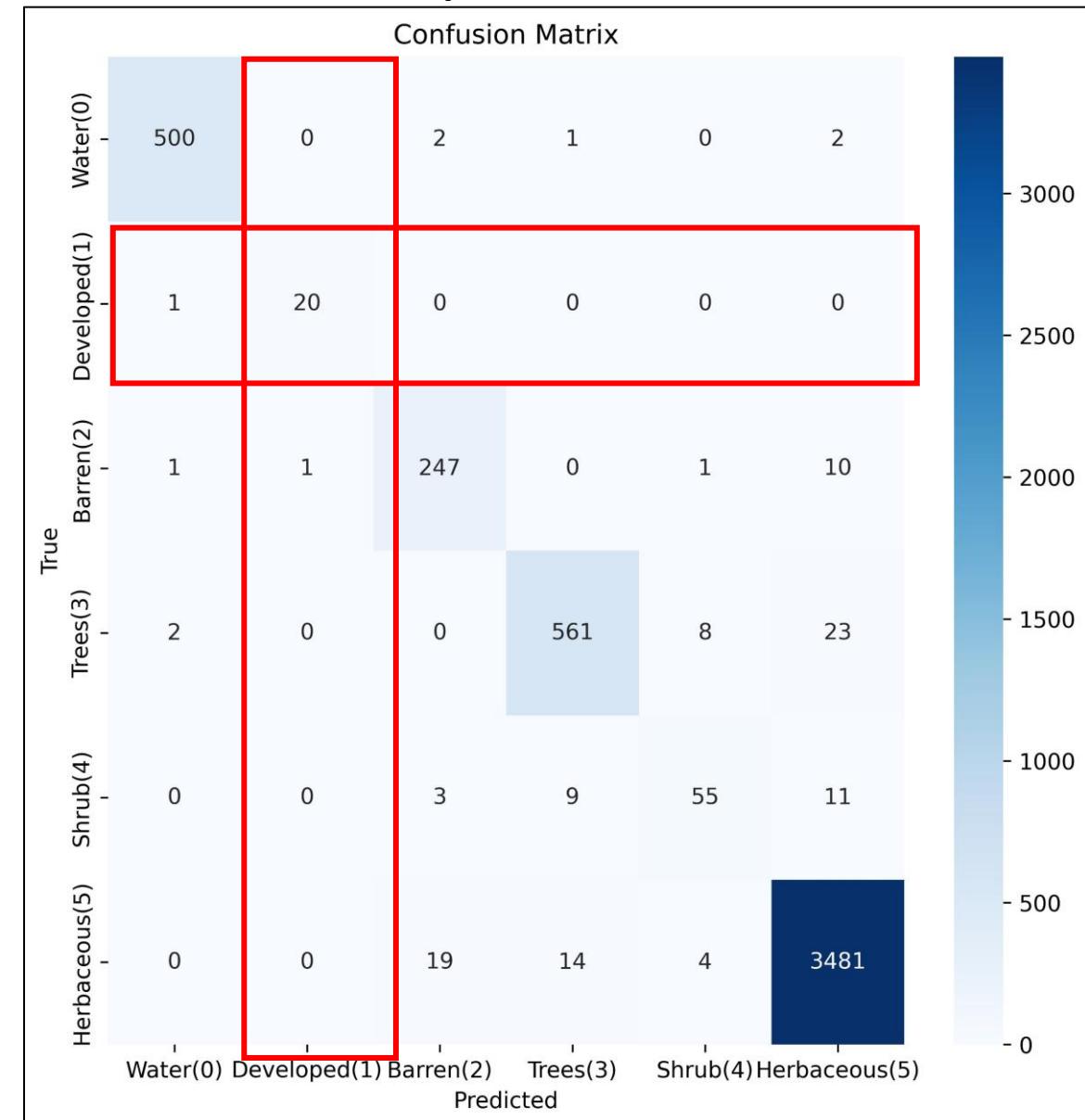
P=0.36, R=0.14, F1-macro = 0.2

Sentinel-2

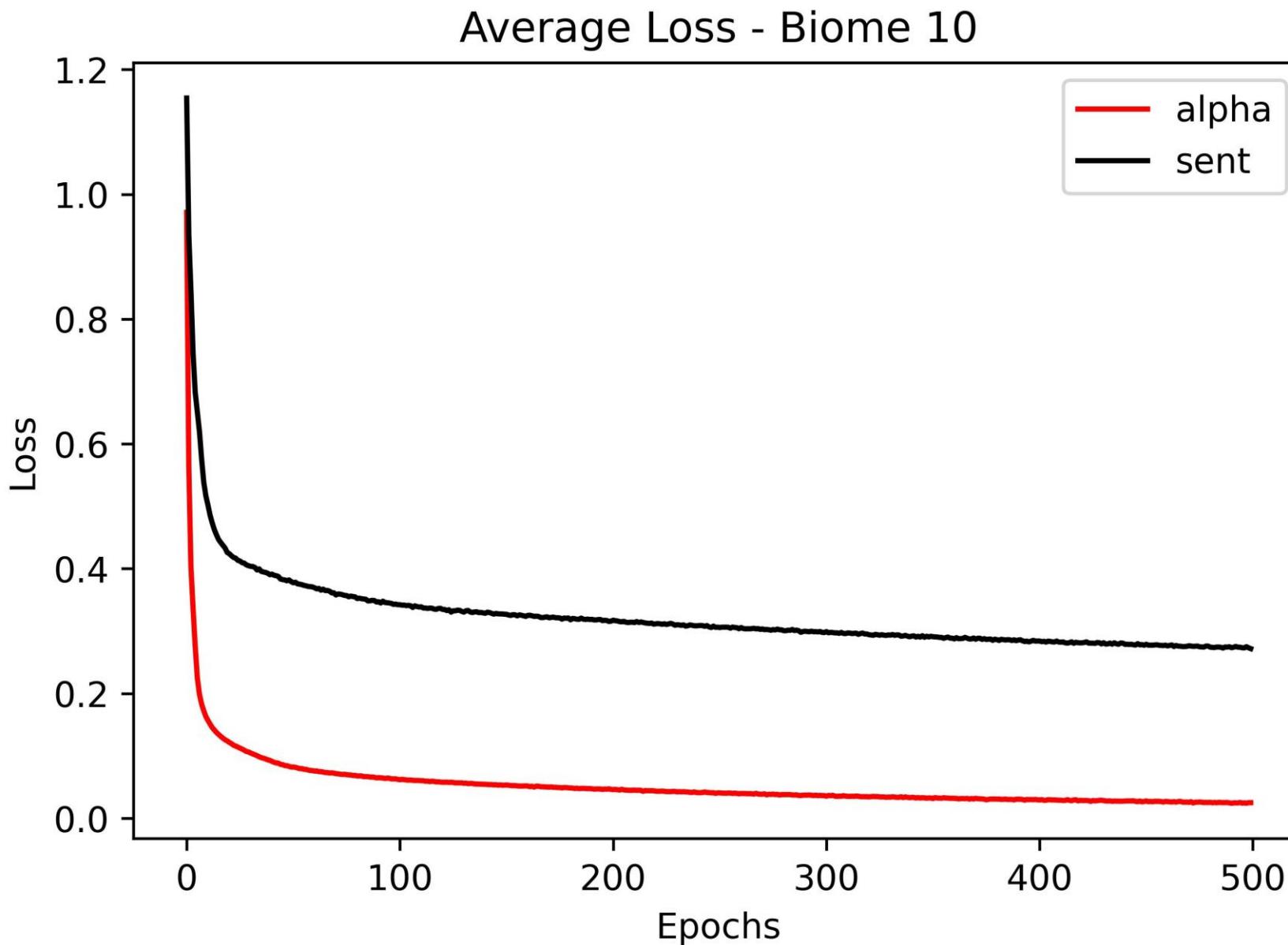


P=0.95, R=0.95, F1-macro = 0.95

AlphaEarth

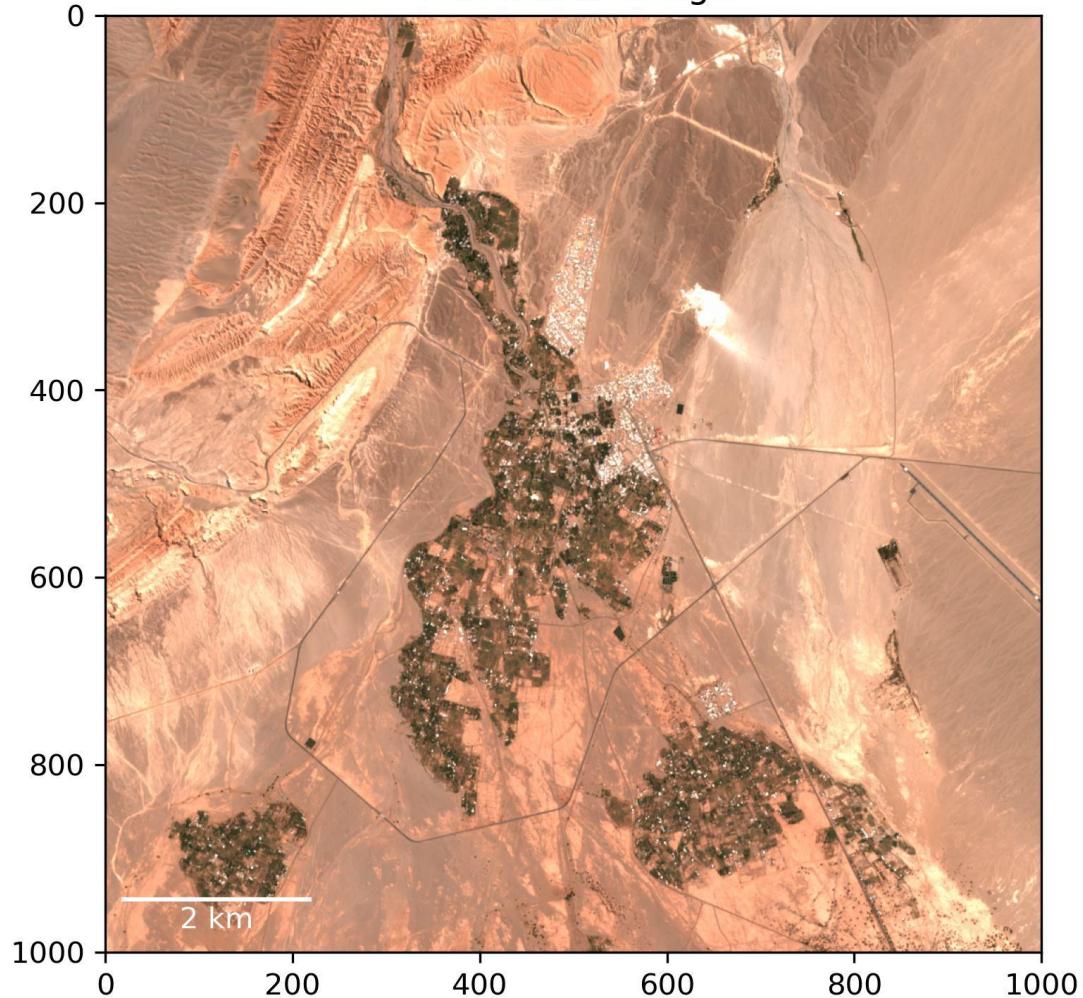


Biome-10. Loss Curves Comparison

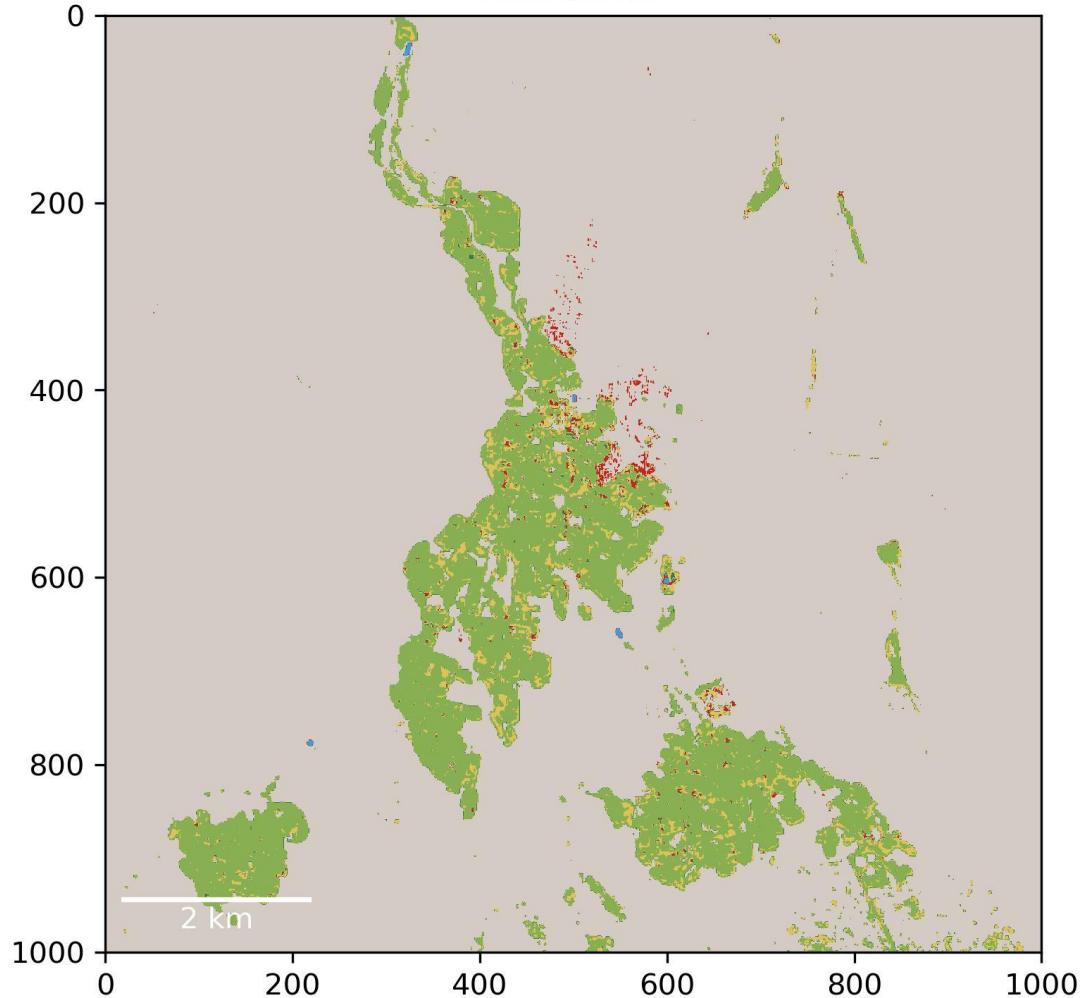


Biome-10. Sentinel-2. Inference

True colour image



Landcover



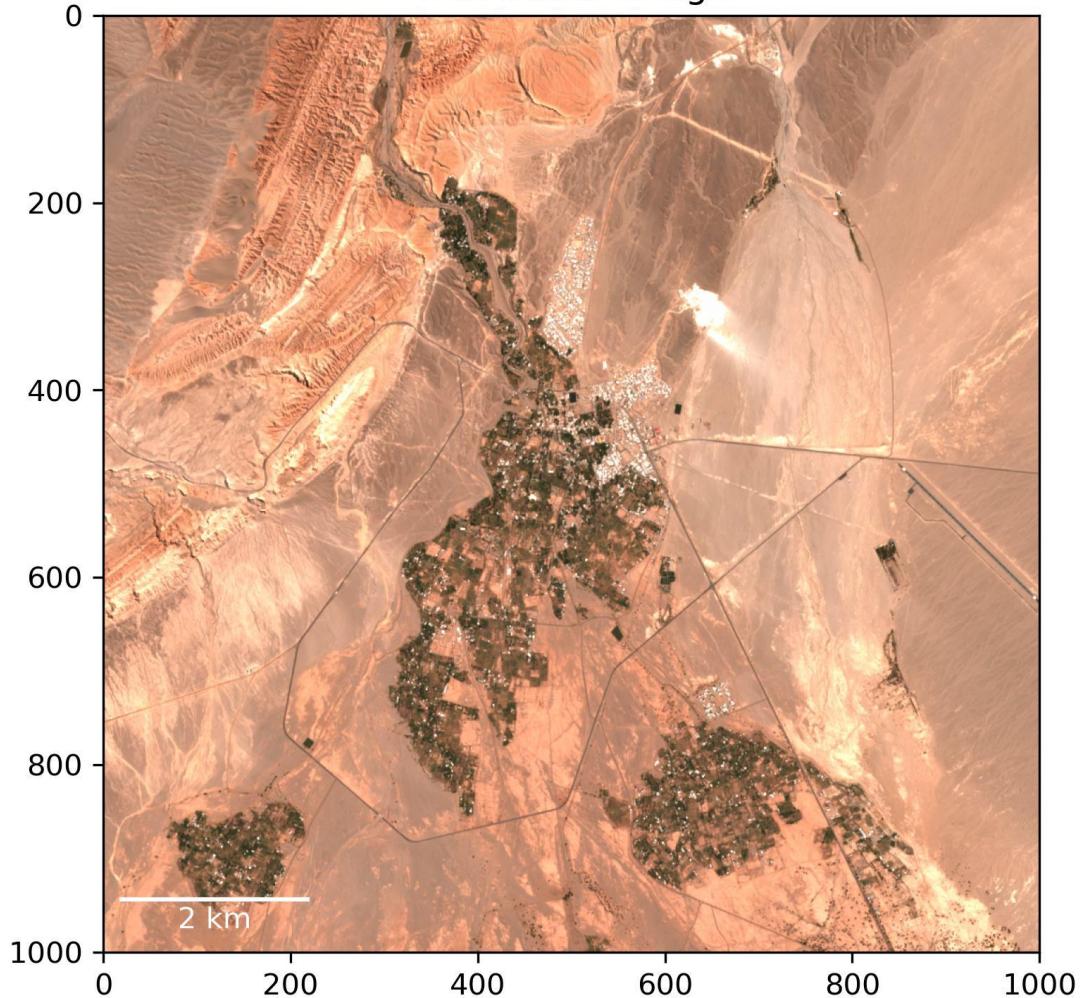
- Water
- Developed
- Barren
- Trees
- Shrub
- Herbaceous

San Pedro, Chile. Montane Grasslands and Shrublands

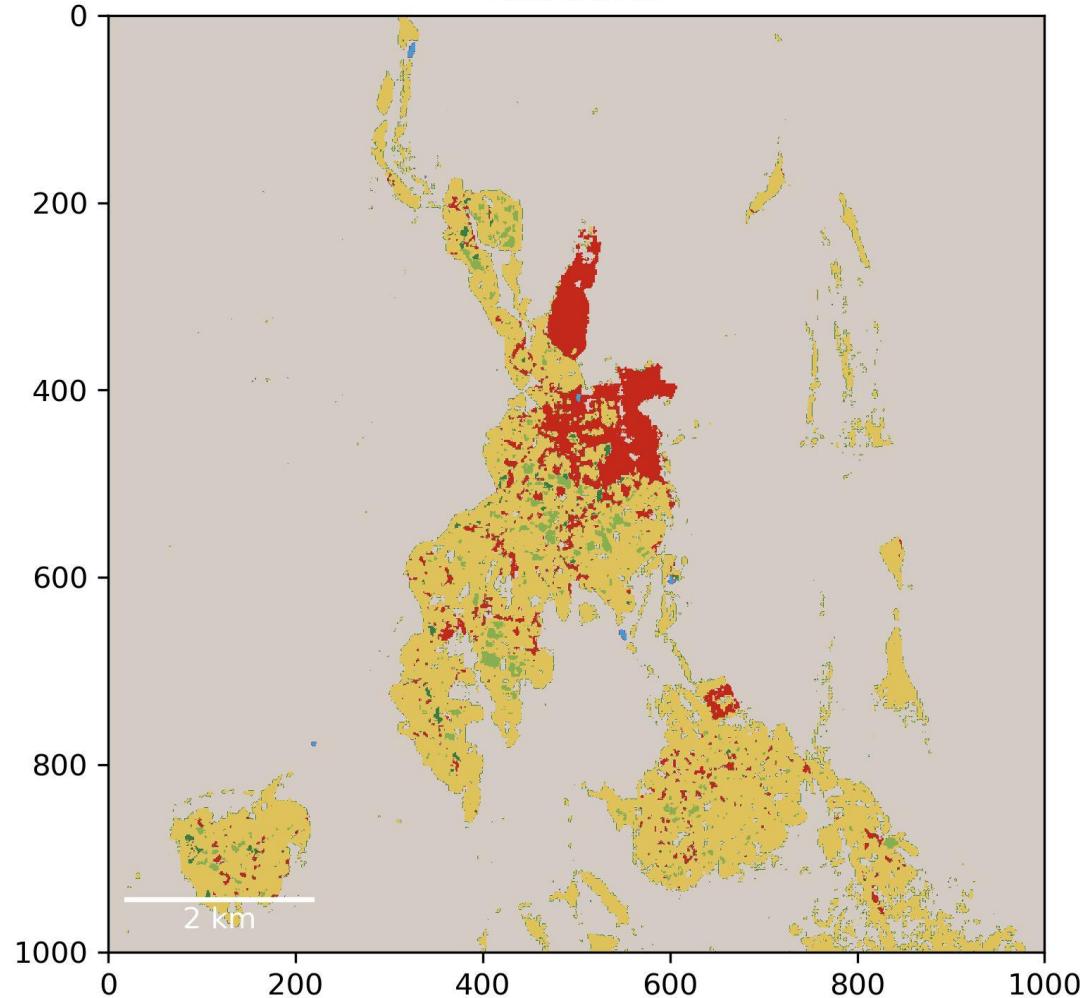
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Biome-10. AlphaEarth. Inference

True colour image



Landcover

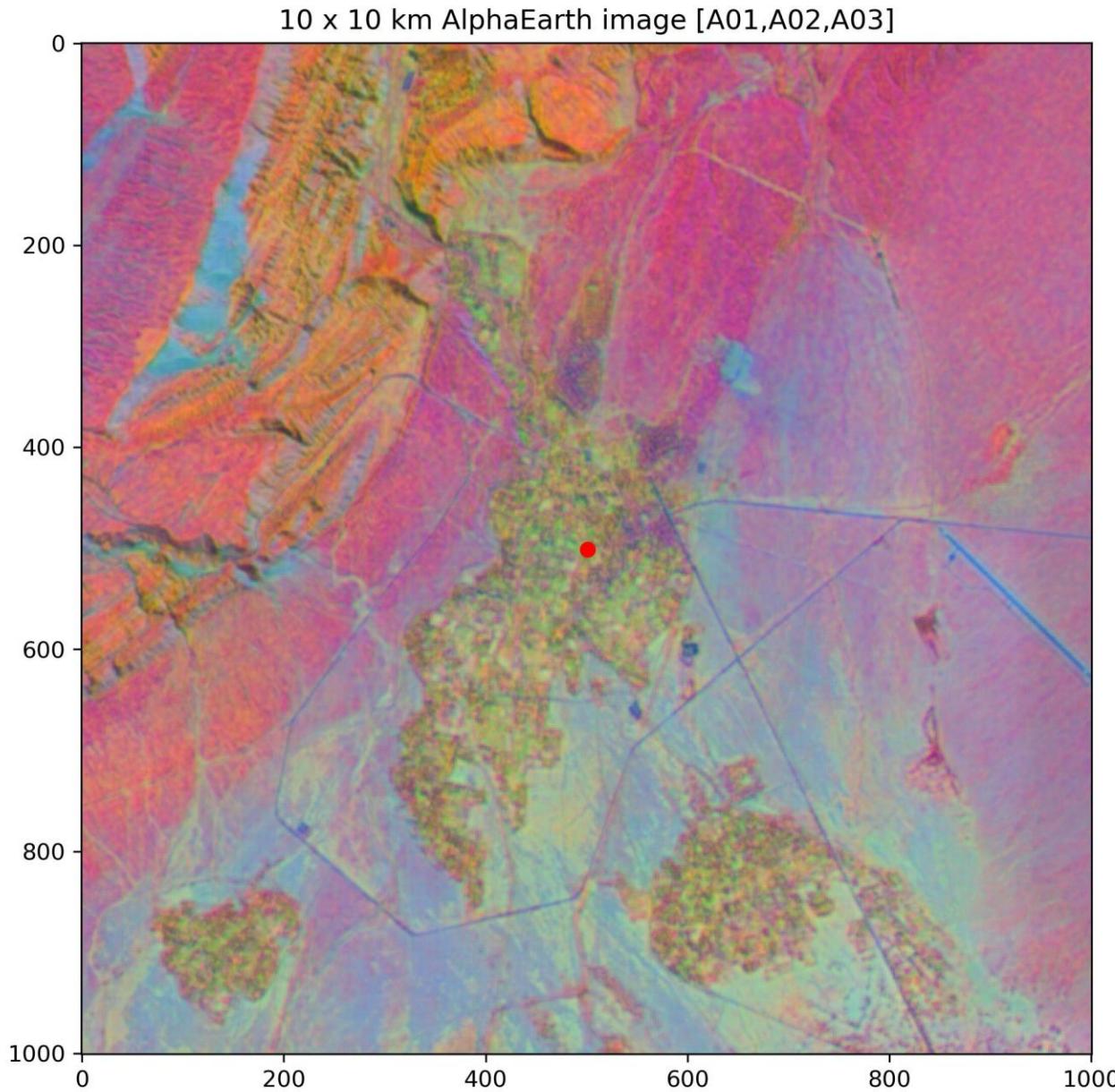


- Water
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- Shrub
- Herbaceous

San Pedro, Chile. Montane Grasslands and Shrublands

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Biome-10. AlphaEarth Training Data



AlphaEarth Geospatial Foundational Model - Inputs

Optical Satellite Imagery - Sentinel-2, Landsat 8, Landsat 9

Radar Data - Sentinel-1, PALSAR2

LiDAR (Light Detection and Ranging) - GEDI (Global Ecosystem Dynamics Investigation):

Provides rasterized metrics on canopy height.

