Seeing the Gallery Forest for the Savanna Chimpanzee

Remote Sensing for Great Ape Conservation in Kedougou, Senegal

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Pennsylvania State University
MGIS Capstone Project Spring 2024
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Co-Authors: Jill D. Pruetz and Landing Badji

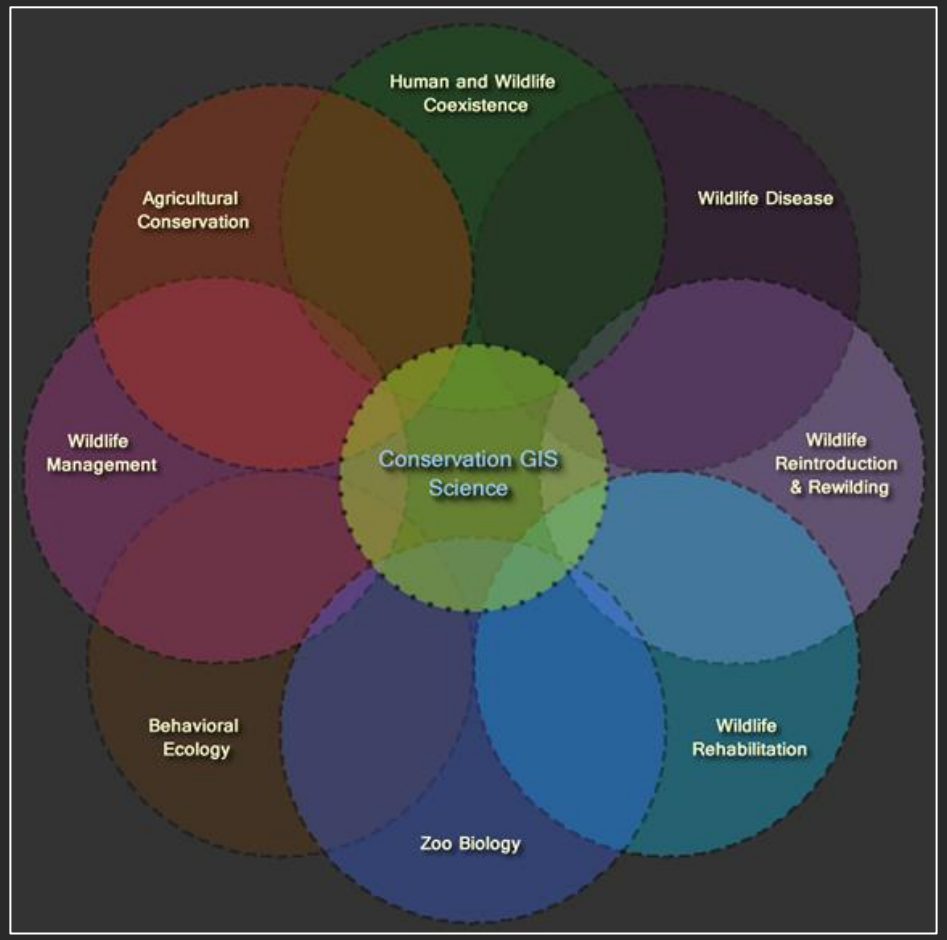
Photo Credit: Jill D. Pruetz

About Me

- I work full-time at Iowa State University in Ames, Iowa, in the Department of Agricultural and Biosystems Engineering as a GIS Analyst for the Daily Erosion Project (DEP) and Agricultural Conservation Planning Framework (ACPF).

- Agricultural Conservation for improving water quality.

- Master of GIS
- B.S. in Animal Ecology
- B.S. in Biology
- A.S. in Zoo Animal Technology
- www.byclaudette.com



These are the topics that interest me most.

Maua at 3 years old.

In another life, I was a 'cats & primates' zoo keeper at The Zoo in Gulf Breeze, Florida.

Presentation Overview

- Goals and Objectives
- Background
- Study Area
- Methodology
- Results
- Lessons Learned
- Questions?