Climate & Environmental Reanalysis - ERA5-Land: Monthly aggregated data on atmospheric and land conditions (e.g., temperature, precipitation). GRACE (Gravity Recovery and Climate Experiment): Data on gravity anomalies, which can relate to large-scale water movement.

Elevation Data - GLO-30 (Copernicus DEM)

Textual & Annotated Data - Geotagged Wikipedia: Textual context linked to specific geographic coordinates. NLCD (National Land Cover Database): Used as an annotated data source for land cover classification.

“While the NLCD is specific to the United States, the model learns the fundamental relationships between sensor data and land cover types, which it can then apply globally.”

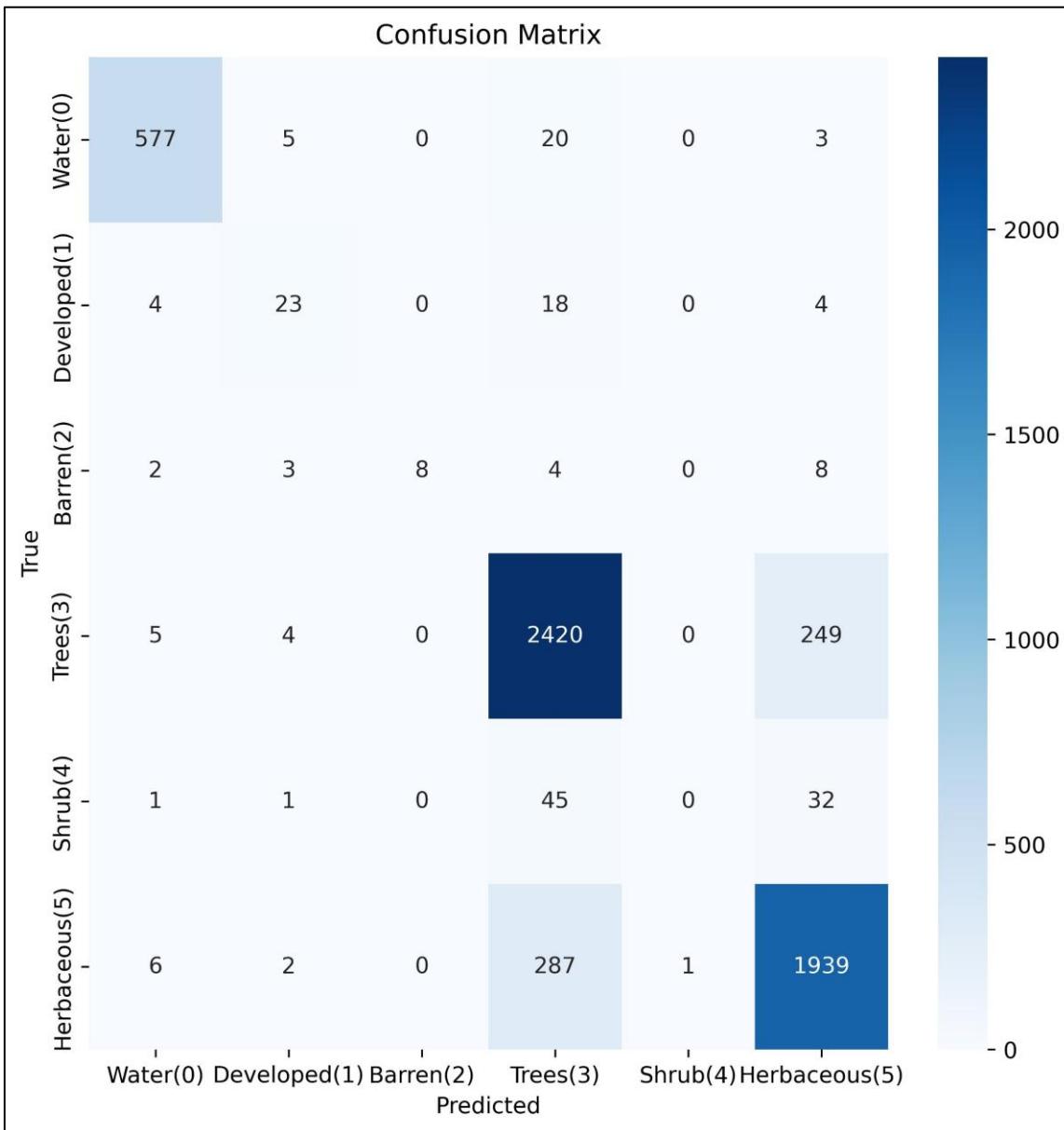
Biome-2. Tropical and Subtropical Dry Broadleaf Forests

Samples	Data	Model	Device	Epochs	Batch	Time	Loss	Accuracy		F1-score	
								size	min	test	train
Biome-2											
28353	Sentinel-2	CNN Patch	cpu	500	32	15	0.31	88%	89%	0.62	0.87
28353	Sentinel-2	CNN Patch4	cpu	500	32	15	0.37	86%	86%	0.58	0.85
28484	AlphaEarth	Fully Connected	cpu	500	10	21	0.02	97%	99%	0.91	0.97

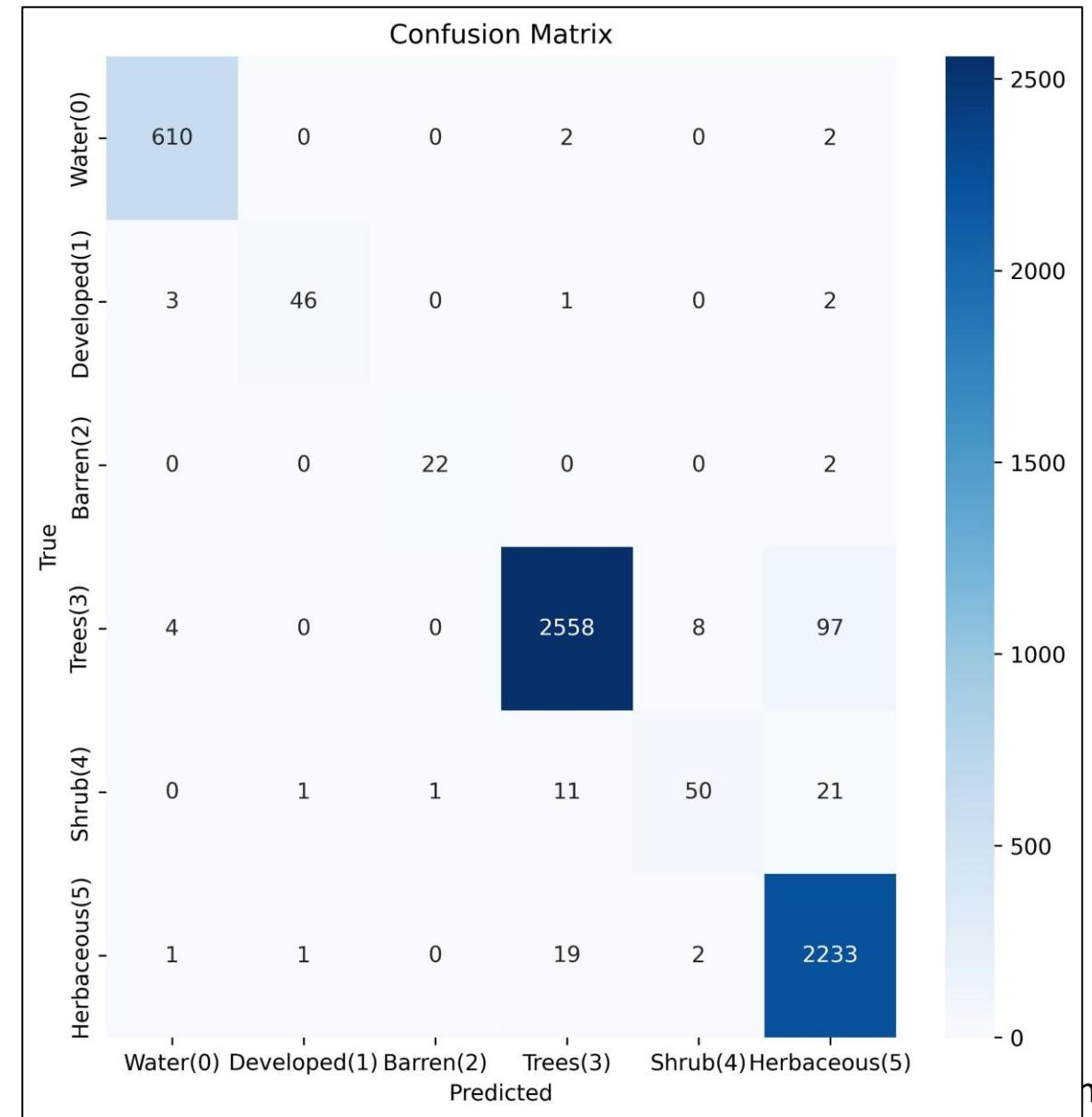
Level 1	Biome 2	Biome 7	Biome 8	Biome 10	Biome 12	Biome 13	All
Water [0]	10.7%	10.2%	2.7%	10.5%	0.6%	1.4%	7.3%
Developed [1]	0.9%	0.9%	3.2%	0.5%	3.9%	2.9%	1.7%
Barren [2]	0.4%	1.5%	2.2%	5.1%	0.8%	25.8%	4.7%
Trees [3]	47.4%	26.2%	7.0%	11.4%	52.5%	4.0%	26.0%
Shrub [4]	1.4%	13.8%	2.5%	1.9%	7.5%	23.1%	10.1%
Herb [5]	39.2%	47.5%	82.4%	70.6%	34.7%	42.9%	50.1%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Biome-2. Confusion Matrices

Sentinel-2

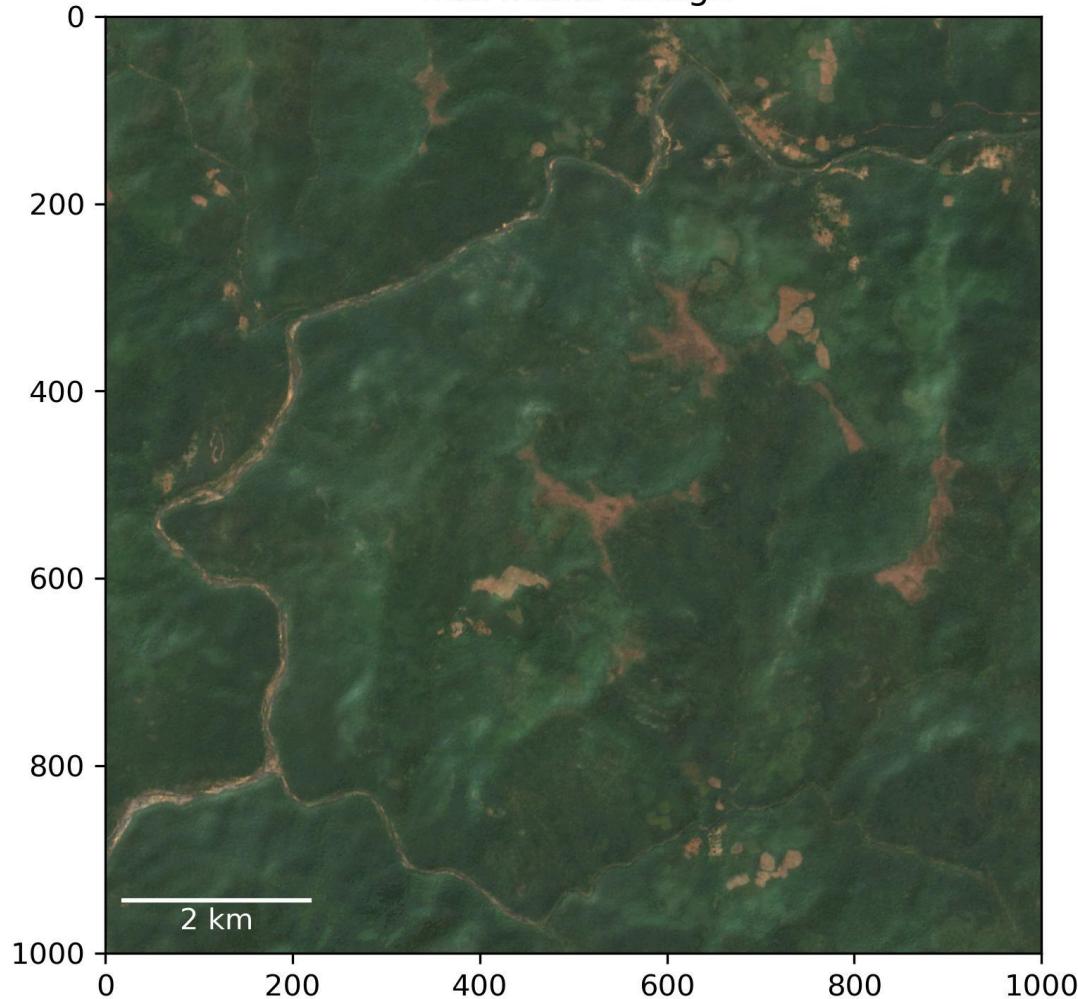


AlphaEarth

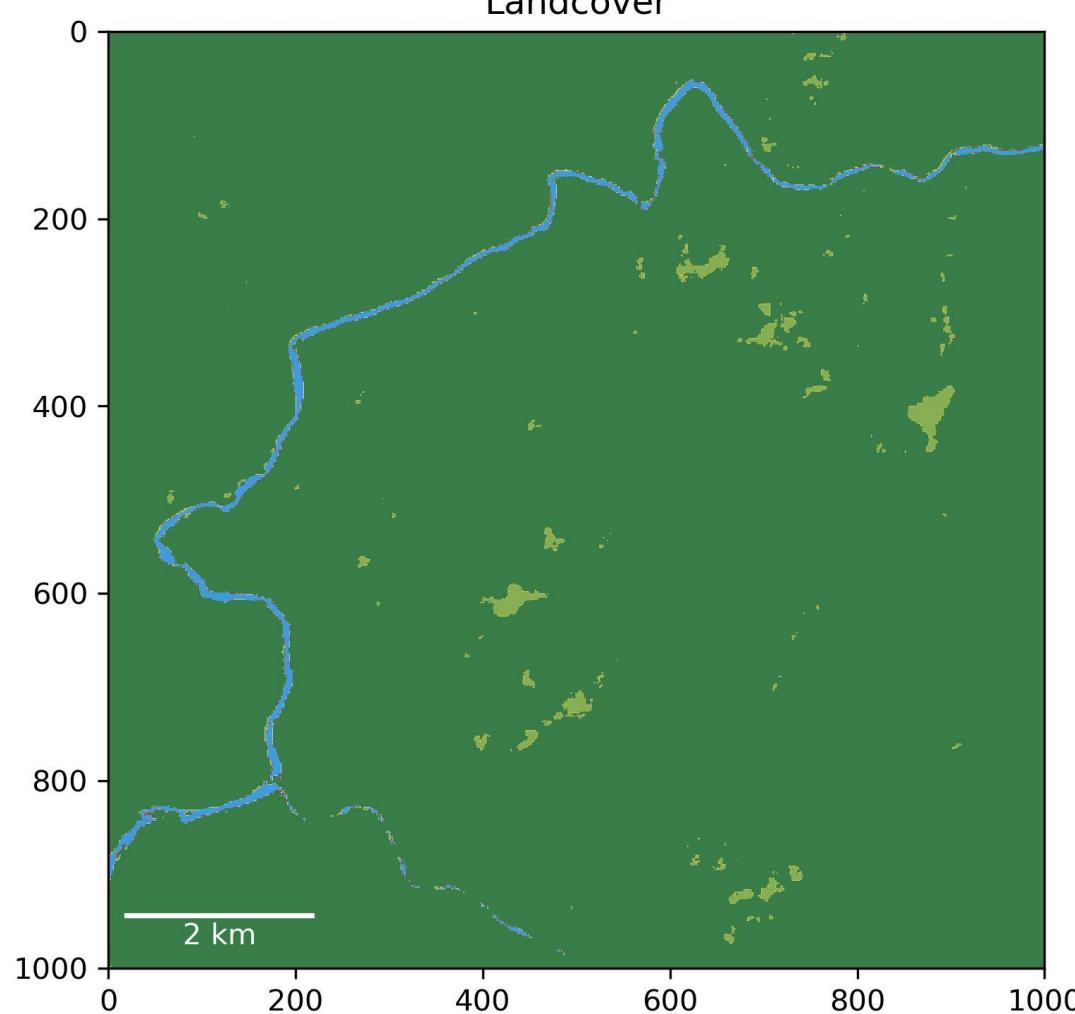


Biome-2. Sentinel-2. Inference

True colour image



Landcover



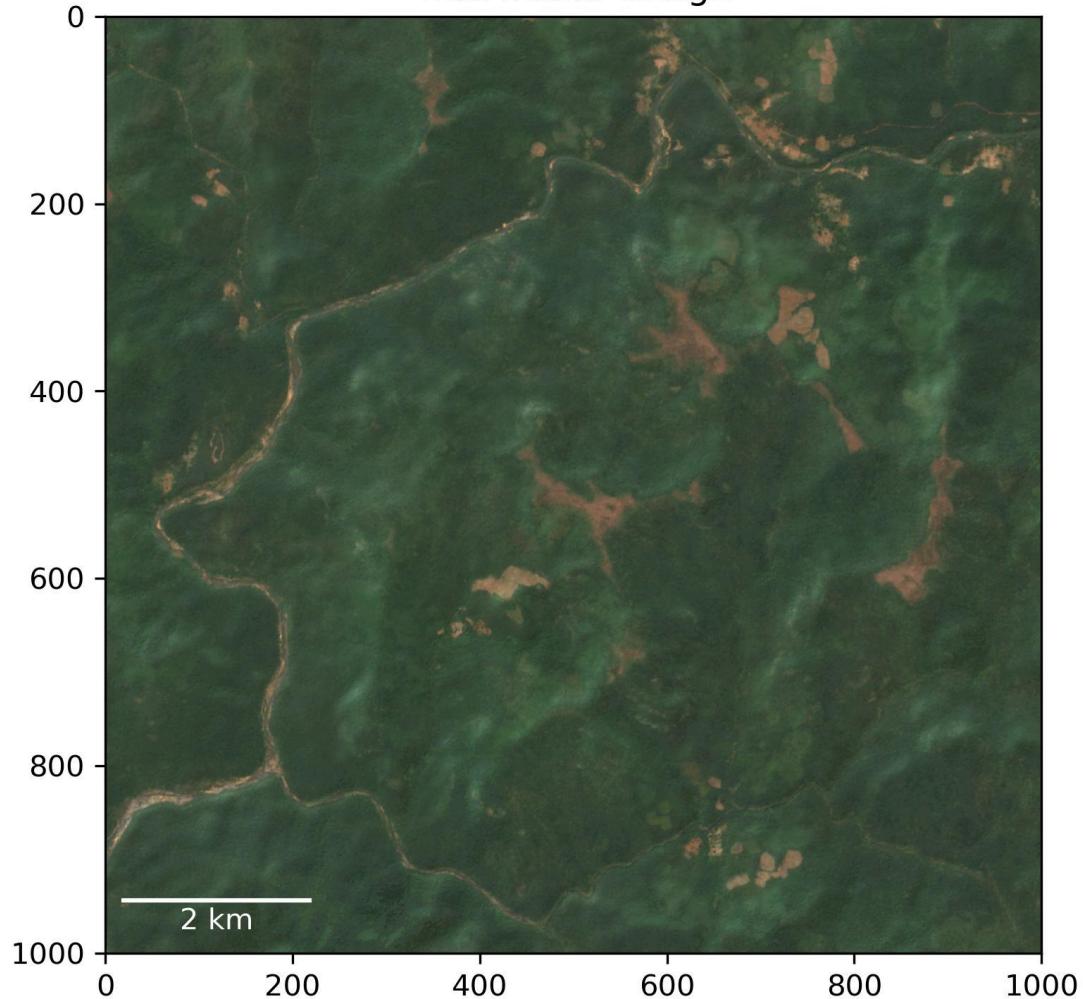
- Water
- Developed
- Barren
- Trees
- Shrub
- Herbaceous

Markud, India. Tropical and Subtropical Dry Broadleaf Forests

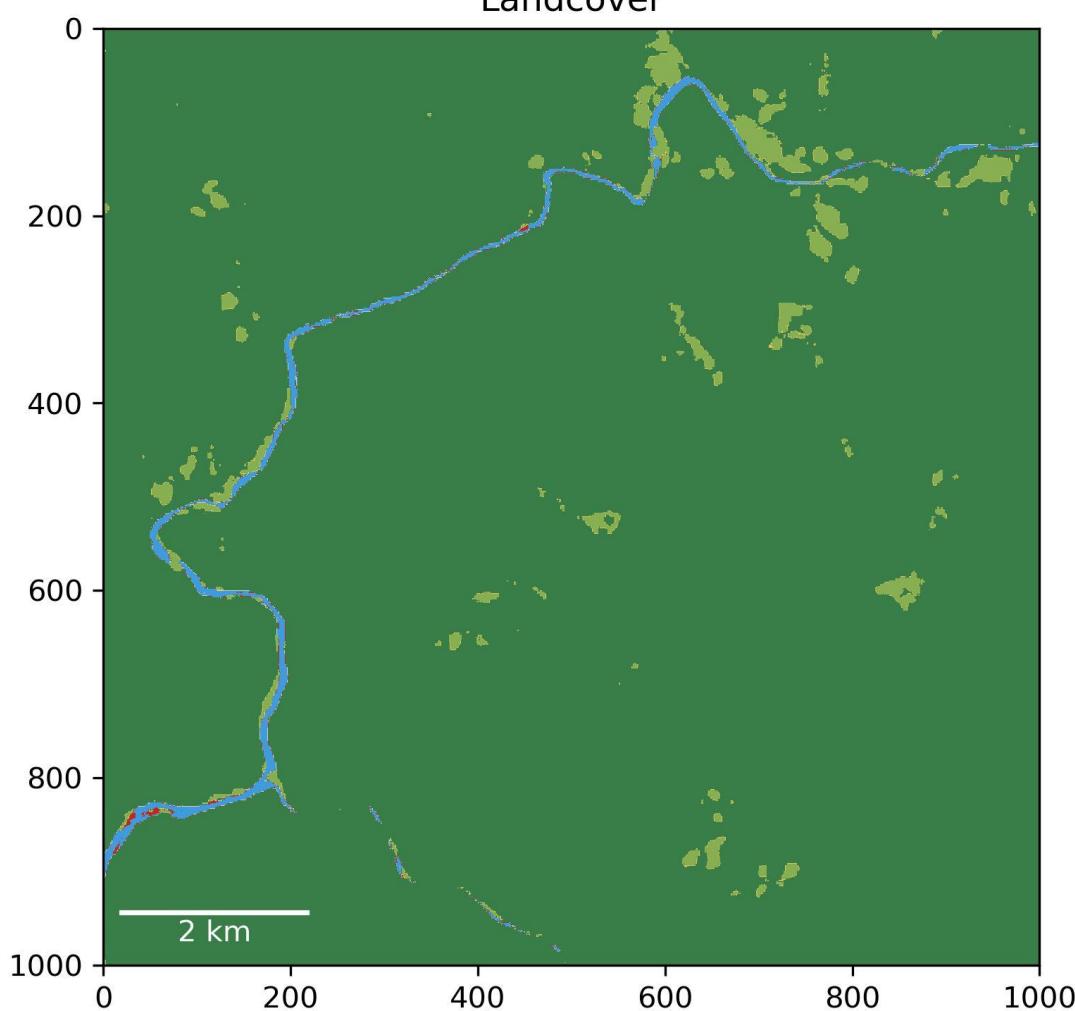
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Biome-2. AlphaEarth. Inference

True colour image



Landcover



Markud, India. Tropical and Subtropical Dry Broadleaf Forests

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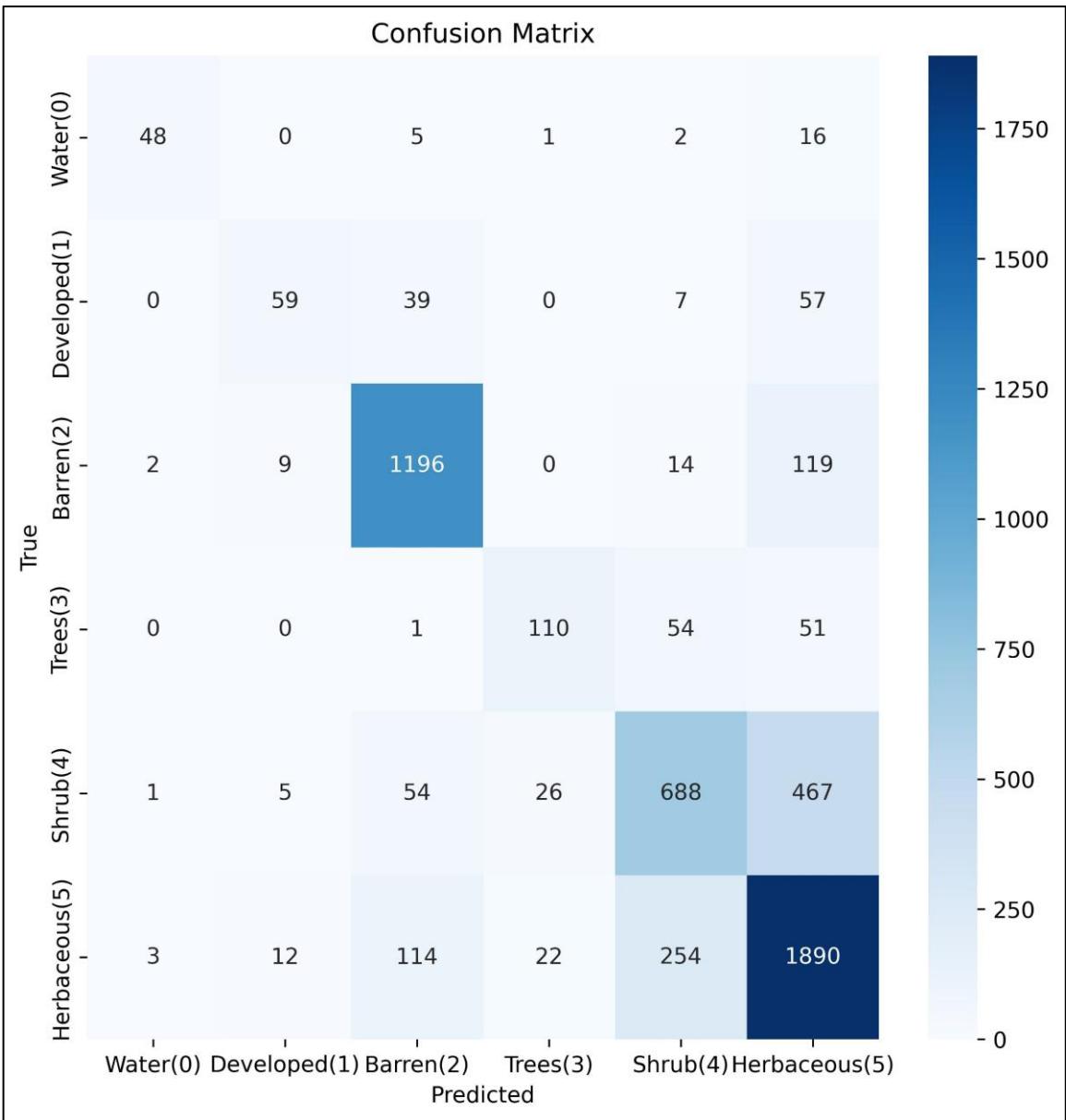
Biome-13. Deserts and Xeric Shrublands

Samples	Data	Model	Device	Epochs	Batch	Time	Loss	Accuracy		F1-score	
								size	min	test	train
Biome-13											
26628	Sentinel-2	CNN Patch	cpu	500	32	16	0.59	75%	77%	0.68	0.74
26628	Sentinel-2	CNN Patch	cpu	1000	32	16	0.51	75%	79%	0.71	0.75
26716	AlphaEarth	Fully Connected	cpu	500	10	19	0.09	93%	97%	0.92	0.93

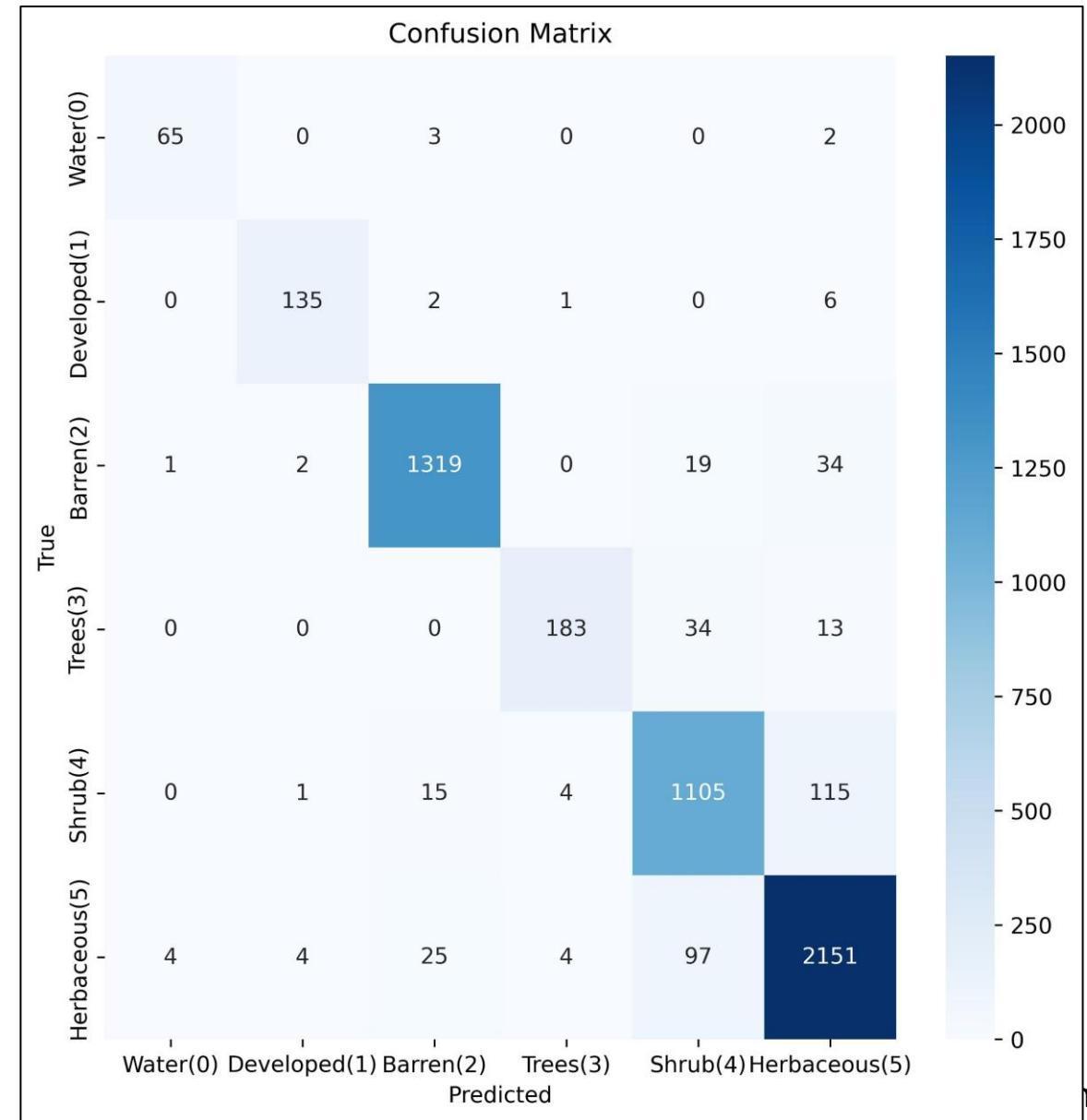
Level 1	Biome 2	Biome 7	Biome 8	Biome 10	Biome 12	Biome 13	All
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Developed [1]	0.9%	0.9%	3.2%	0.5%	3.9%	2.9%	1.7%
Barren [2]	0.4%	1.5%	2.2%	5.1%	0.8%	25.8%	4.7%
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Herb [5]	39.2%	47.5%	82.4%	70.6%	34.7%	42.9%	50.1%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Biome-13. Confusion Matrices

Sentinel-2

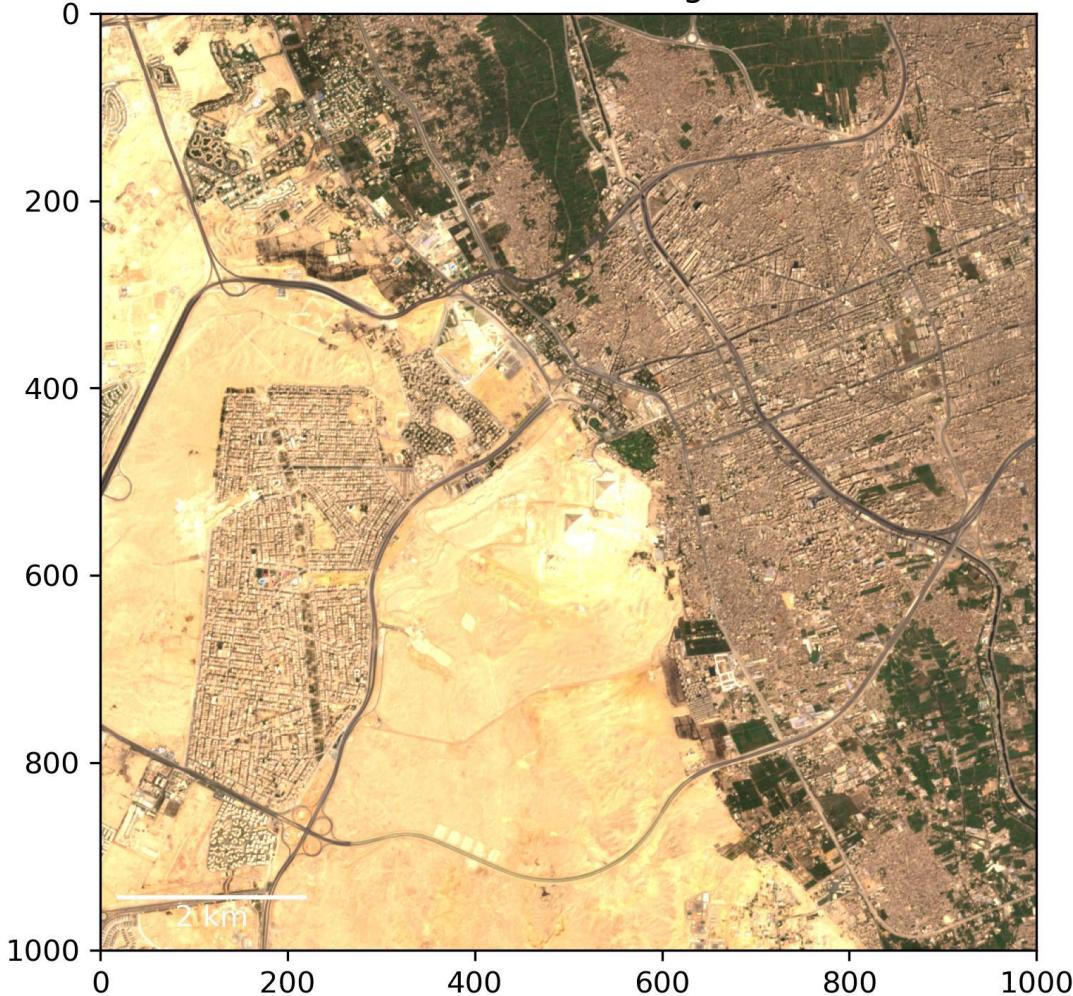


AlphaEarth

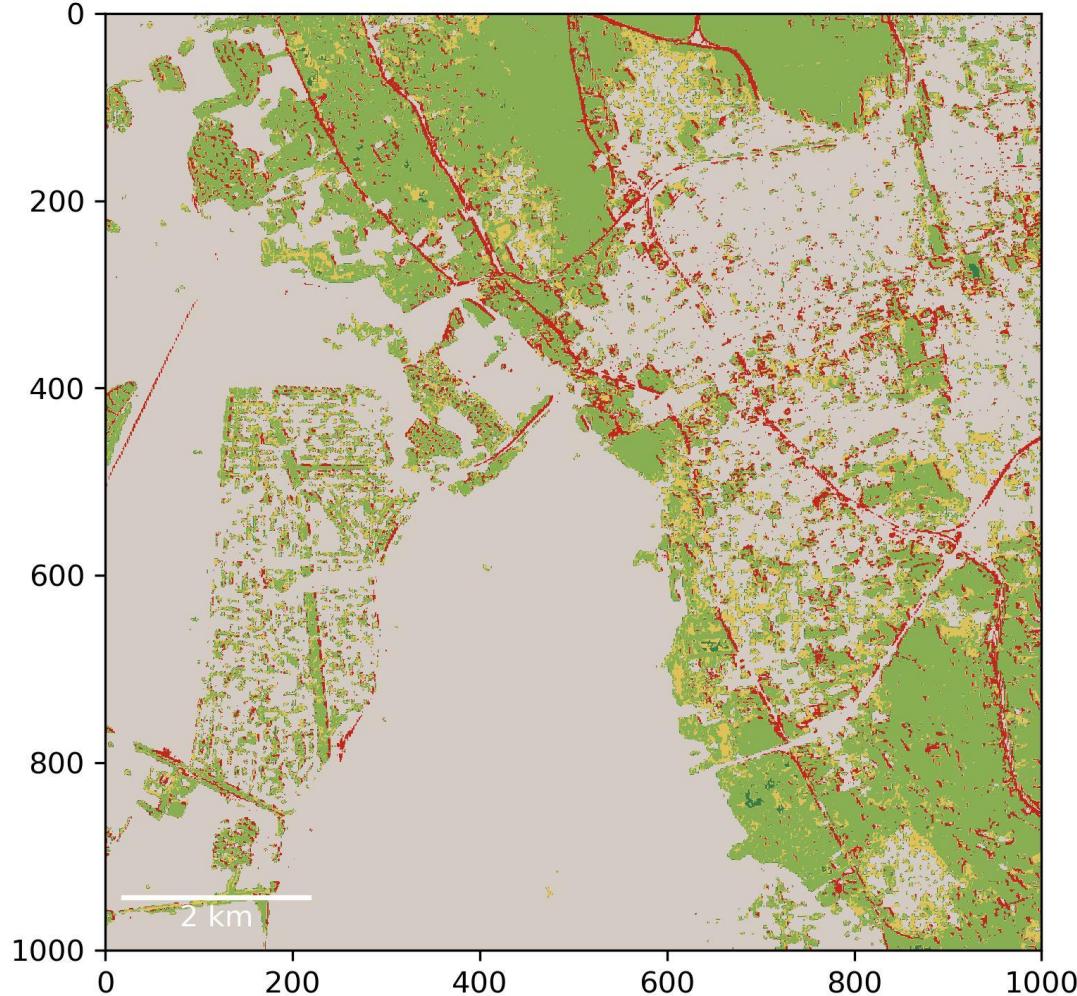


Biome-13. Sentinel-2. Inference

True colour image



Landcover



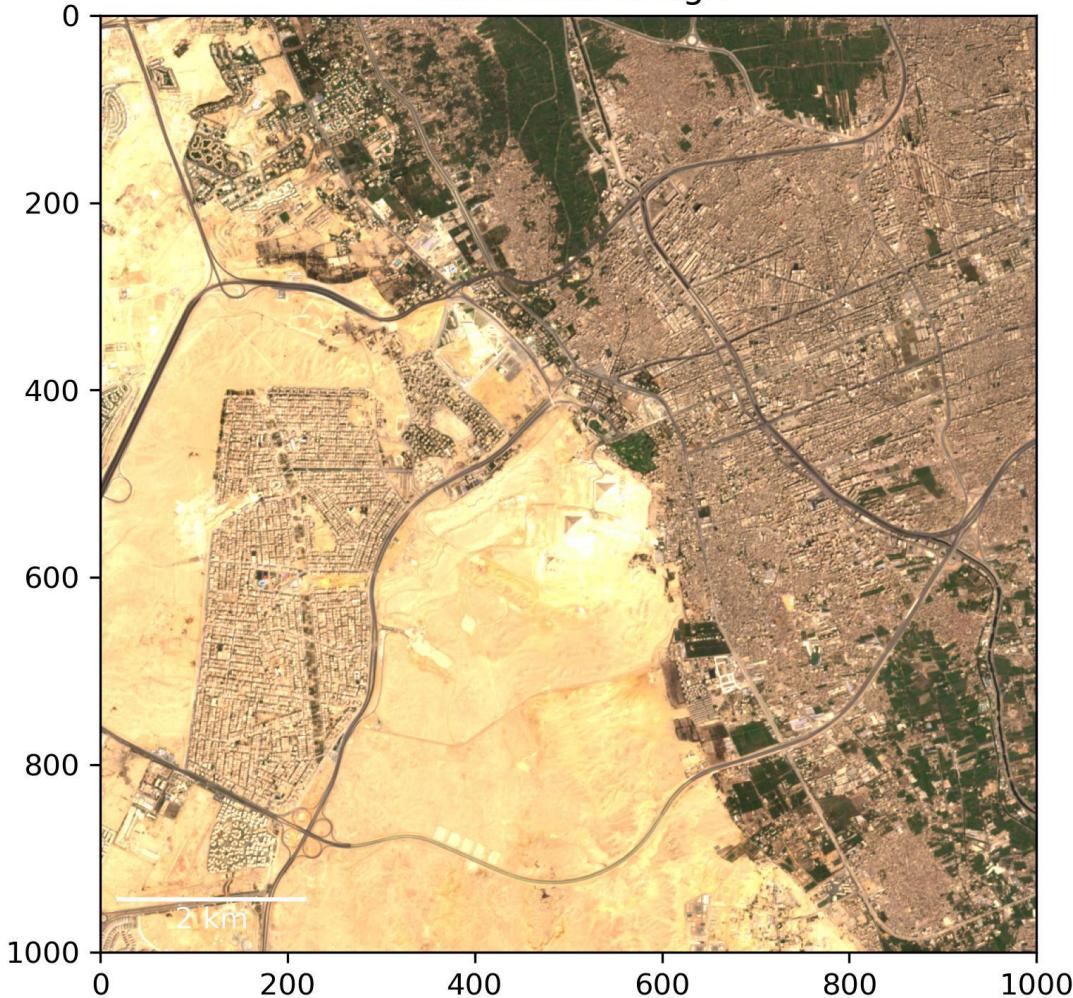
- Water
- Developed
- Barren
- Trees
- Shrub
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Pyramids, Egypt. Deserts and Xeric Shrublands

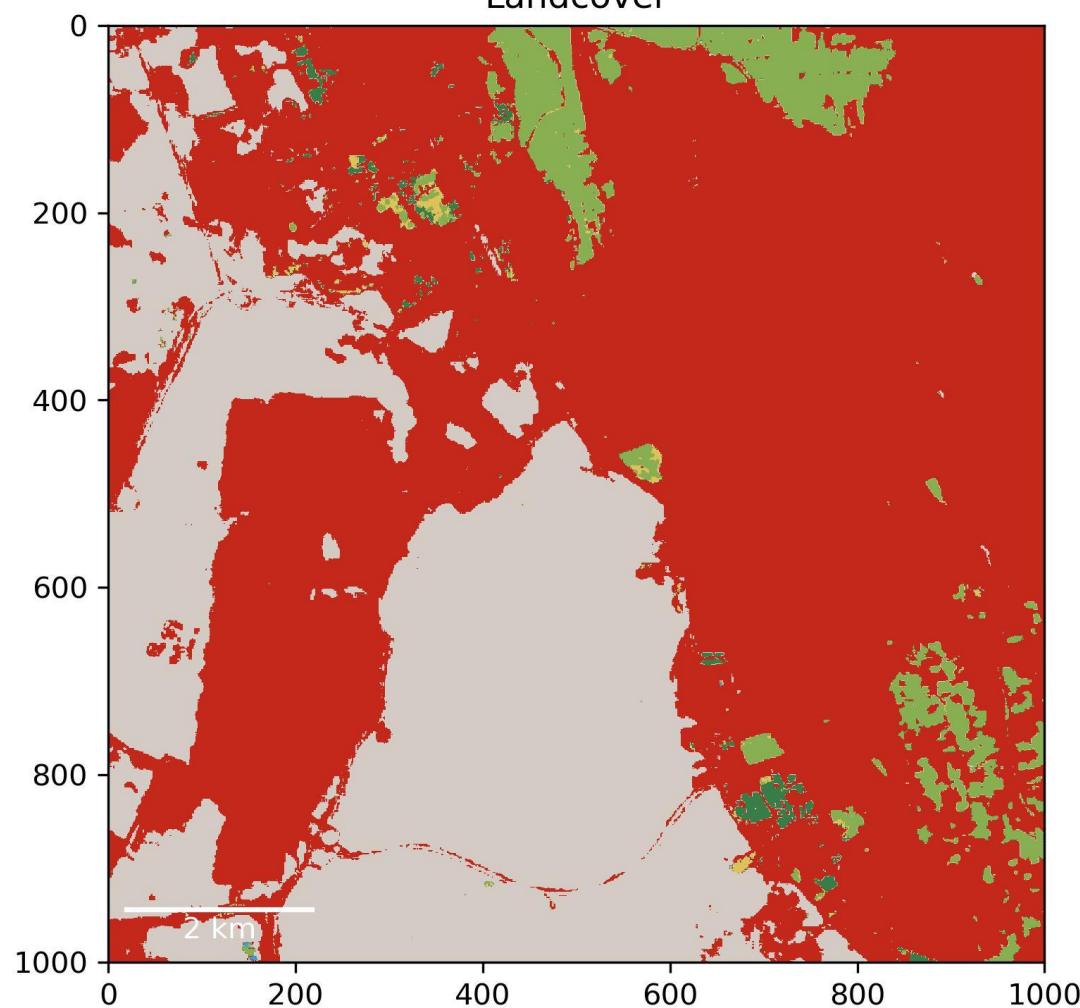
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Biome-13. AlphaEarth. Inference

True colour image



Landcover

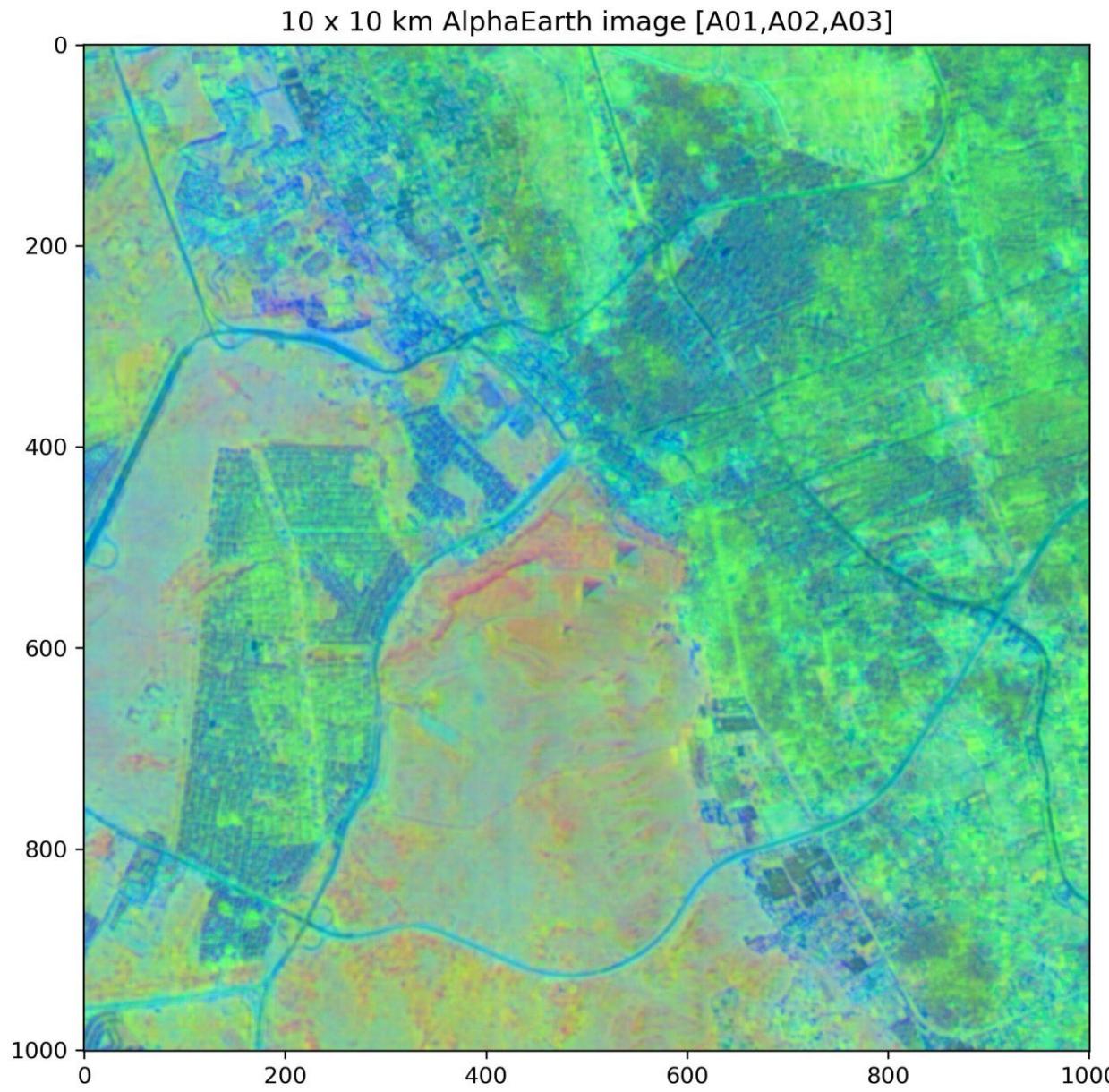


- Water
- Developed
- Barren
- Trees
- Shrub
- Herbaceous

Pyramids, Egypt. Deserts and Xeric Shrublands

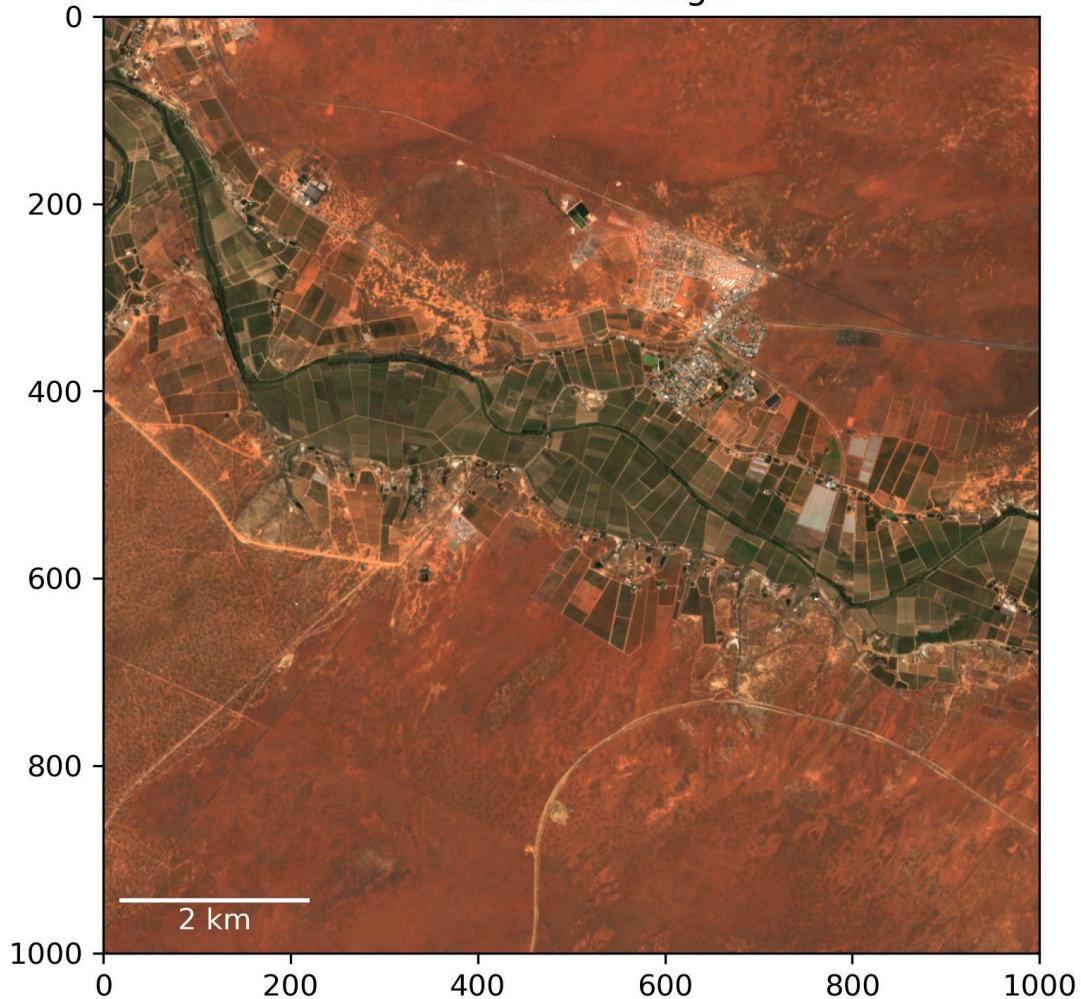
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Biome-13. AlphaEarth Training Data

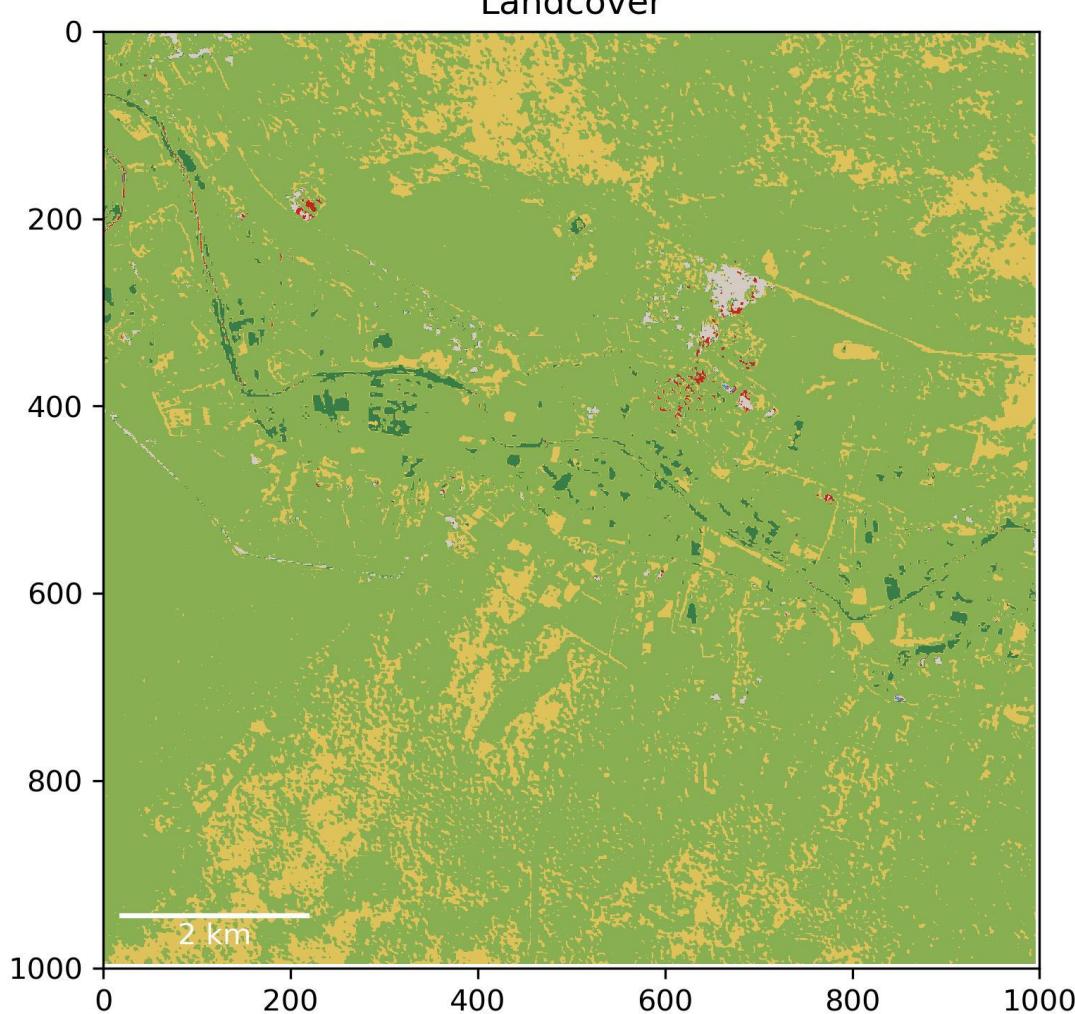


Biome-13. Sentinel-2. Inference

True colour image



Landcover



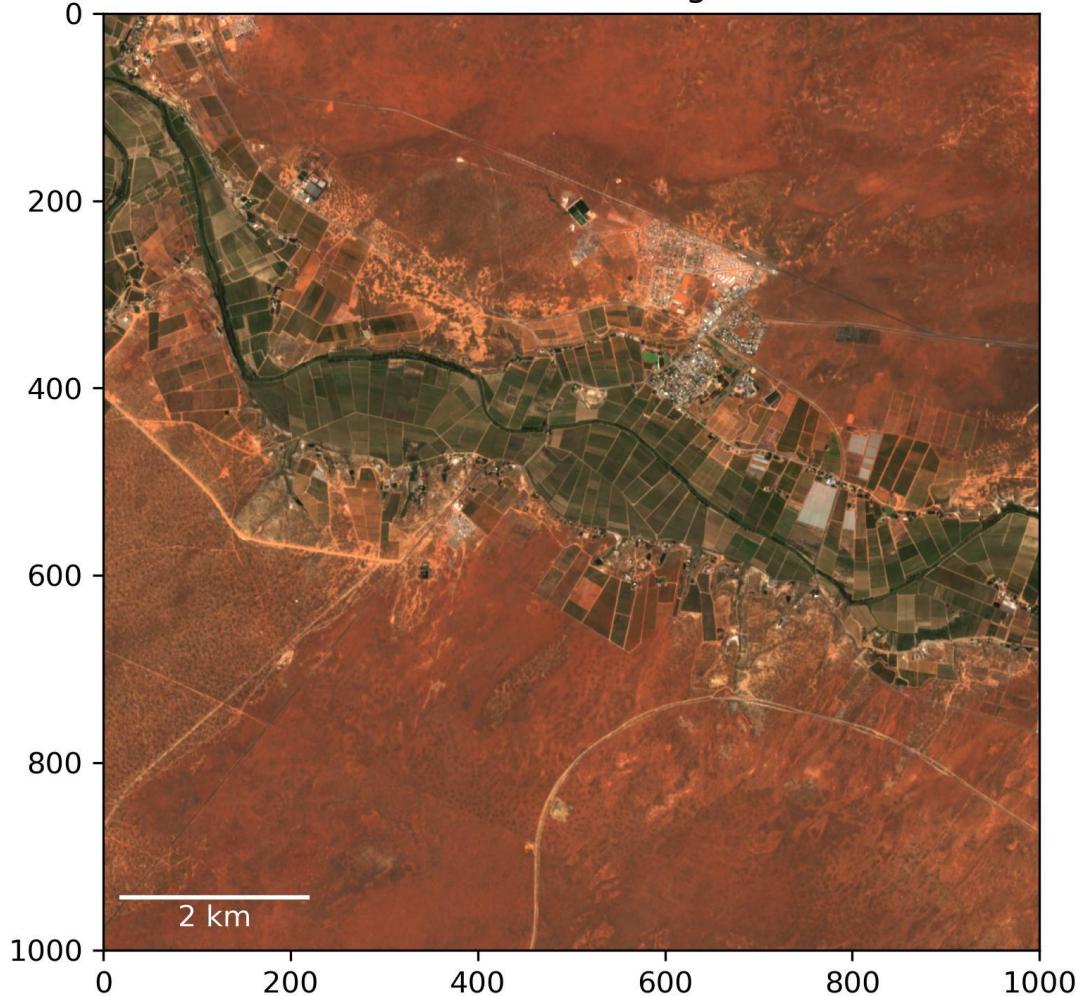
- Water
- Developed
- Barren
- Trees
- Shrub
- Herbaceous

Lutzville, South Africa, Deserts and Xeric Shrublands

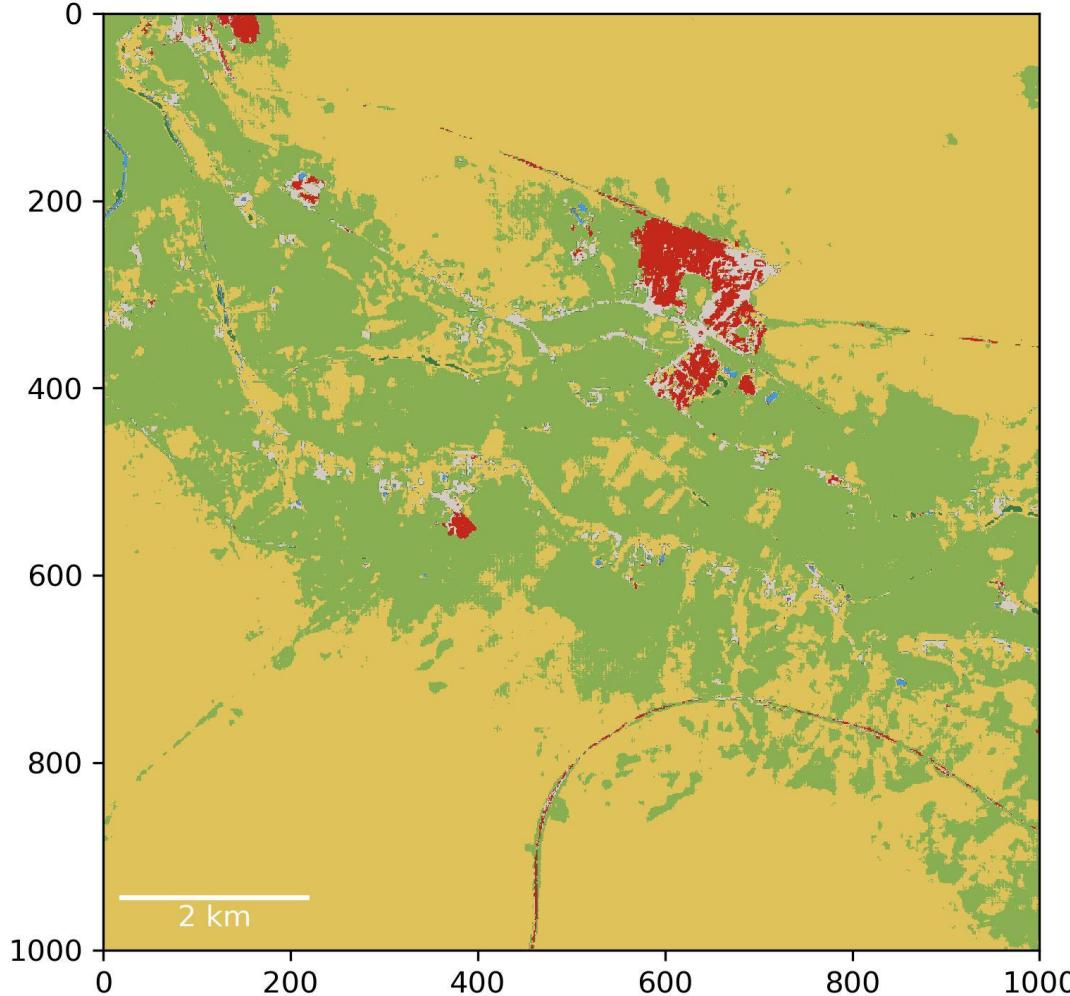
John Toth

Biome-13. AlphaEarth. Inference

True colour image



Landcover

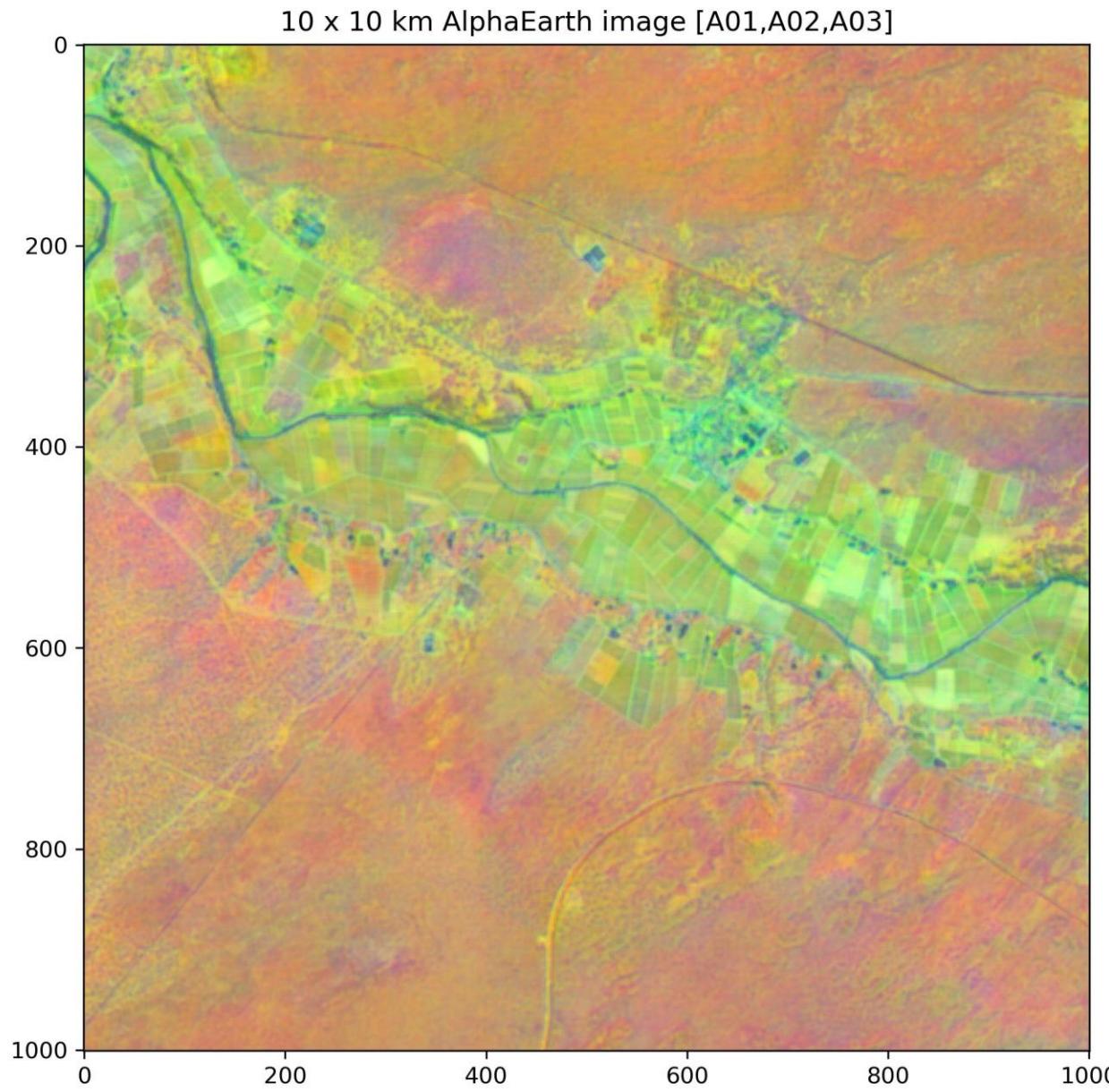


- Water
- Developed
- Barren
- Trees
- Shrub
- Herbaceous

Lutzville, South Africa. Deserts and Xeric Shrublands

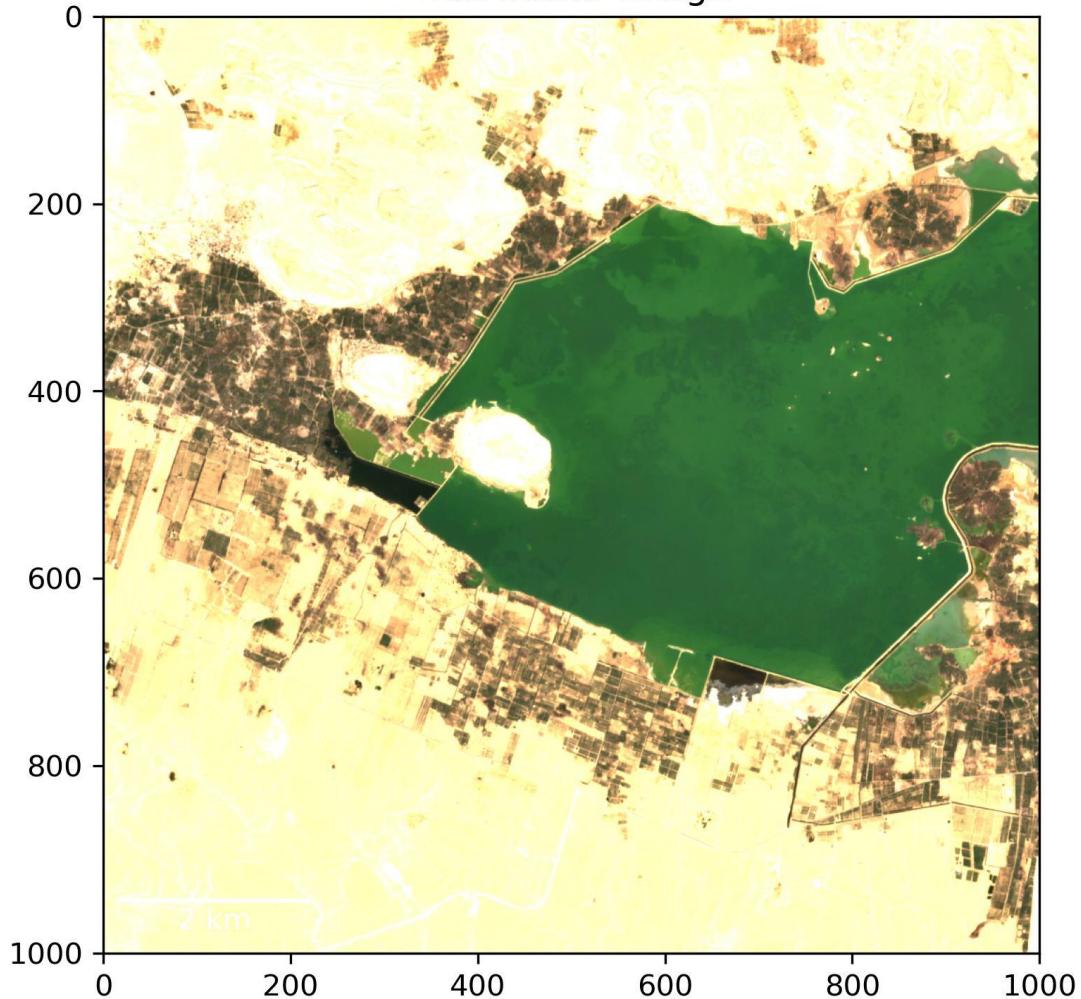
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Biome-13. AlphaEarth Training Data

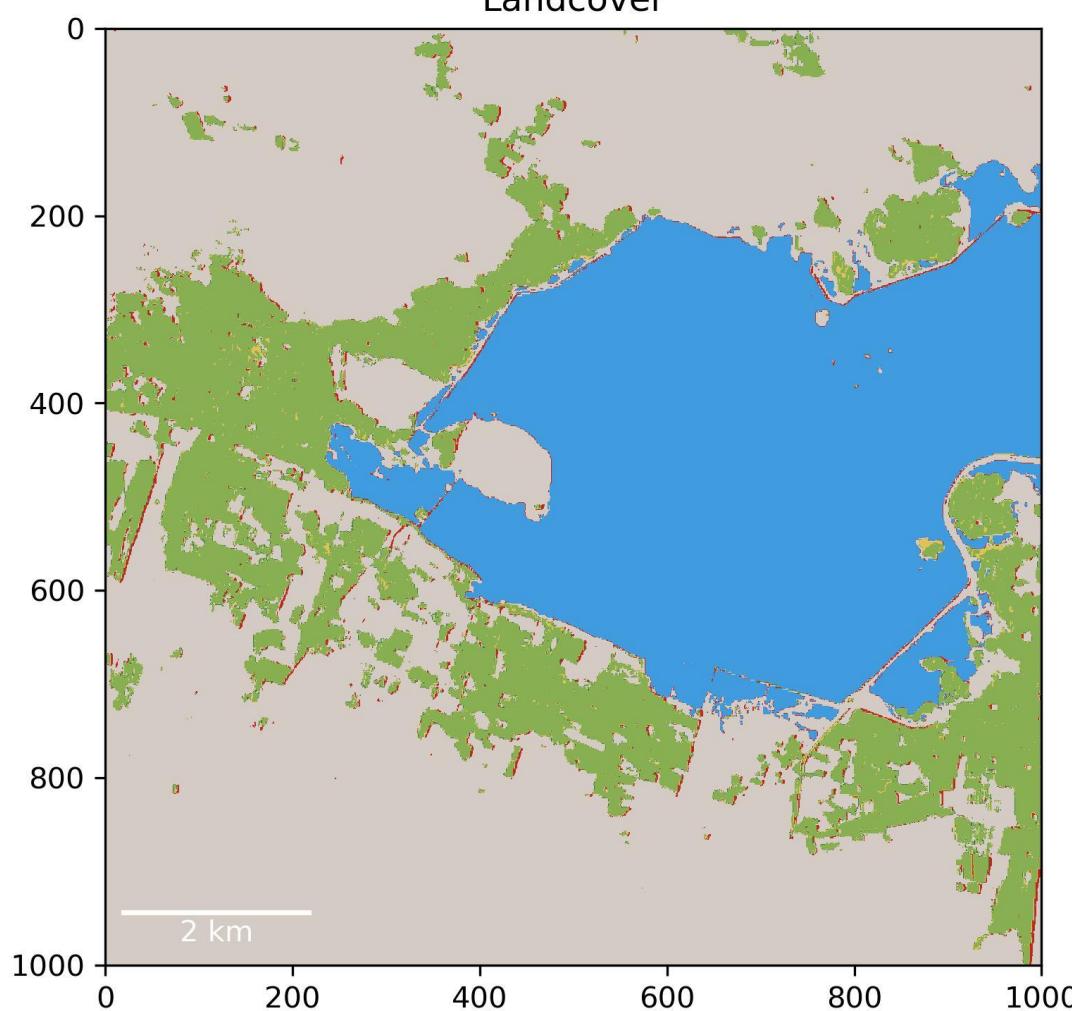


Biome-13. Sentinel-2. Inference

True colour image



Landcover

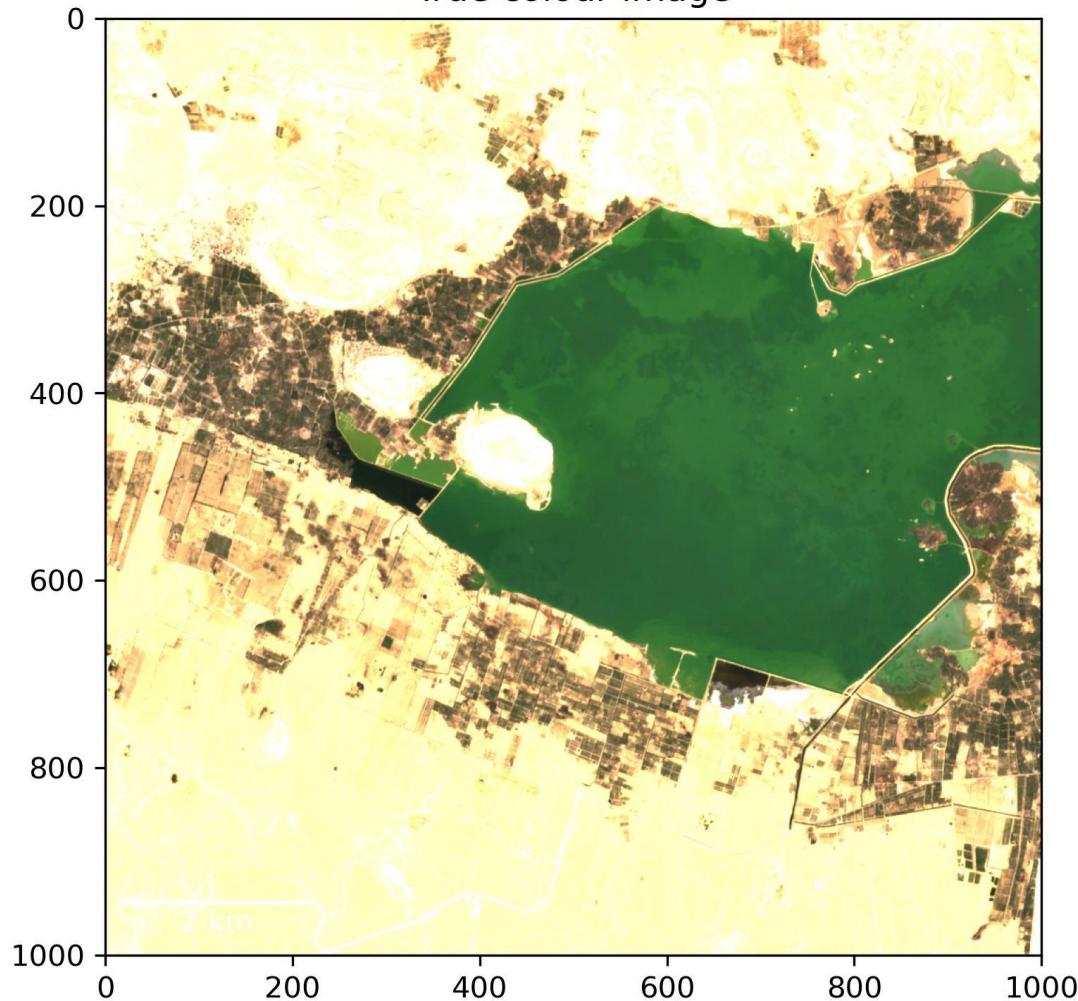


Siwa Oasis, Egypt. Deserts and Xeric Shrublands

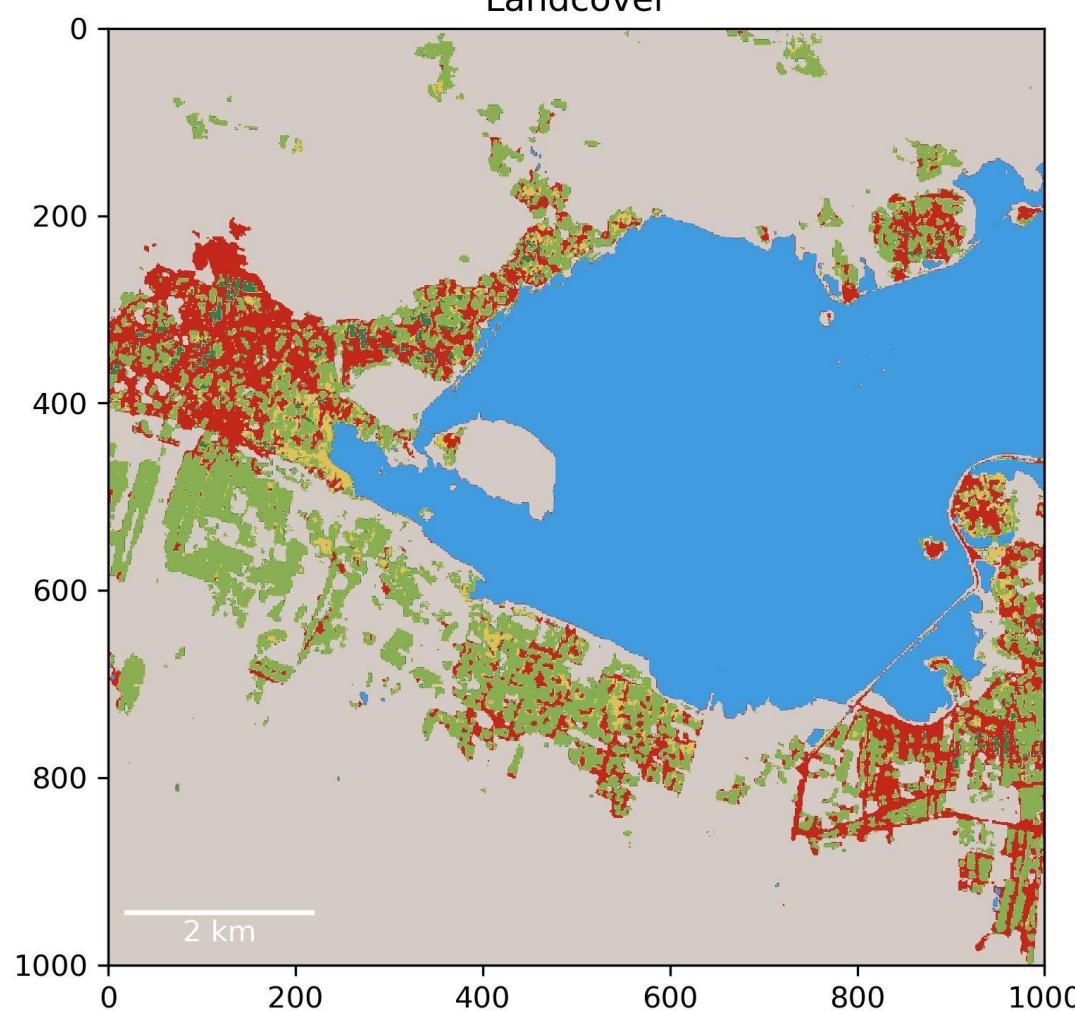
John Toth

Biome-13. AlphaEarth. Inference

True colour image



Landcover

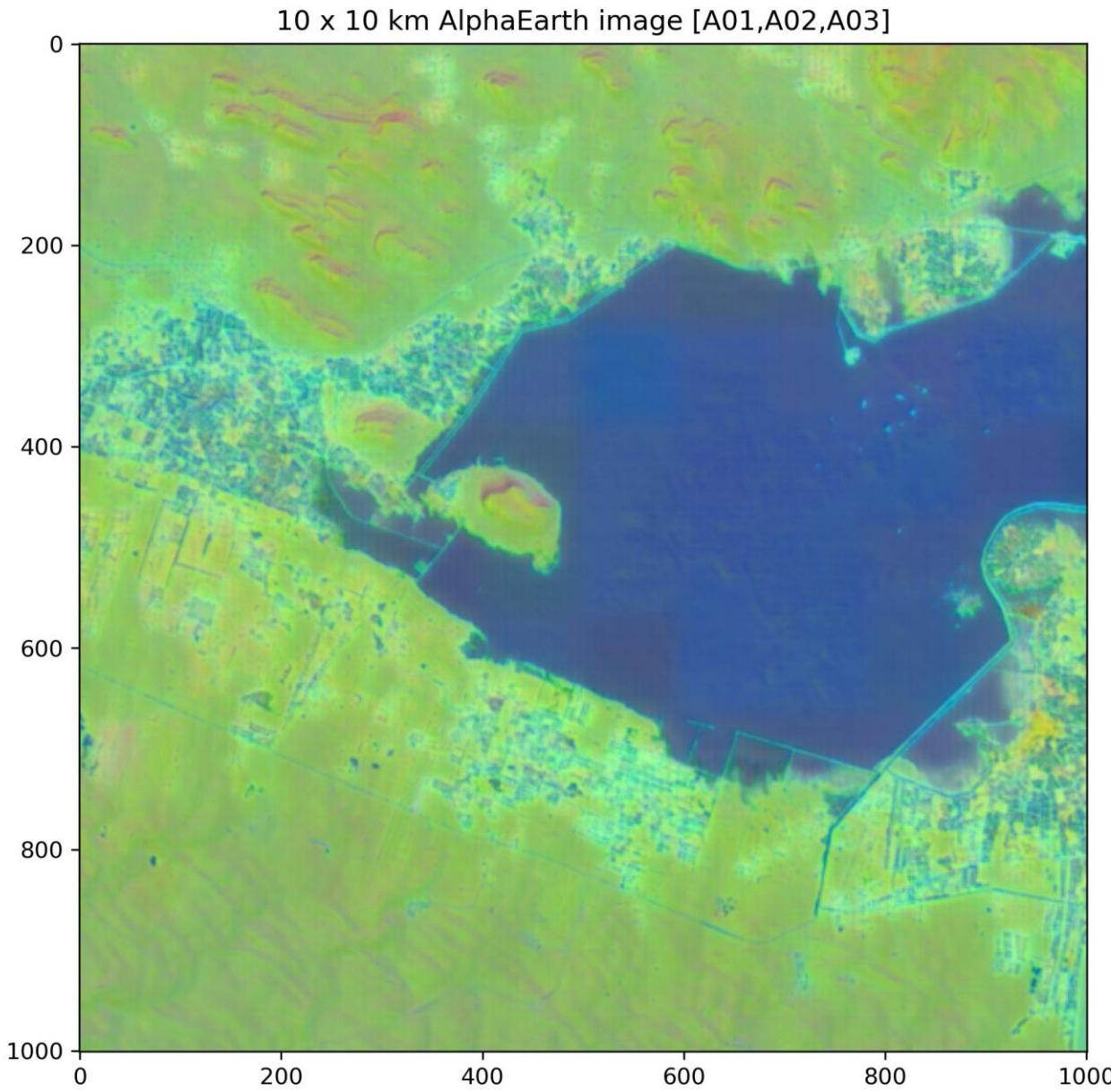


- Water
- Developed
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- Trees
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Siwa Oasis, Egypt. Deserts and Xeric Shrublands

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Biome-13. AlphaEarth Training Data



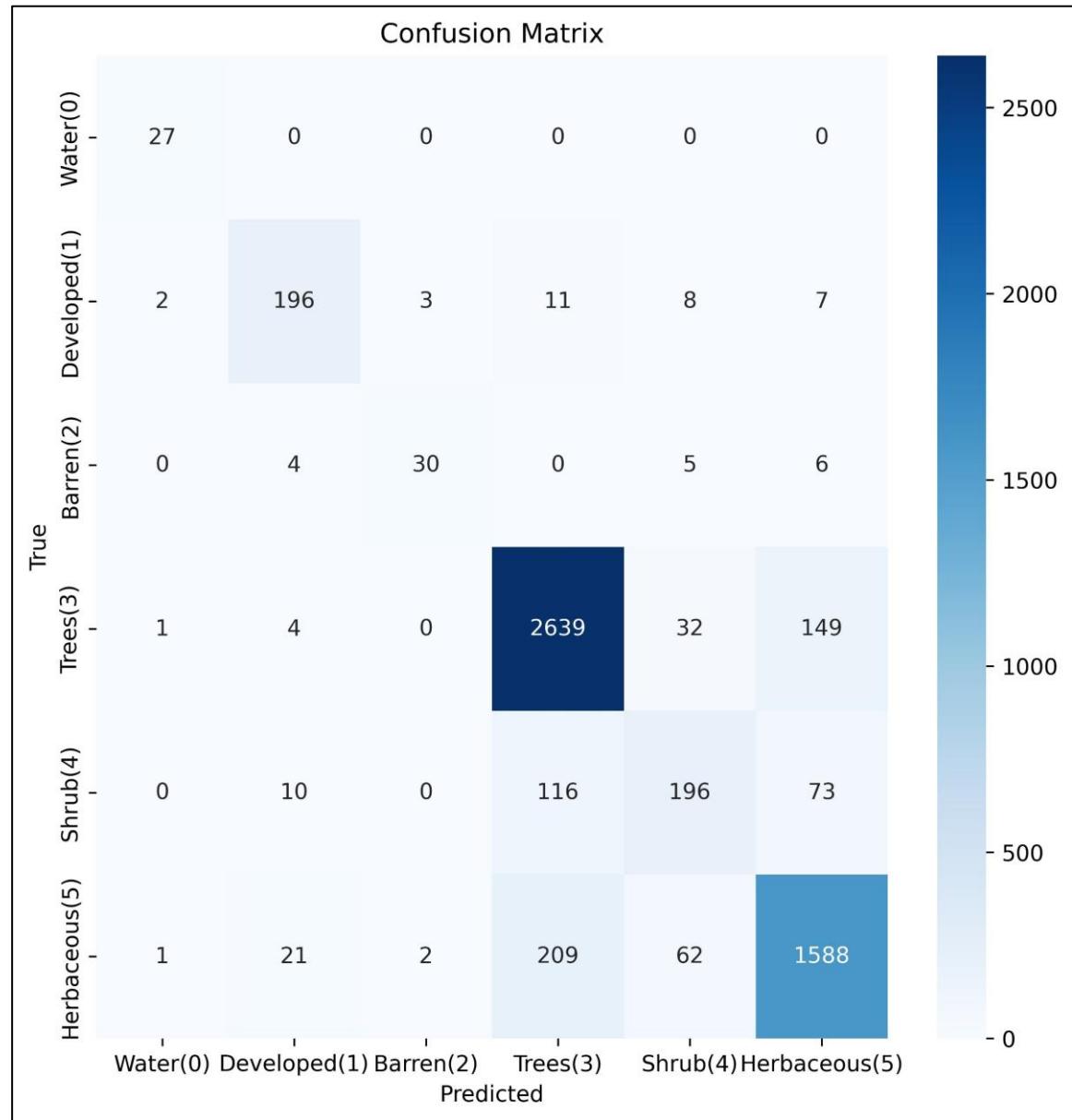
Biome-12. Mediterranean Forests, Woodlands and Scrub

Samples	Data	Model	Device	Epochs	Batch size	Time min	Loss	Accuracy		F1-score	
								test	train	macro	weighted
Biome-12											
27006	Sentinel-2	CNN Patch	cpu	500	32	16	0.34	87%	88%	0.81	0.86
27006	Sentinel-2	CNN Patch	cpu	1000	32	17	0.27	87%	90%	0.80	0.87
27006	Sentinel-2	CNN Patch4	cpu	500	32	13	0.42	86%	85%	0.76	0.85
26953	AlphaEarth	Fully Connected	cpu	500	10	20	0.07	96%	98%	0.90	0.96
26953	AlphaEarth	FC 0 to 1	cpu	500	10	20	0.09	95%	97%	0.90	0.95
26953	AlphaEarth	FC tanh	cpu	500	10	20	0.08	95%	97%	0.91	0.95
26953	AlphaEarth	FC sigmoid	cpu	500	10	20	0.13	95%	96%	0.87	0.95

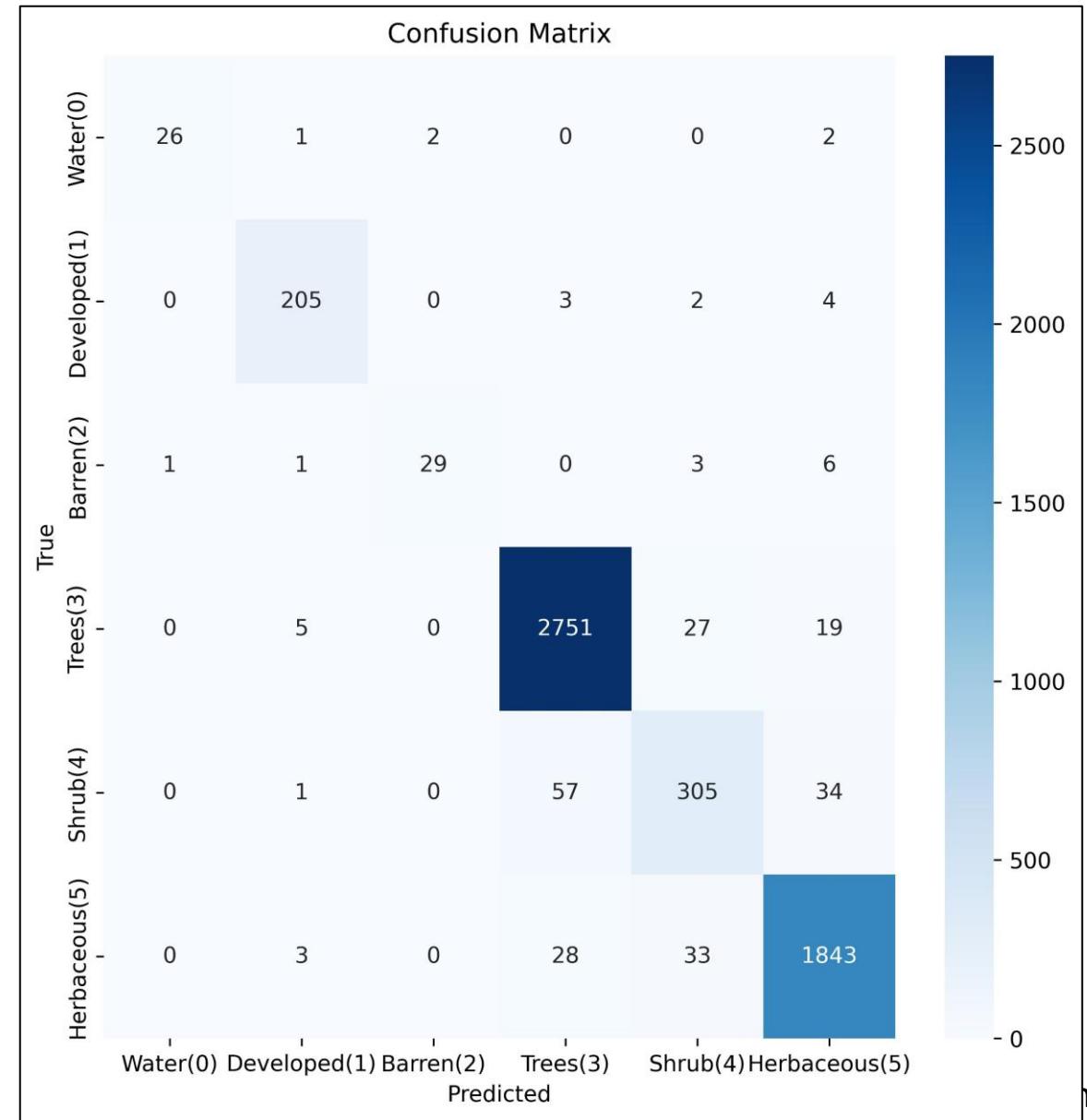
Level 1	Biome 2	Biome 7	Biome 8	Biome 10	Biome 12	Biome 13	All
Water [0]	10.7%	10.2%	2.7%	10.5%	0.6%	1.4%	7.3%
Developed [1]	0.9%	0.9%	3.2%	0.5%	3.9%	2.9%	1.7%
Barren [2]	0.4%	1.5%	2.2%	5.1%	0.8%	25.8%	4.7%
Trees [3]	47.4%	26.2%	7.0%	11.4%	52.5%	4.0%	26.0%
Shrub [4]	1.4%	13.8%	2.5%	1.9%	7.5%	23.1%	10.1%
Herb [5]	39.2%	47.5%	82.4%	70.6%	34.7%	42.9%	50.1%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Biome-12. Confusion Matrices

Sentinel-2

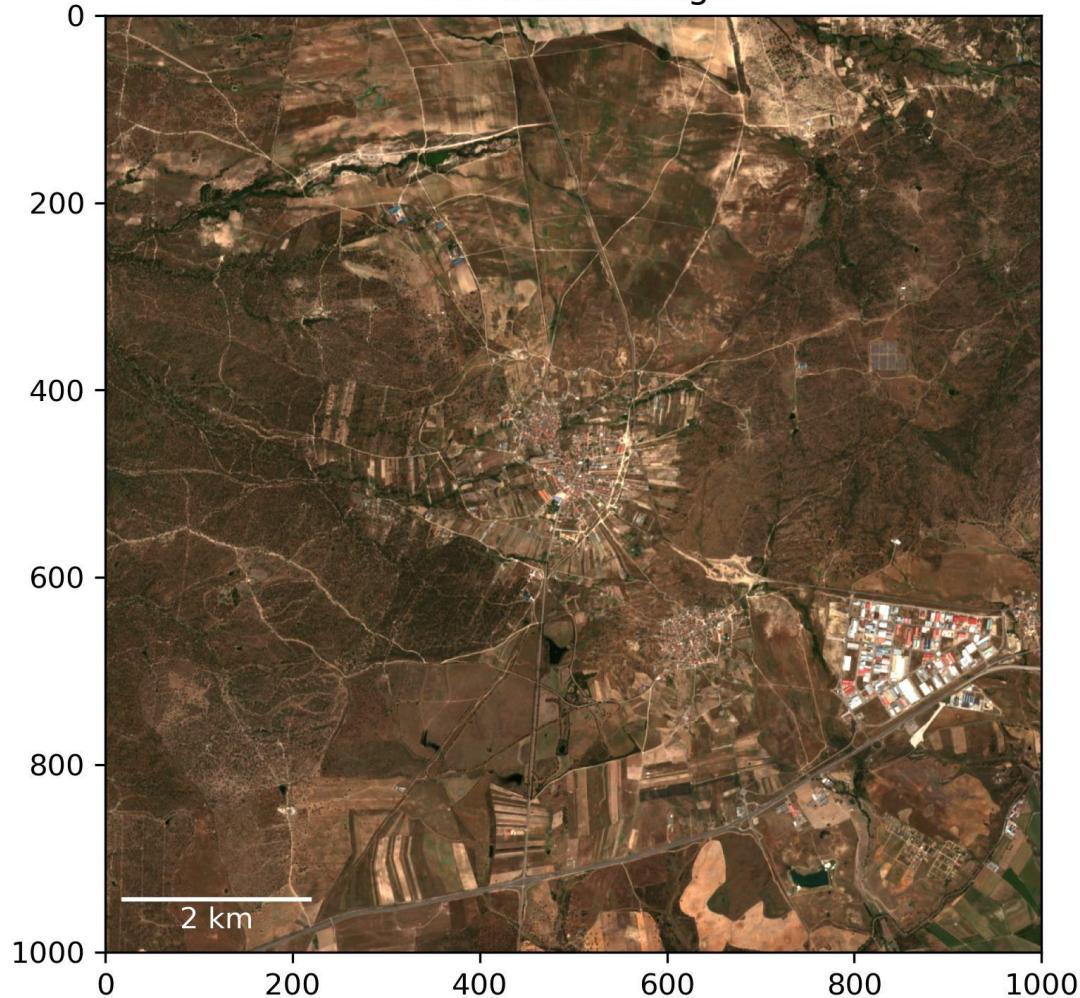


AlphaEarth

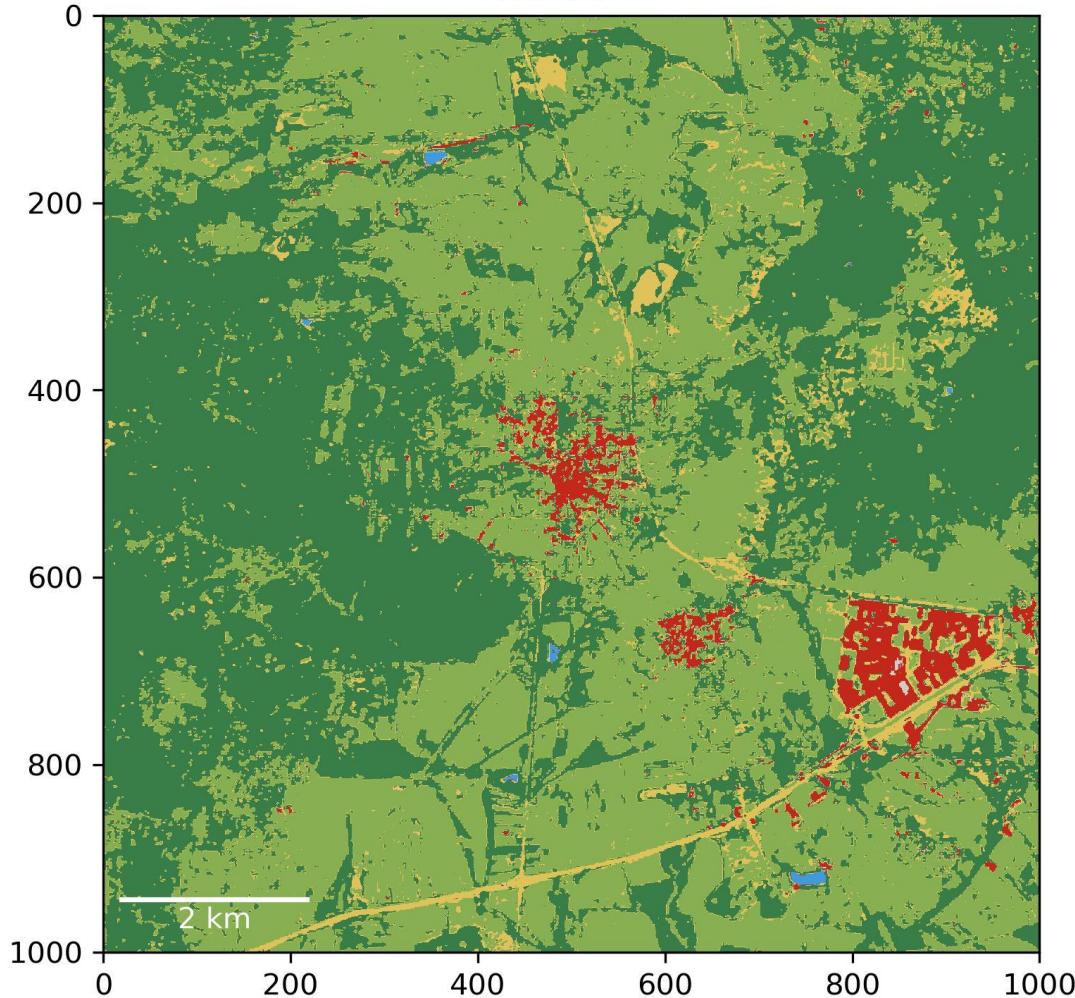


Biome-12. Sentinel-2. Inference

True colour image



Landcover

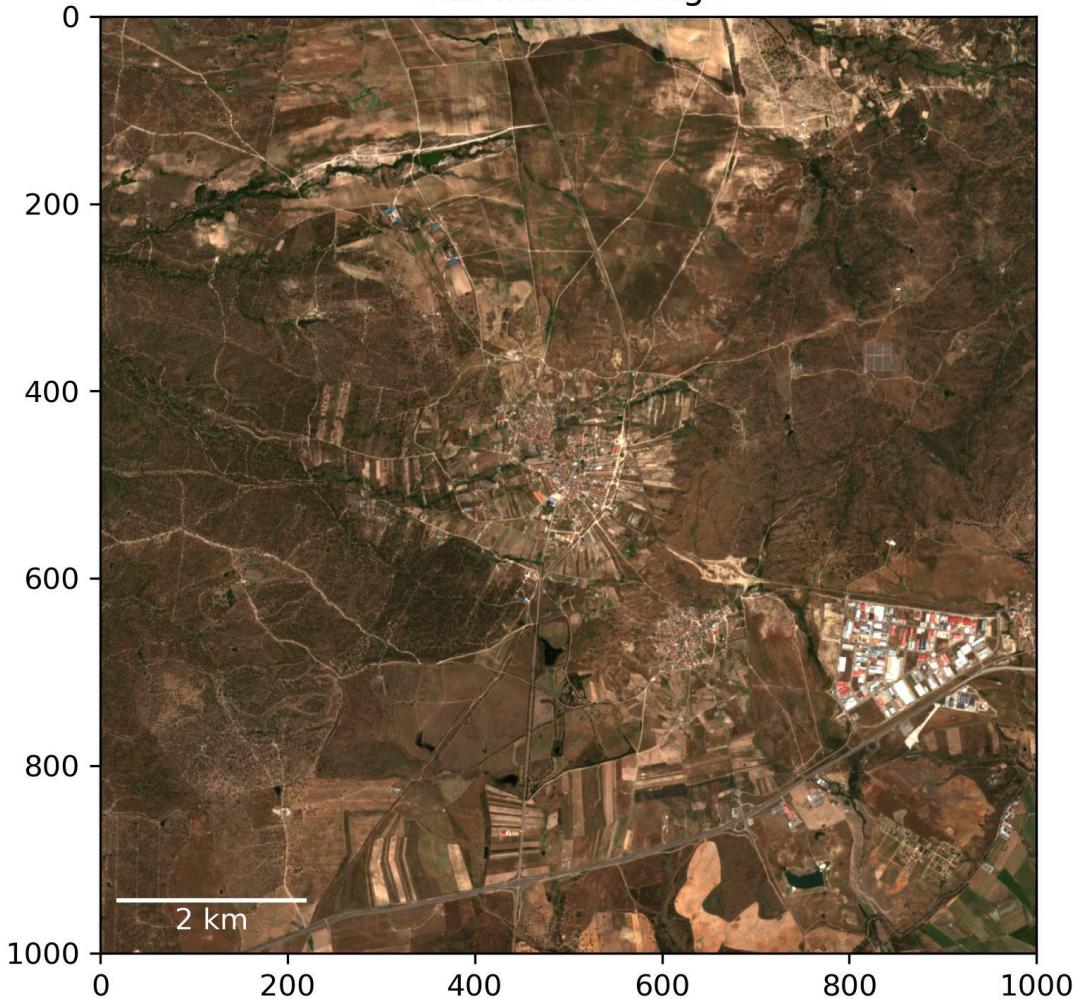


Velada, Spain. Mediterranean Forests, Woodlands and Scrub

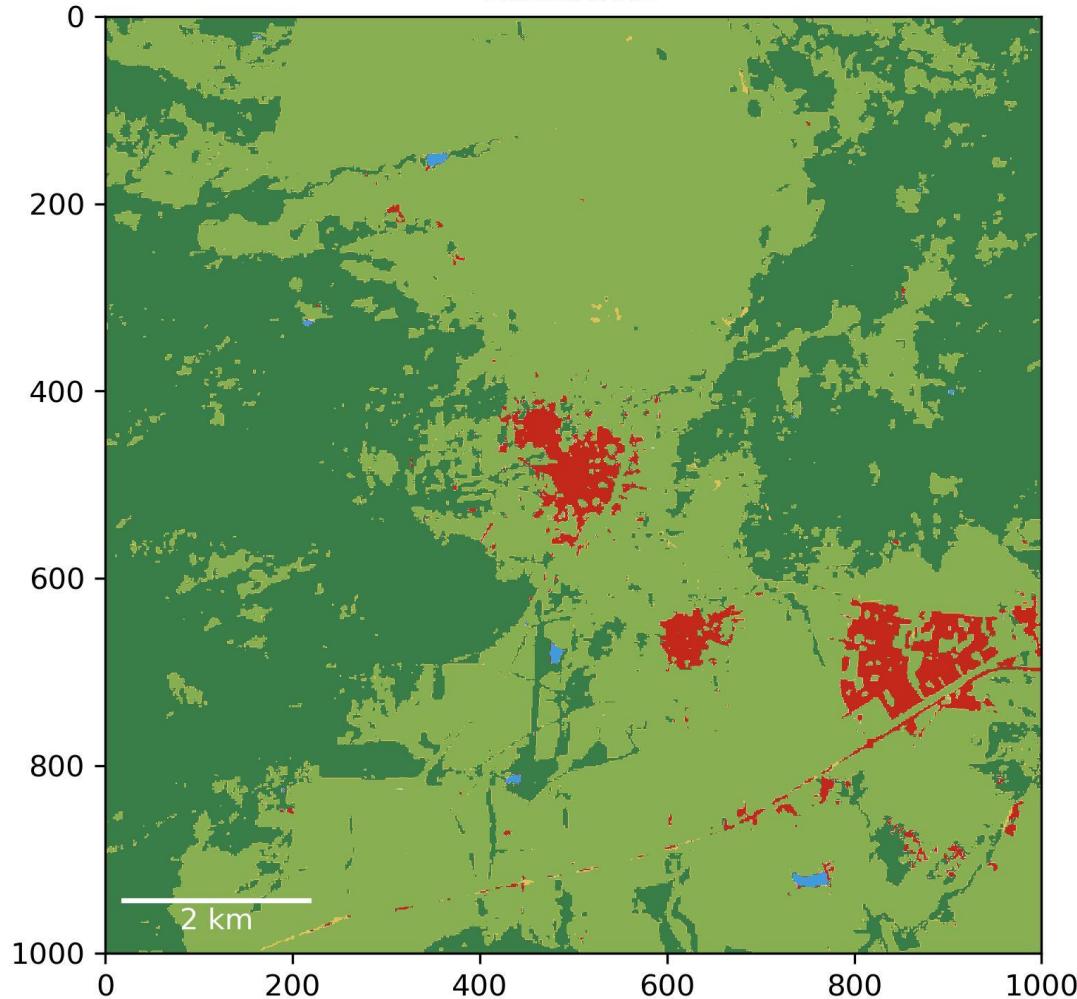
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Biome-12. AlphaEarth. Inference

True colour image



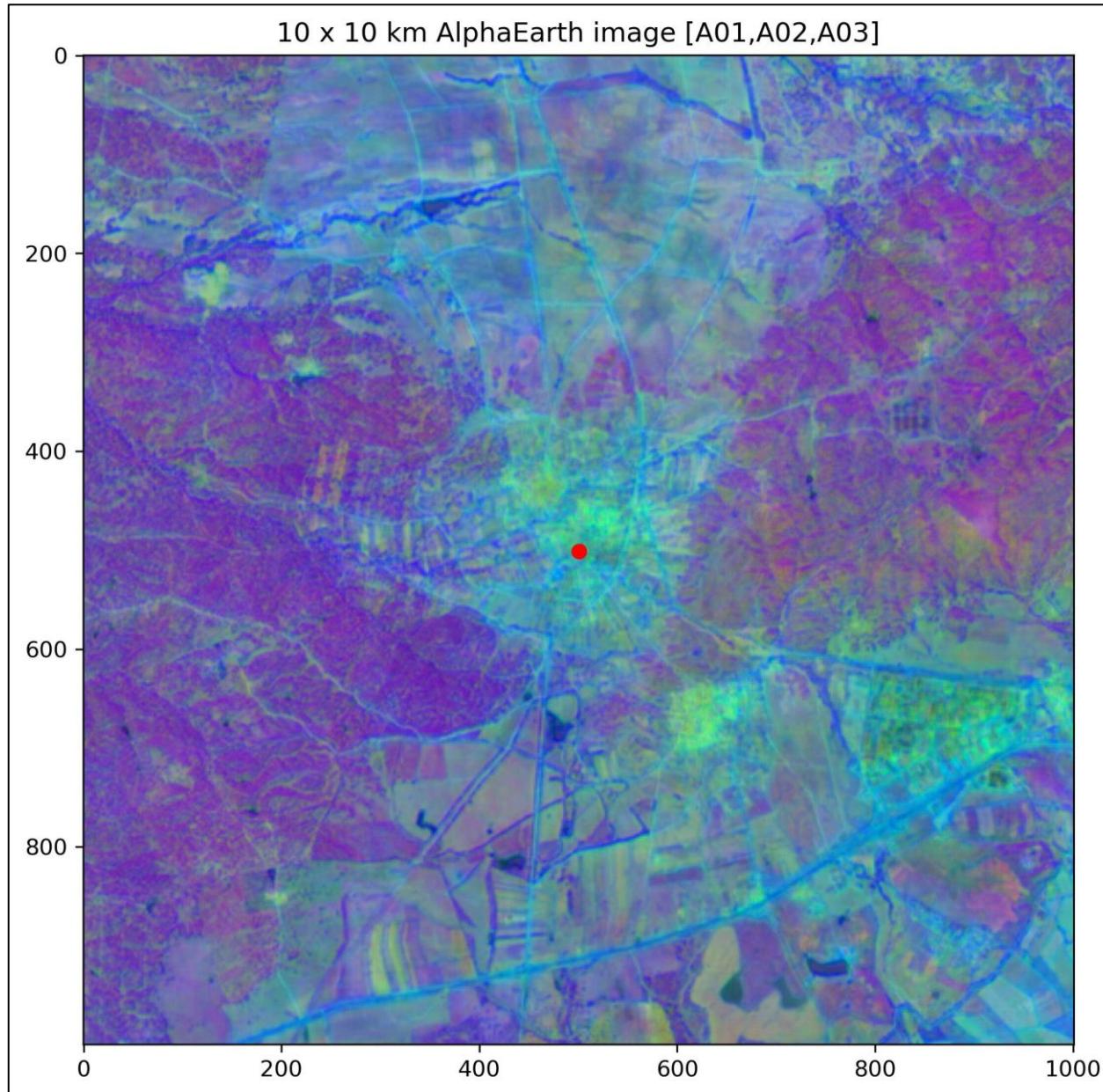
Landcover



Velada, Spain. Mediterranean Forests, Woodlands and Scrub

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Biome-12. AlphaEarth Training Data



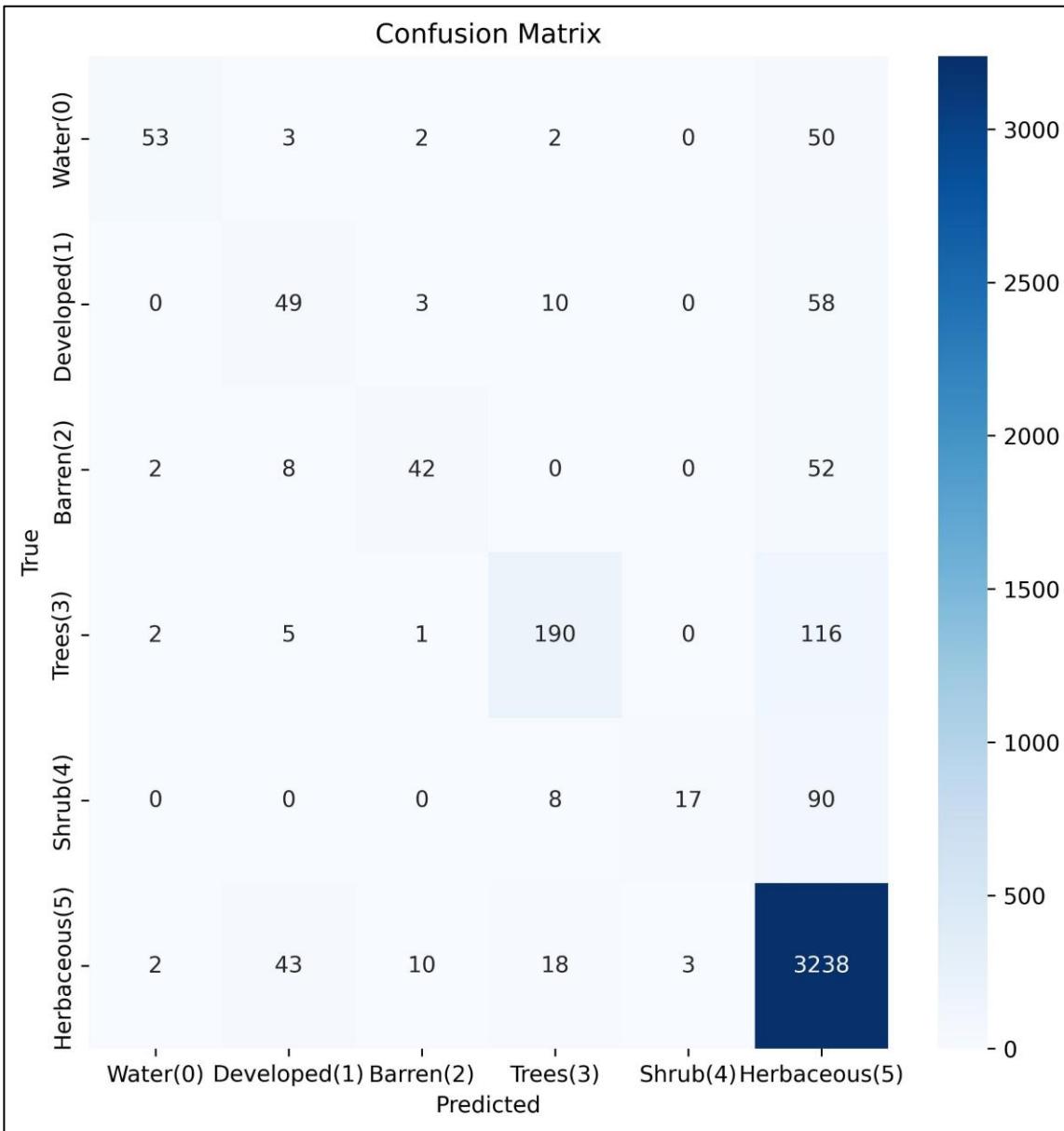
Biome-8. Temperate Grasslands, Savannas, and Shrublands

Samples	Data	Model	Device	Epochs	Batch size	Time min	Loss	Accuracy		F1-score	
								test	train	macro	weighted
Biome-8											
20381	Sentinel-2	CNN Patch	cpu	500	32	11	0.31	88%	90%	0.58	0.86
20335	AlphaEarth	Fully Connected	cpu	500	10	15	0.02	97%	99%	0.91	0.97

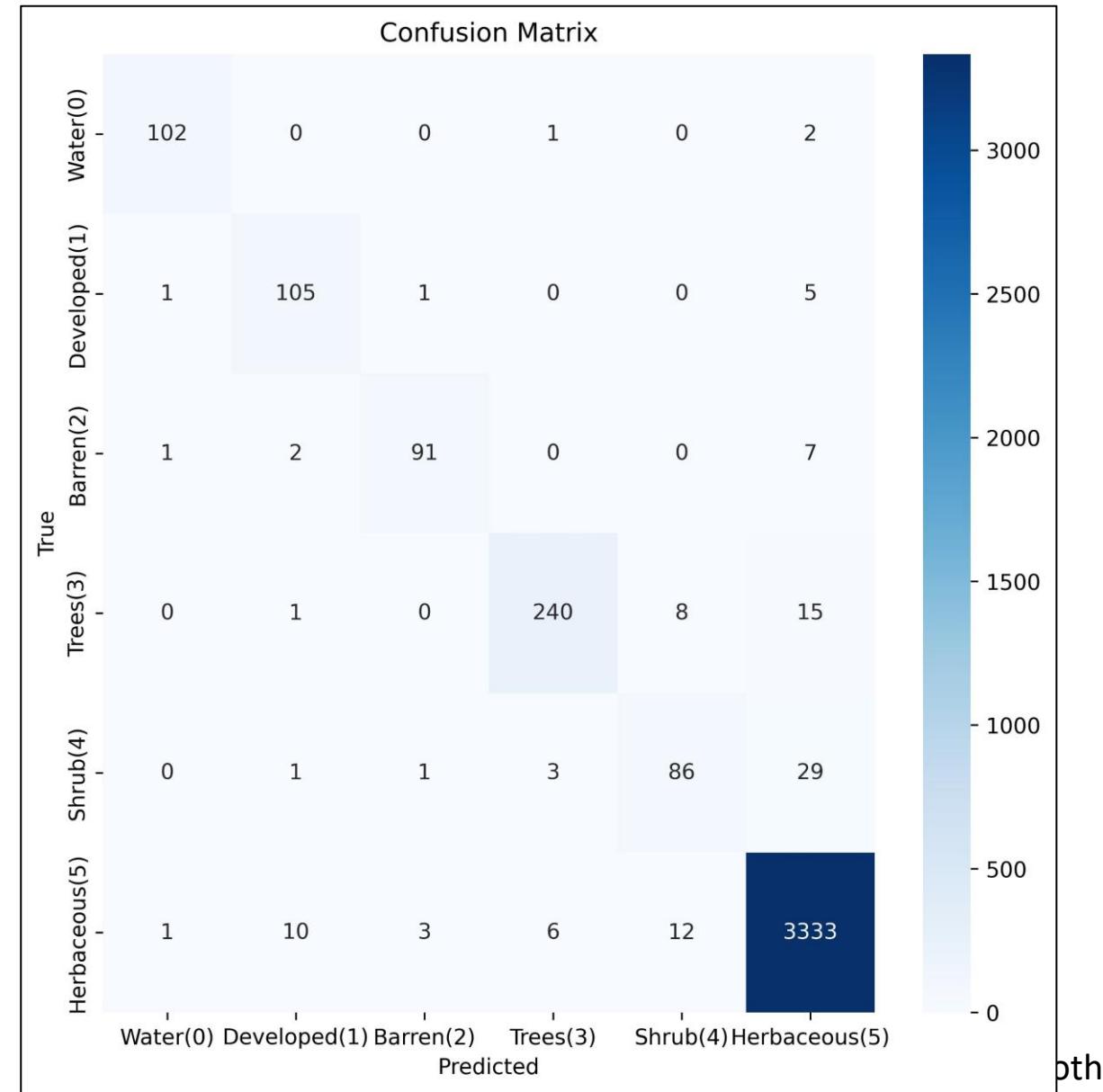
Level 1	Biome 2	Biome 7	Biome 8	Biome 10	Biome 12	Biome 13	All
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Barren [2]	0.4%	1.5%	2.2%	5.1%	0.8%	25.8%	4.7%
Trees [3]	47.4%	26.2%	7.0%	11.4%	52.5%	4.0%	26.0%
Shrub [4]	1.4%	13.8%	2.5%	1.9%	7.5%	23.1%	10.1%
Herb [5]	39.2%	47.5%	82.4%	70.6%	34.7%	42.9%	50.1%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Biome-8. Confusion Matrices

Sentinel-2

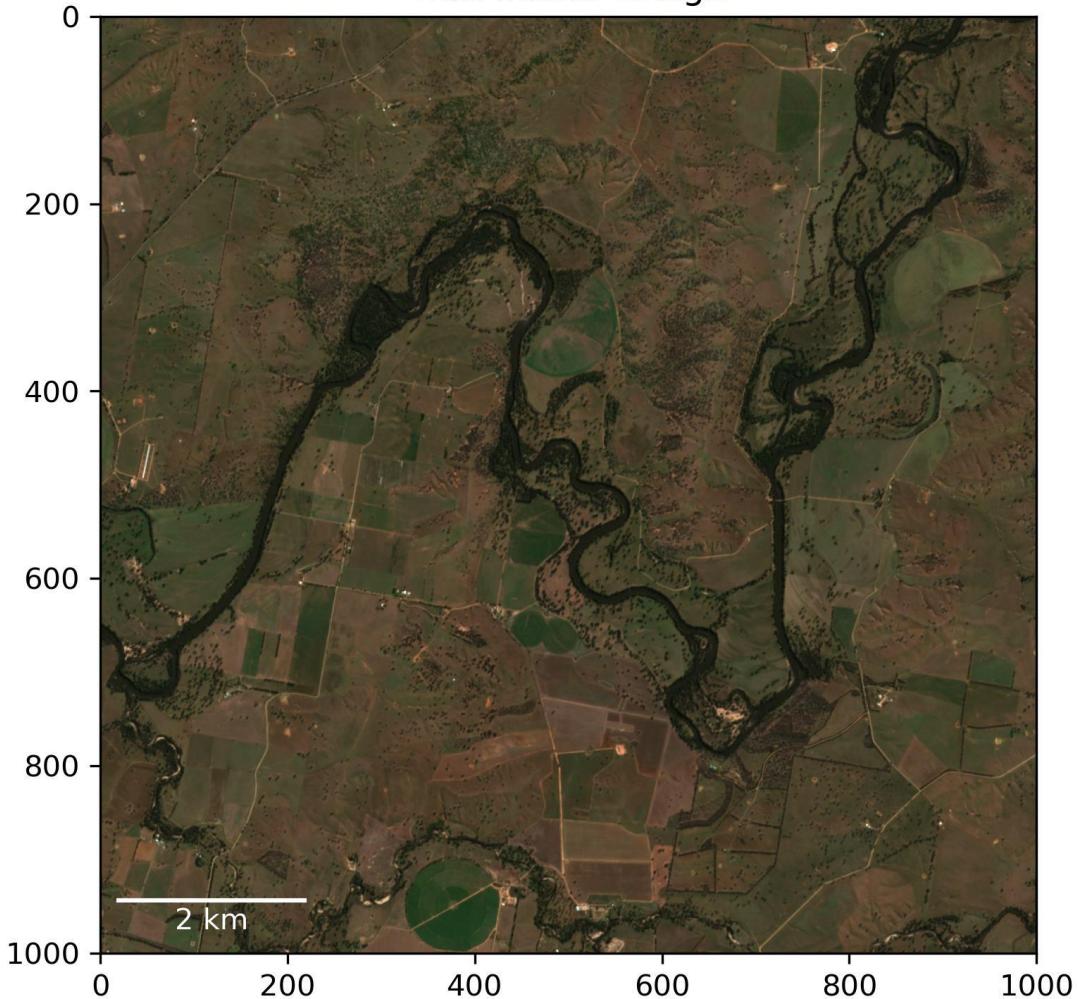


AlphaEarth

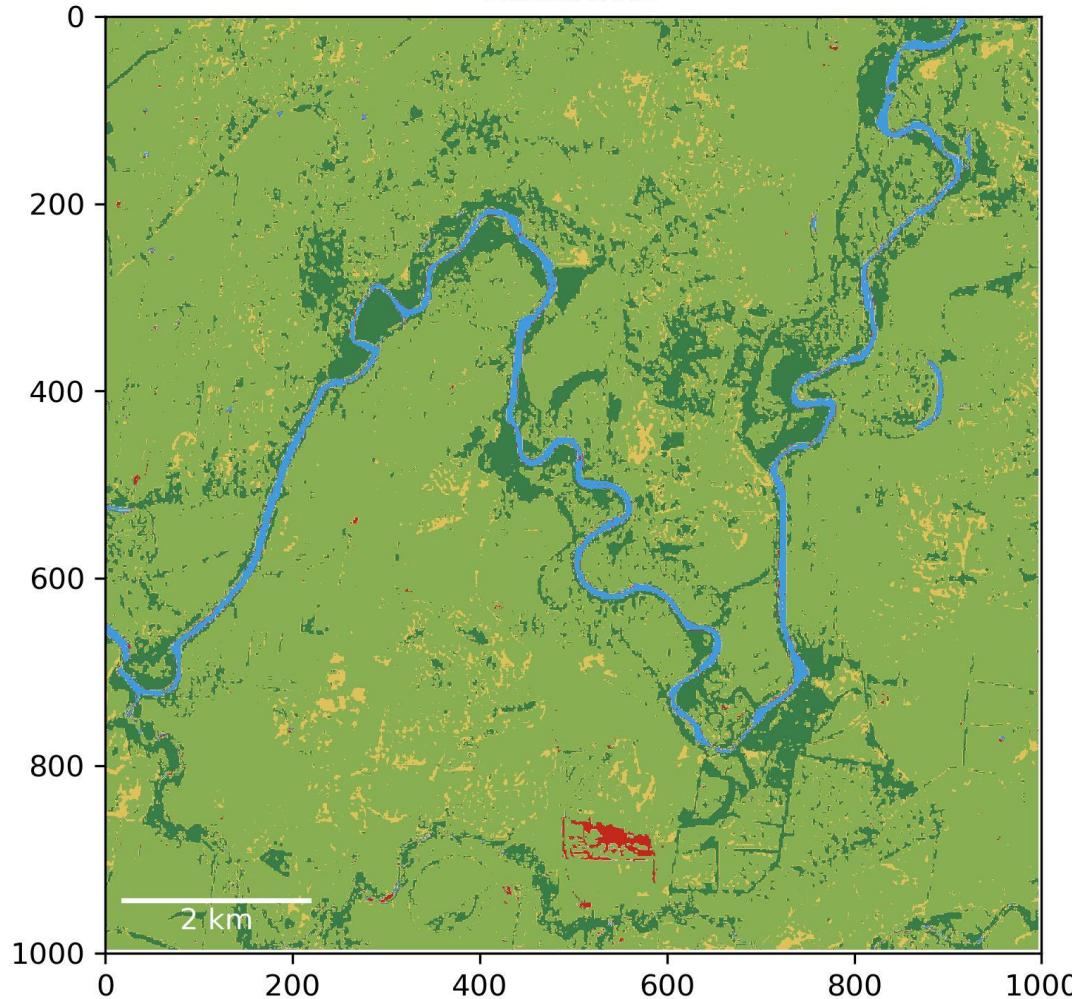


Biome-8. Sentinel-2. Inference

True colour image



Landcover

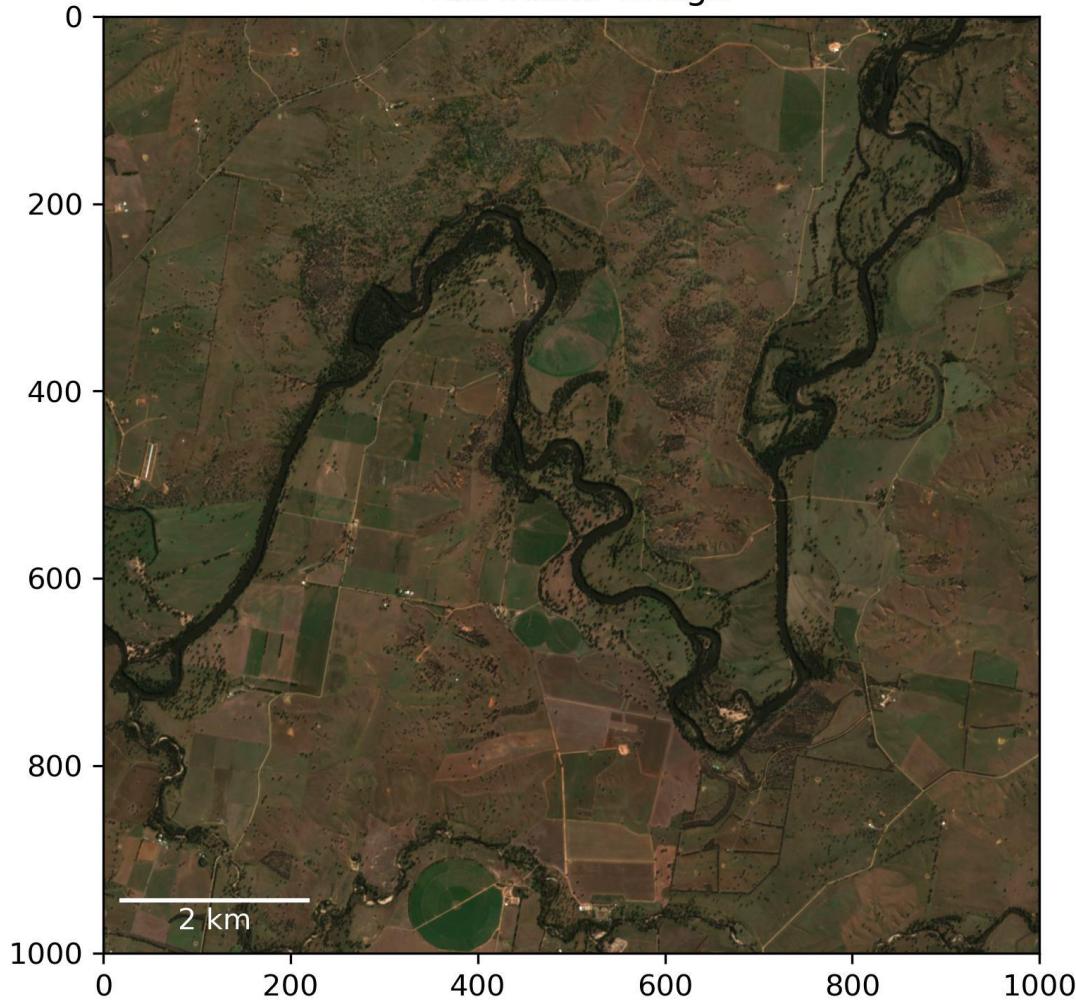


Boramola, Australia. Temperate Grasslands, Savannas, and Shrublands

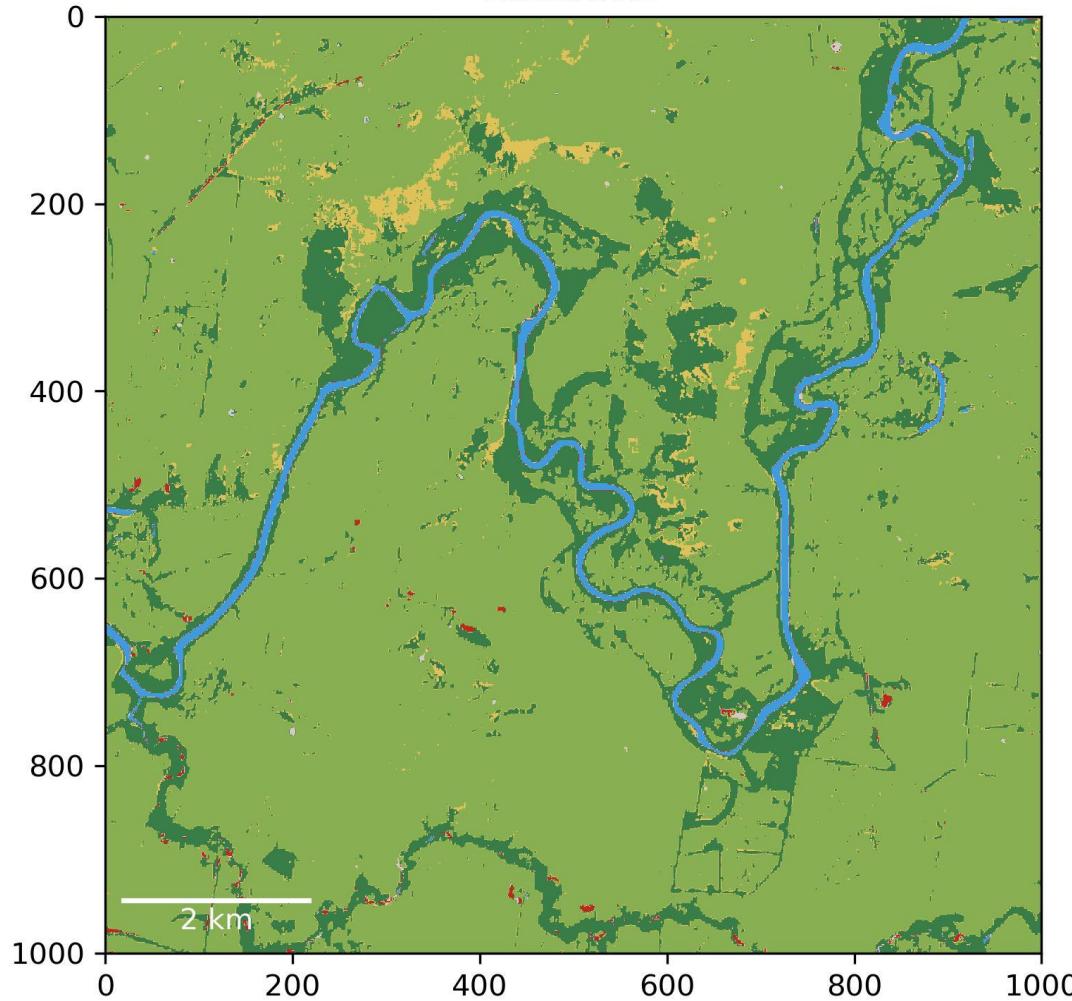
John Toth

Biome-8. AlphaEarth. Inference

True colour image



Landcover



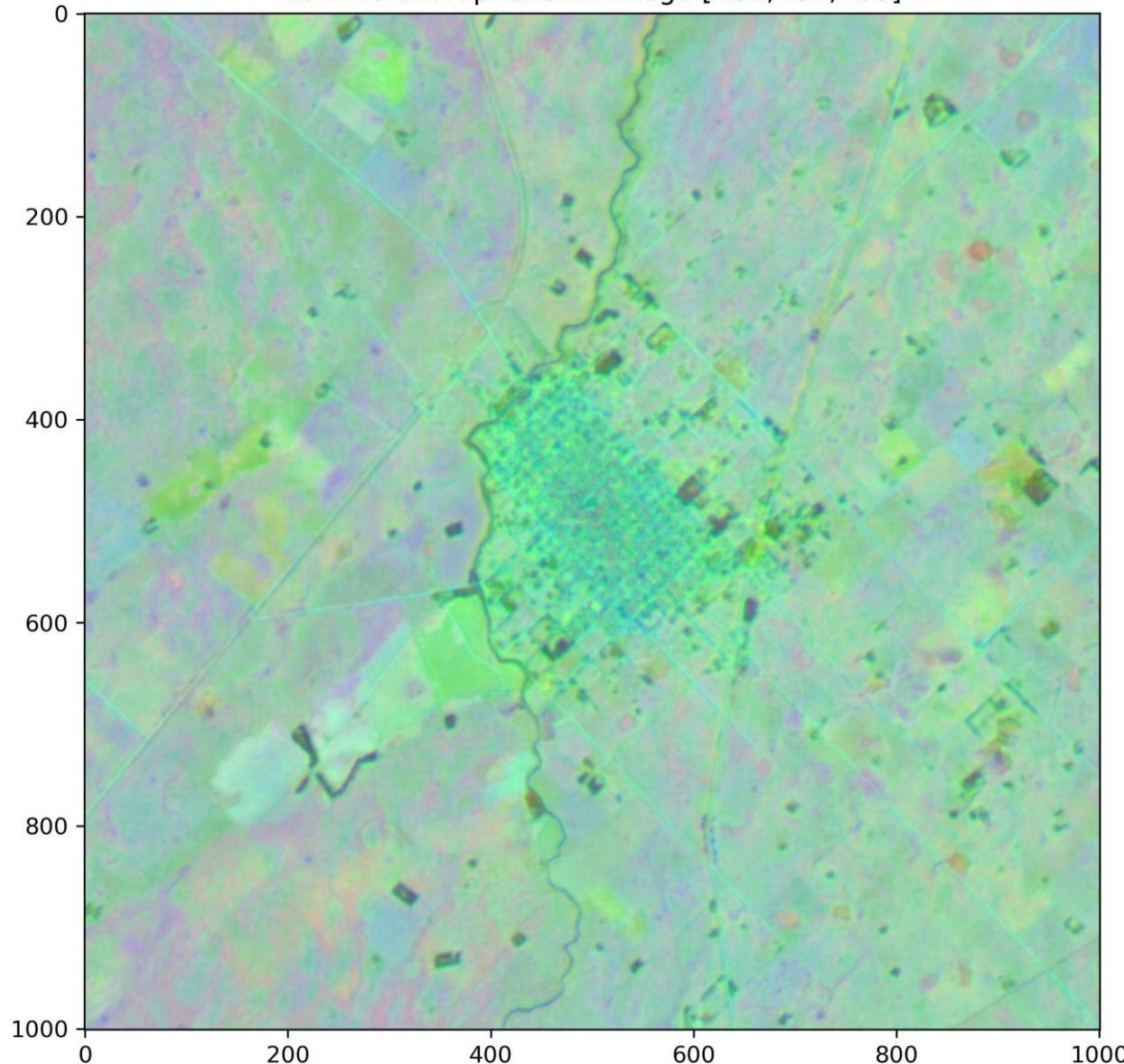
- Water
- Developed
- Barren
- Trees
- Shrub
- Herbaceous

Boramola, Australia. Temperate Grasslands, Savannas, and Shrublands

John Toth

Biome-8. AlphaEarth Training Data

10 x 10 km AlphaEarth image [A01,A02,A03]



Biome-7. Tropical and Subtropical Grasslands, Savannas, and Shrublands

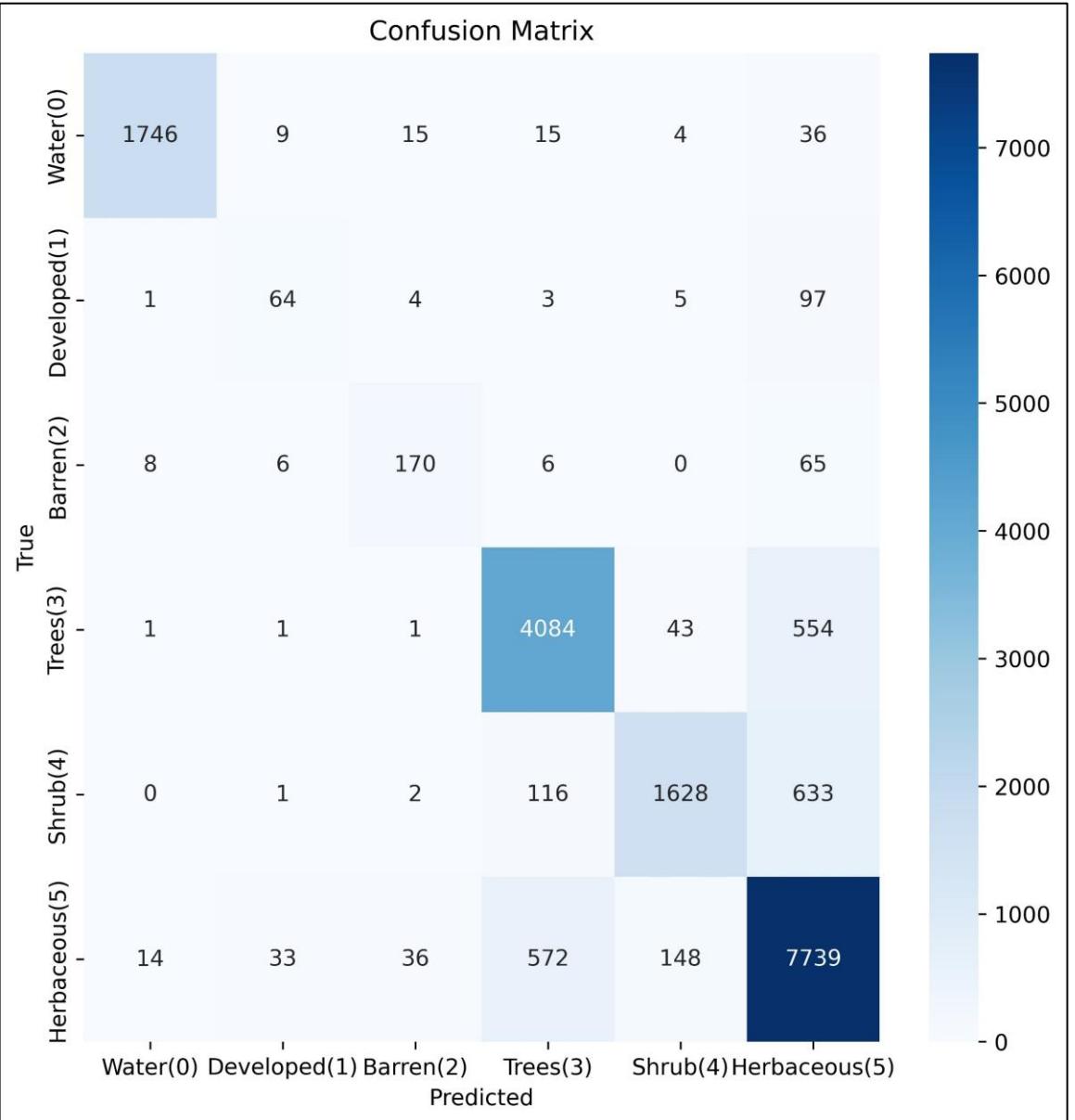
Samples	Data	Model	Device	Epochs	Batch size	Time min	Loss	Accuracy		F1-score	
								test	train	macro	weighted
Biome-7											
89297	Sentinel-2	CNN Patch	cpu	500	32	51	0.36	86%	87%	0.77	0.86
89724	AlphaEarth	Fully Connected	cpu	500	10	67	0.08	96%	97%	0.93	0.96

Level 1	Biome 2	Biome 7	Biome 8	Biome 10	Biome 12	Biome 13	All
Water [0]	10.7%	10.2%	2.7%	10.5%	0.6%	1.4%	7.3%
Developed [1]	0.9%	0.9%	3.2%	0.5%	3.9%	2.9%	1.7%
Barren [2]	0.4%	1.5%	2.2%	5.1%	0.8%	25.8%	4.7%
Trees [3]	47.4%	26.2%	7.0%	11.4%	52.5%	4.0%	26.0%
Shrub [4]	1.4%	13.8%	2.5%	1.9%	7.5%	23.1%	10.1%
Herb [5]	39.2%	47.5%	82.4%	70.6%	34.7%	42.9%	50.1%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Biome-7. Confusion Matrices

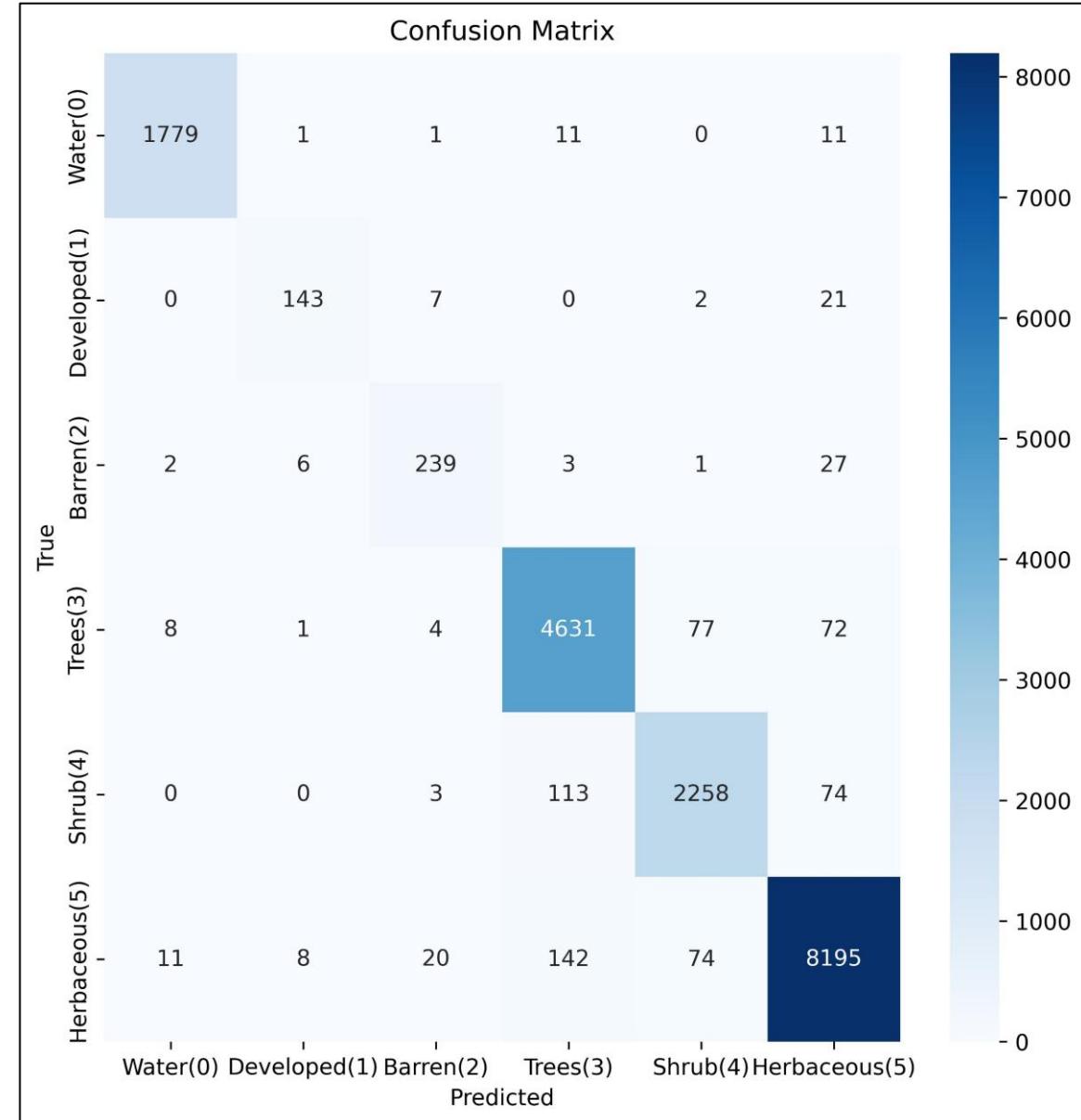
Sentinel-2

Confusion Matrix



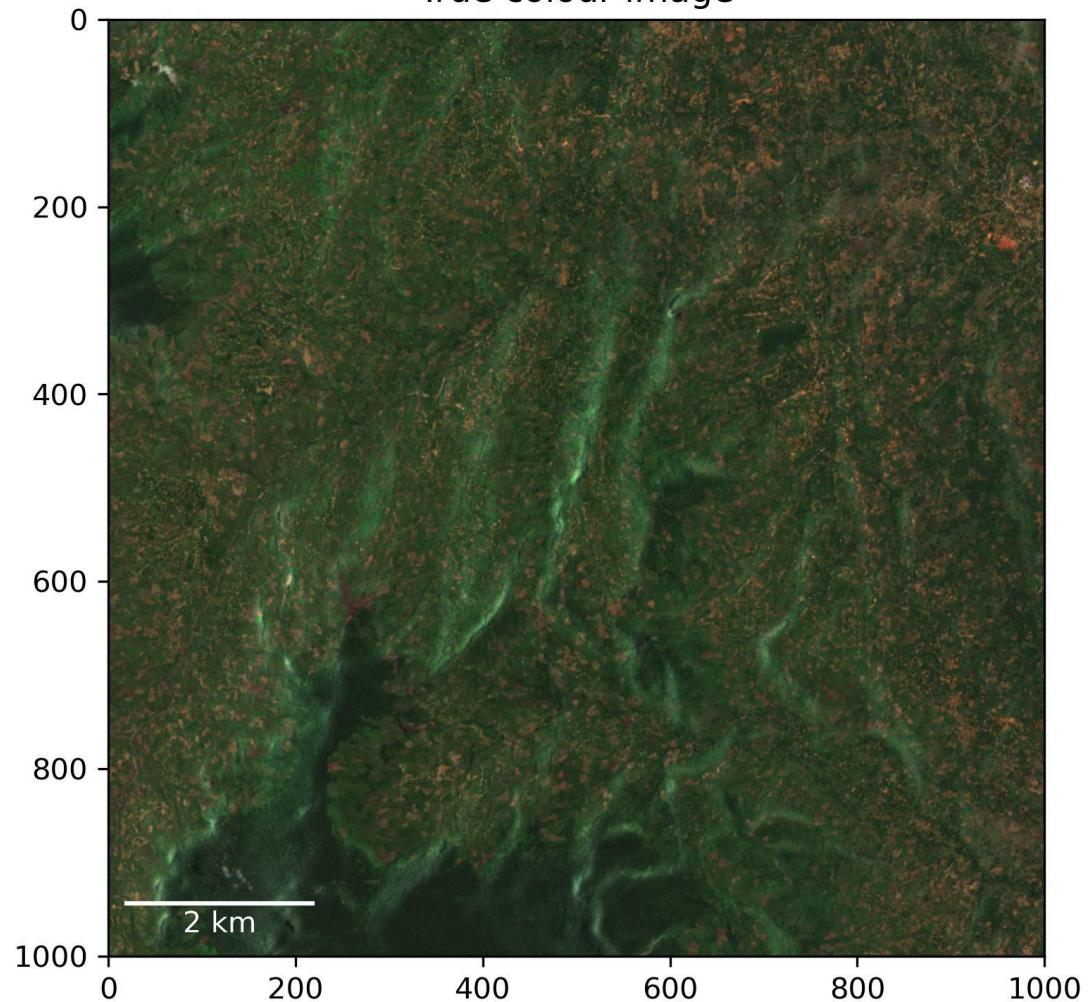
AlphaEarth

Confusion Matrix

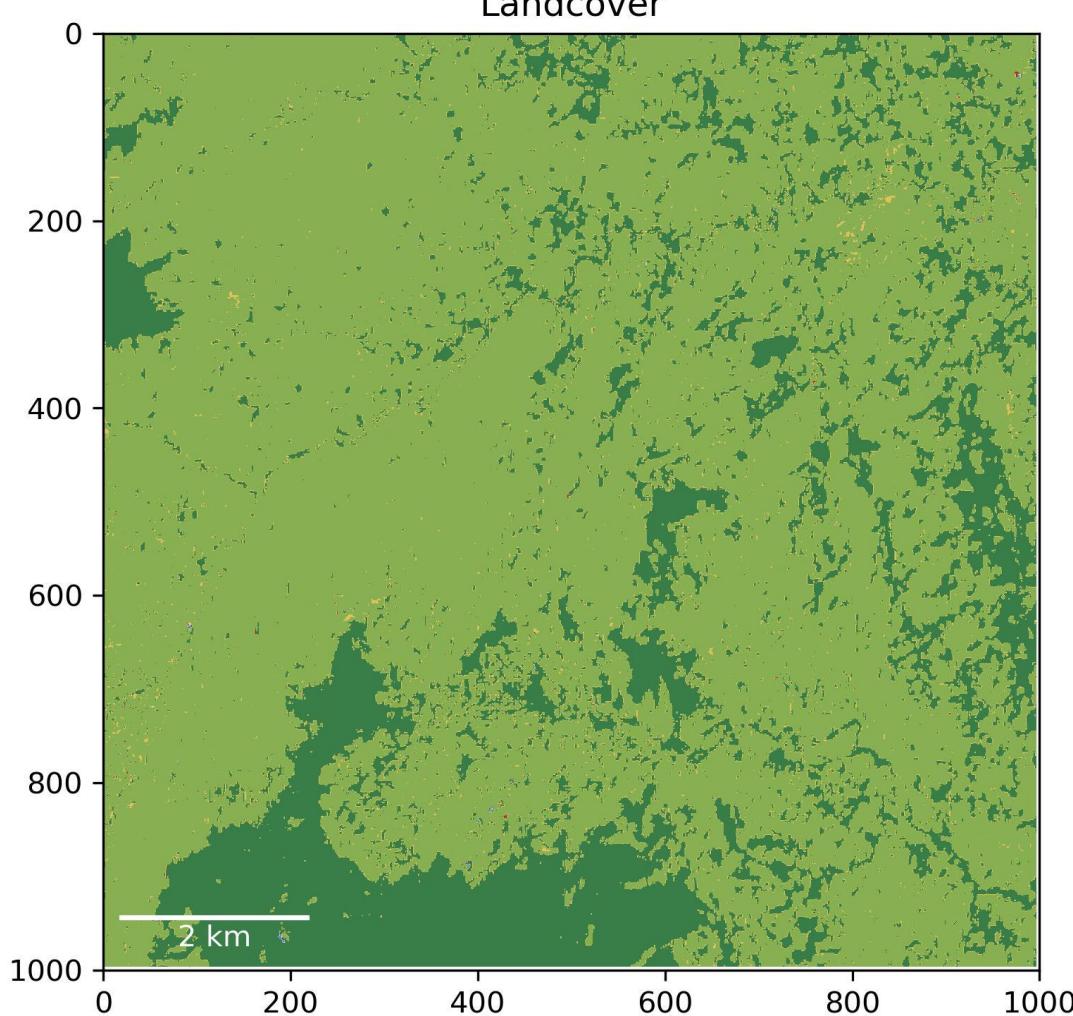


Biome-7. Sentinel-2. Inference

True colour image



Landcover



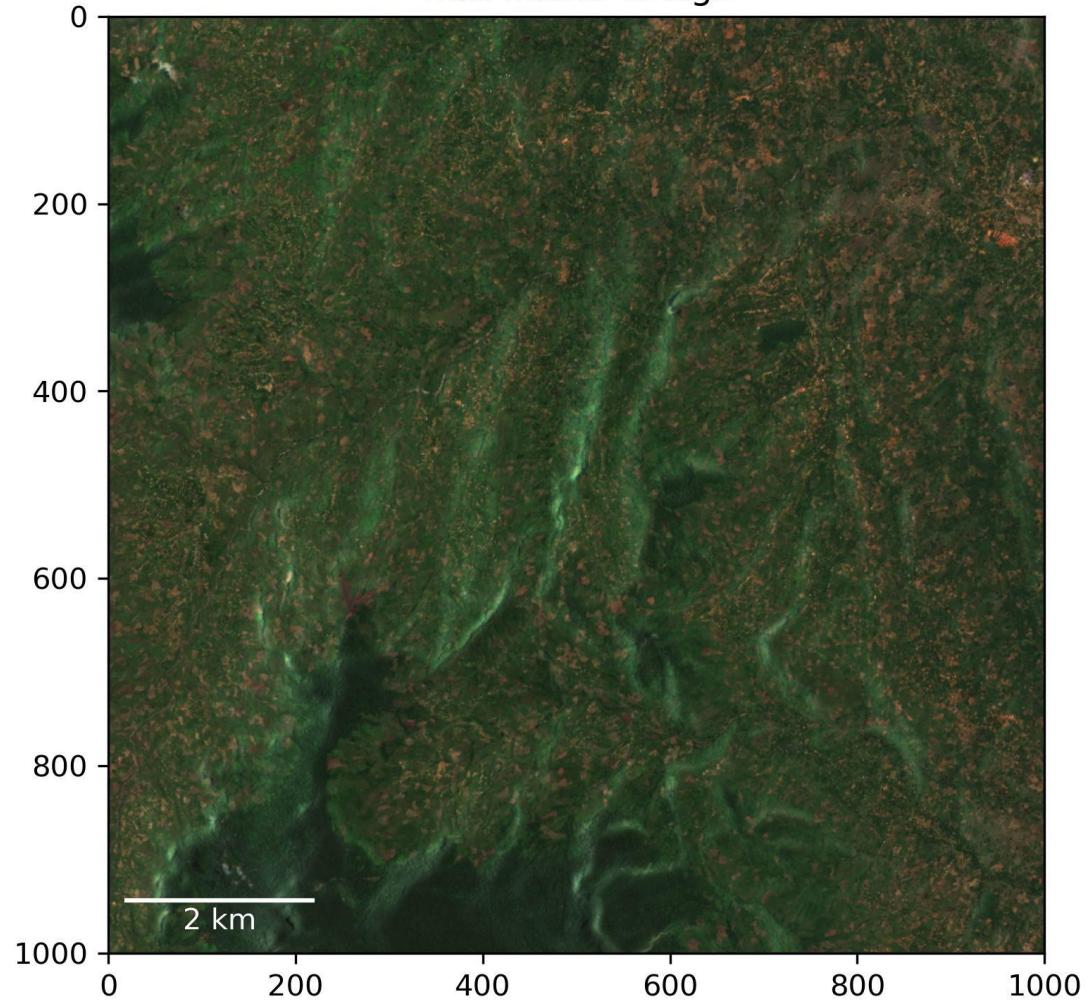
- Water
- Developed
- Barren
- Trees
- Shrub
- Herbaceous

Lanzi, Tanzania. Tropical and Subtropical Grasslands and Savannas

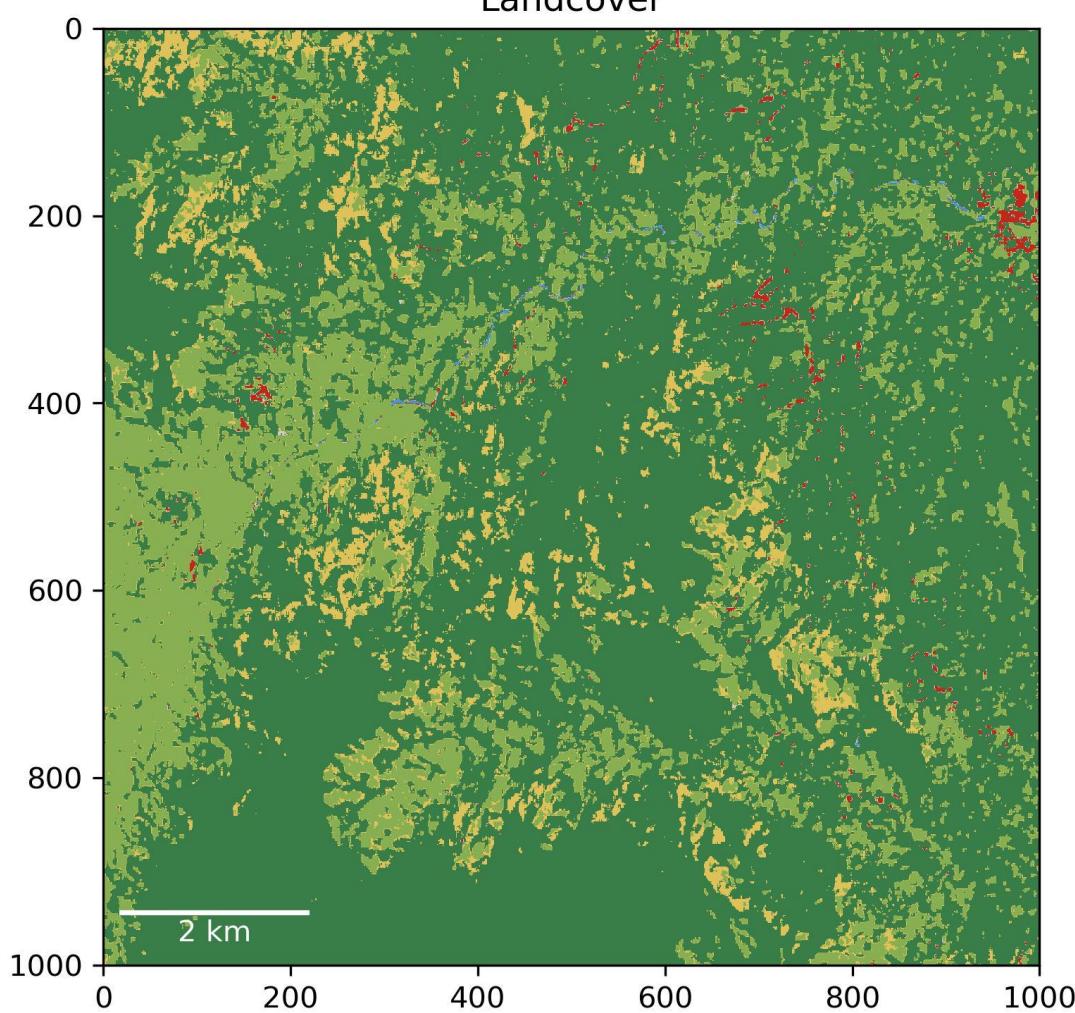
John Toth

Biome-7. AlphaEarth. Inference

True colour image



Landcover

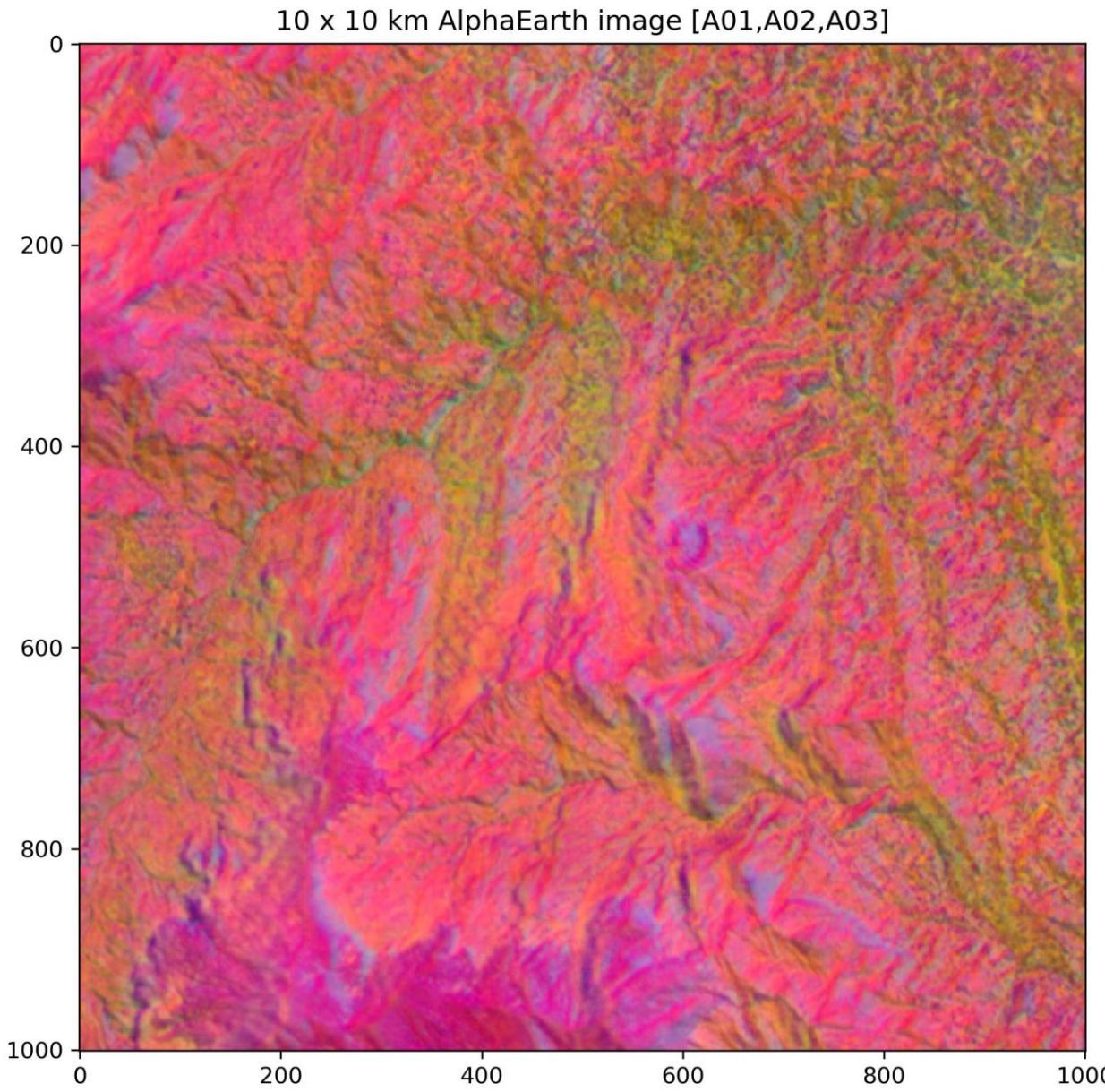


- Water
- Developed
- Barren
- Trees
- Shrub
- Herbaceous

Lanzi, Tanzania. Tropical and Subtropical Grasslands and Savannas

John Toth

Biome-7. AlphaEarth Training Data



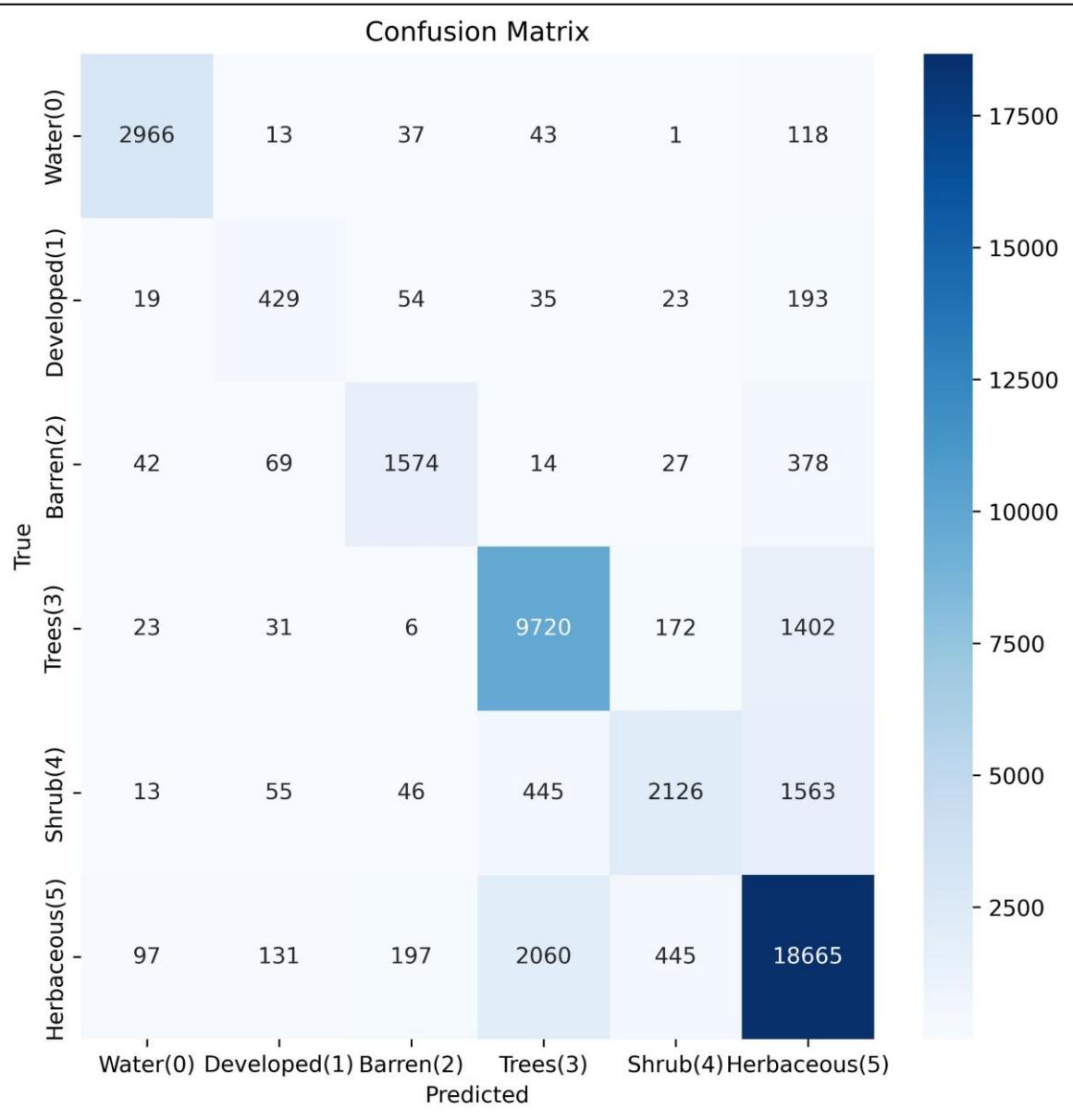
Biome-All. All Dryland Biomes

Samples	Data	Model	Device	Epochs	Batch	Time	Loss	Accuracy		F1-score	
					size	min		test	train	macro	weighted
Biome-All											
216159	Sentinel-2	CNN Patch	cpu	500	32	131	0.47	82%	82%	0.76	0.82
216159	Sentinel-2	CNN Patch4	cpu	500	32	119	0.57	78%	79%	0.71	0.77
217090	AlphaEarth	Fully Connected	cpu	500	10	182	0.1	96%	96%	0.94	0.96

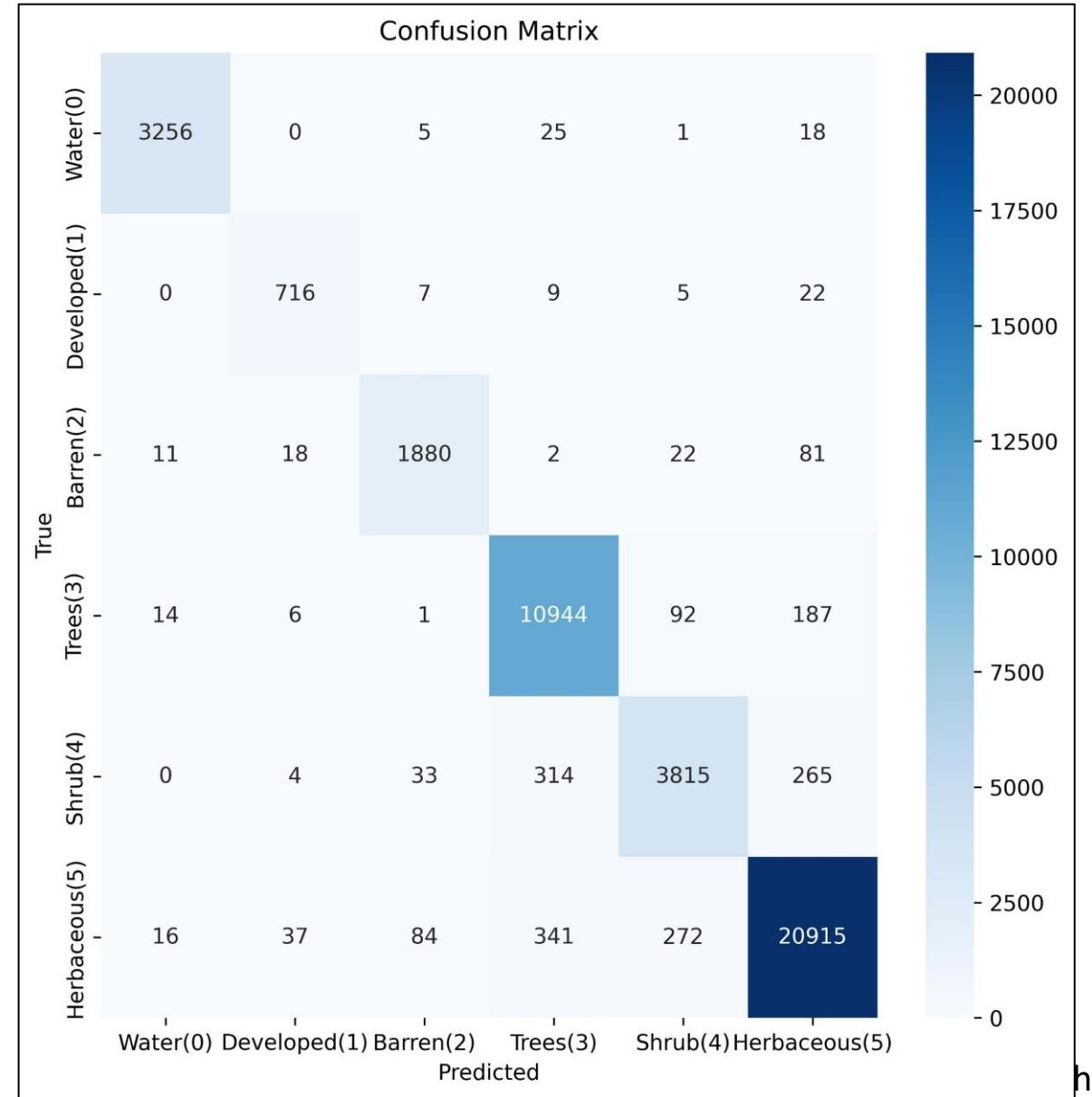
Level 1	Biome 2	Biome 7	Biome 8	Biome 10	Biome 12	Biome 13	All
Water [0]	10.7%	10.2%	2.7%	10.5%	0.6%	1.4%	7.3%
Developed [1]	0.9%	0.9%	3.2%	0.5%	3.9%	2.9%	1.7%
Barren [2]	0.4%	1.5%	2.2%	5.1%	0.8%	25.8%	4.7%
Trees [3]	47.4%	26.2%	7.0%	11.4%	52.5%	4.0%	26.0%
Shrub [4]	1.4%	13.8%	2.5%	1.9%	7.5%	23.1%	10.1%
Herb [5]	39.2%	47.5%	82.4%	70.6%	34.7%	42.9%	50.1%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Biome-All. Confusion Matrices

Sentinel-2



AlphaEarth



Next

Balance Sample Classes

Level 1	Biome 2	Biome 7	Biome 8	Biome 10	Biome 12	Biome 13	All
Water	3020	9088	551	2560	156	378	15753
Developed	251	837	647	126	1066	760	3687
Barren	111	1353	450	1245	205	6879	10243
Trees	13443	23357	1427	2804	14186	1059	56276
Shrub	401	12279	510	455	2020	6141	21806
Herb	11127	42383	16796	17304	9373	11411	108394
Total	28353	89297	20381	24494	27006	26628	216159
million sqkm	3.01	20.18	10.10	5.19	3.22	27.89	69.59
samples / 100 sqkm	0.94	0.44	0.20	0.47	0.84	0.10	0.31

Level 1	Biome 2	Biome 7	Biome 8	Biome 10	Biome 12	Biome 13	All
Water [0]	10.7%	10.2%	2.7%	10.5%	0.6%	1.4%	7.3%
Developed [1]	0.9%	0.9%	3.2%	0.5%	3.9%	2.9%	1.7%
Barren [2]	0.4%	1.5%	2.2%	5.1%	0.8%	25.8%	4.7%
Trees [3]	47.4%	26.2%	7.0%	11.4%	52.5%	4.0%	26.0%
Shrub [4]	1.4%	13.8%	2.5%	1.9%	7.5%	23.1%	10.1%
Herb [5]	39.2%	47.5%	82.4%	70.6%	34.7%	42.9%	50.1%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Crop max sample size at 20,000

John Toth

GLanCE Level-2 Classes – Agriculture + Grass

Level 2	Biome 2	Biome 7	Biome 8	Biome 10	Biome 12	Biome 13	All
Water	3020	9088	551	2560	156	378	15753
Developed	251	837	647	126	1066	760	3687
Barren	97	541	315	427	174	2750	4304
Trees	583	1643	358	128	14018	338	17068
Shrub	401	12279	510	455	2020	6141	21806
Grass	2744	30638	10679	14140	3156	8565	69922
Agriculture	858	7622	5444	1281	6041	2754	24000
Undefined	20399	26649	1877	5377	375	4942	59619
Total	28353	89297	20381	24494	27006	26628	216159
Total Defined	7954	62648	18504	19117	26631	21686	156540
million sqkm	3.01	20.18	10.1	5.19	3.22	27.89	69.59
samples / 100 sqkm	0.26	0.31	0.18	0.37	0.83	0.08	0.22

Level 2	Biome 2	Biome 7	Biome 8	Biome 10	Biome 12	Biome 13	All
Water	38.0%	14.5%	3.0%	13.4%	0.6%	1.7%	10.1%
Developed	3.2%	1.3%	3.5%	0.7%	4.0%	3.5%	2.4%
Barren	1.2%	0.9%	1.7%	2.2%	0.7%	12.7%	2.7%
Trees	7.3%	2.6%	1.9%	0.7%	52.6%	1.6%	10.9%
Shrub	5.0%	19.6%	2.8%	2.4%	7.6%	28.3%	13.9%
Grass	34.5%	48.9%	57.7%	74.0%	11.9%	39.5%	44.7%
Agriculture	10.8%	12.2%	29.4%	6.7%	22.7%	12.7%	15.3%
Total Defined	100.0%						

Trees, forests and land use in drylands

Corrected 12 May 2017. See full text.

FOREST ECOLOGY

The extent of forest in dryland biomes

Jean-François Bastin,^{1,2*} Nora Berrahmouni,¹ Alan Grainger,³ Danae Maniatis,^{4,5} Danilo Mollicone,¹ Rebecca Moore,⁶ Chiara Patriarca,¹ Nicolas Picard,¹ Ben Sparrow,⁷ Elena Maria Abraham,⁸ Kamel Aloui,⁹ Ayhan Atesoglu,¹⁰ Fabio Attore,¹¹ Çağlar Bassüllü,¹² Adia Bey,¹ Monica Garzuglia,¹ Luis G. García-Montero,¹³ Nikée Groot,³ Greg Guerin,⁷ Lars Laestadius,¹⁴ Andrew J. Lowe,¹⁵ Bako Mamane,¹⁶ Giulio Marchi,¹ Paul Patterson,¹⁷ Marcelo Rezende,¹ Stefano Ricci,¹ Ignacio Salcedo,¹⁸ Alfonso Sanchez-Paus Diaz,¹ Fred Stolle,¹⁹ Venera Surappaeva,²⁰ Rene Castro^{1*}

Dryland biomes cover two-fifths of Earth's land surface, but their forest area is poorly known. Here, we report an estimate of global forest extent in dryland biomes, based on analyzing more than 210,000 0.5-hectare sample plots through a photo-interpretation approach using large databases of satellite imagery at (i) very high spatial resolution and (ii) very high temporal resolution, which are available through the Google Earth platform. We show that in 2015, 1327 million hectares of drylands had more than 10% tree-cover, and 1079 million hectares comprised forest. Our estimate is 40 to 47% higher than previous estimates, corresponding to 467 million hectares of forest that have never been reported before. This increases current estimates of global forest cover by at least 9%.

John Toth

location_x	location_y	dryland_assessment_region	Aridity_zone	land_use_category	tree_cover
132.0972625	-25.324777	Australia	Arid	Non-forest	0
118.4249039	-26.405587	Australia	Arid	Non-forest	0
121.1198498	-26.417594	Australia	Arid	Non-forest	0
126.1144827	-29.06421	Australia	Arid	Non-forest	0.02
141.116348	-26.324328	Australia	Arid	Non-forest	0
138.3675032	-20.879545	Australia	Arid	Non-forest	0
141.9607643	-30.351234	Australia	Arid	Non-forest	0
139.6790435	-30.27053	Australia	Arid	Non-forest	0
124.4436163	-31.565673	Australia	Arid	Non-forest	0.02
129.9233395	-25.309864	Australia	Arid	Non-forest	0
142.2302589	-27.754592	Australia	Arid	Non-forest	0.02
142.1224611	-26.687067	Australia	Arid	forest	0.85
131.6121723	-27.895108	Australia	Arid	Non-forest	0.08
128.5040014	-24.63864	Australia	Arid	Non-forest	0
124.3897174	-24.908779	Australia	Arid	Non-forest	0.04
120.5269617	-20.11491	Australia	Arid	Non-forest	0
121.3534117	-26.435621	Australia	Arid	Non-forest	0
131.3786103	-25.323452	Australia	Arid	Non-forest	0
123.7968293	-33.25501	Australia	Arid	forest	0.45

200,000 samples from dryland biomes collected in late 2015. FAO

John Toth

- Apply to specific area with specific question.
- Prepare paper – will give my project structure