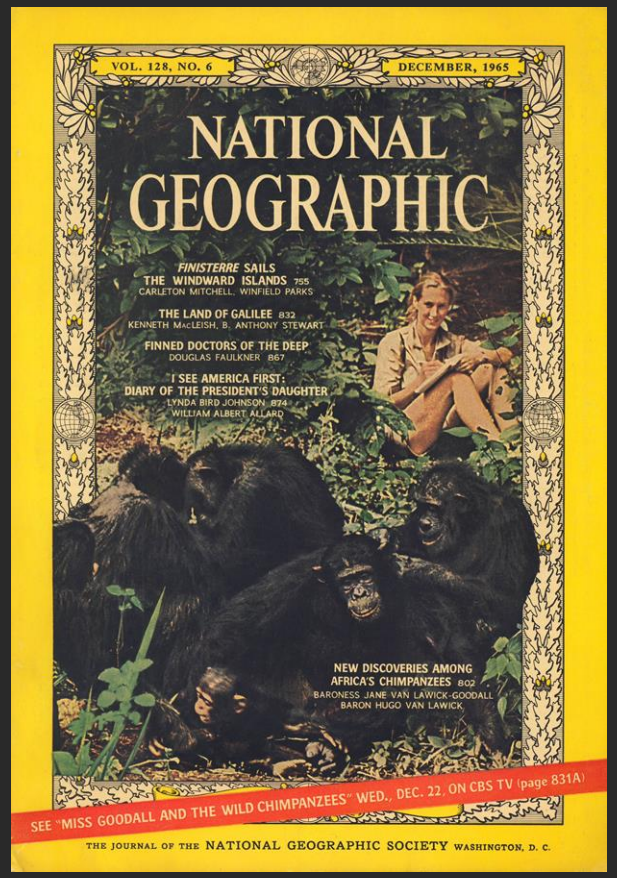
Goals and Objectives

Spatial Problem

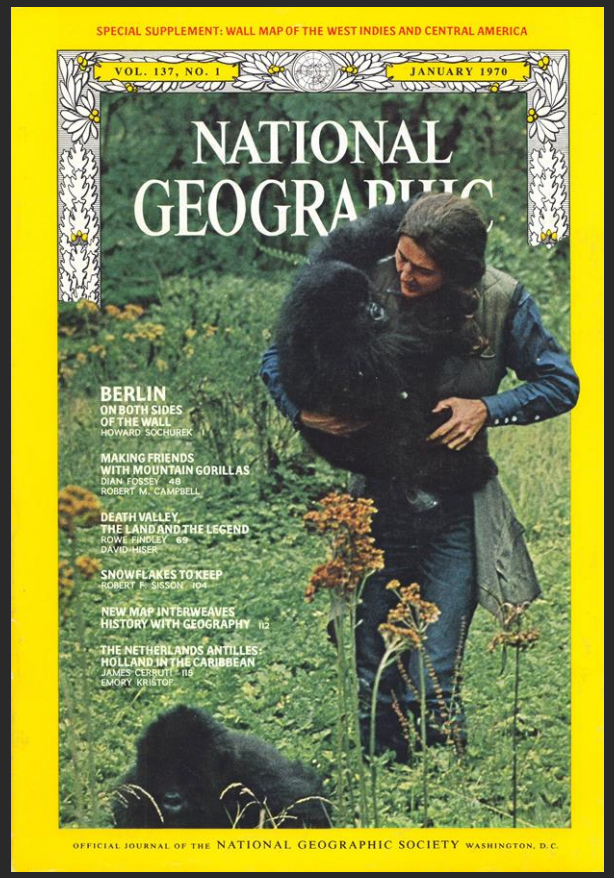
- ALL wild chimpanzees need trees to survive.
- The gallery forests are ecosystems unique to the Sudanian Zone of southeast Senegal that occur along seasonally flooded arterial watercourses.
- These ecosystems provide vital habitat for the critically endangered savanna chimpanzee *(Pan troglodytes verus)* but comprise only 2% of their natural range.
- Today, they are under increasing anthropogenic pressures, primarily from mining, agriculture, and settlement development, and their preservation is becoming critical for savanna chimpanzee conservation.
- This project begins to survey the health of the gallery forests since the expansion of a 10-year gold mining boom in Kedougou, Senegal.
- This study developed a remote sensing method for tracking and mapping gallery forests in Kedougou, Senegal, using Trimble eCognition 10.3 software to apply an unsupervised classification with data fusion and object-based image analysis segmentation.
- This project supports the conservation effort to simultaneously protect gallery forest ecosystems and the critically endangered savanna chimpanzee.

Background

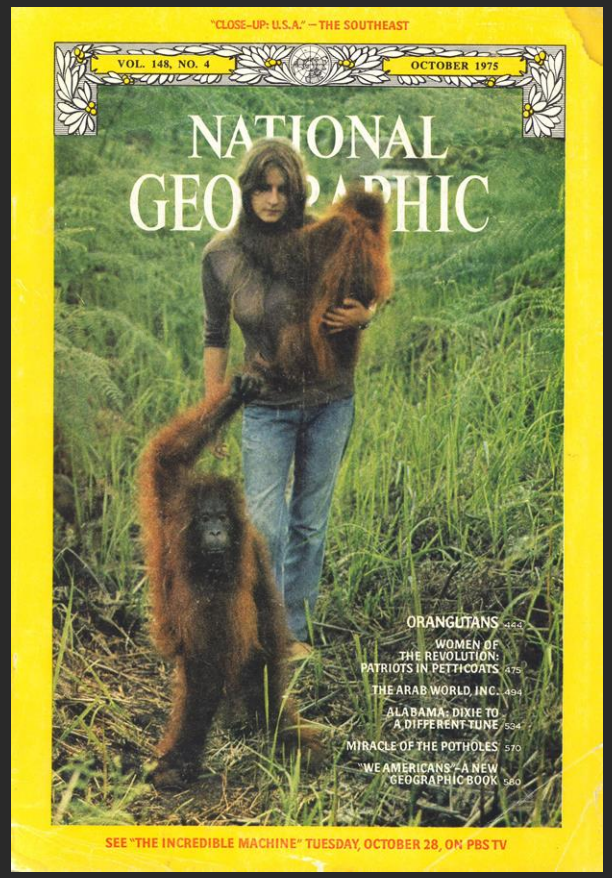
In the beginning, there were the Trimates or Leakey's Angels



JANE GOODALL
Chimpanzees
1960 to present



DIANE FOSSEY
Mountain Gorillas
1967 to 1985



BIRUTE GALDIKAS
Orangutans
1971 to present

Louis Leakey, a famous anthropologist, hired these three women to study great ape behavior in the field.

In many ways, all three were the trailblazers for great ape conservation.

They still inspire people today.

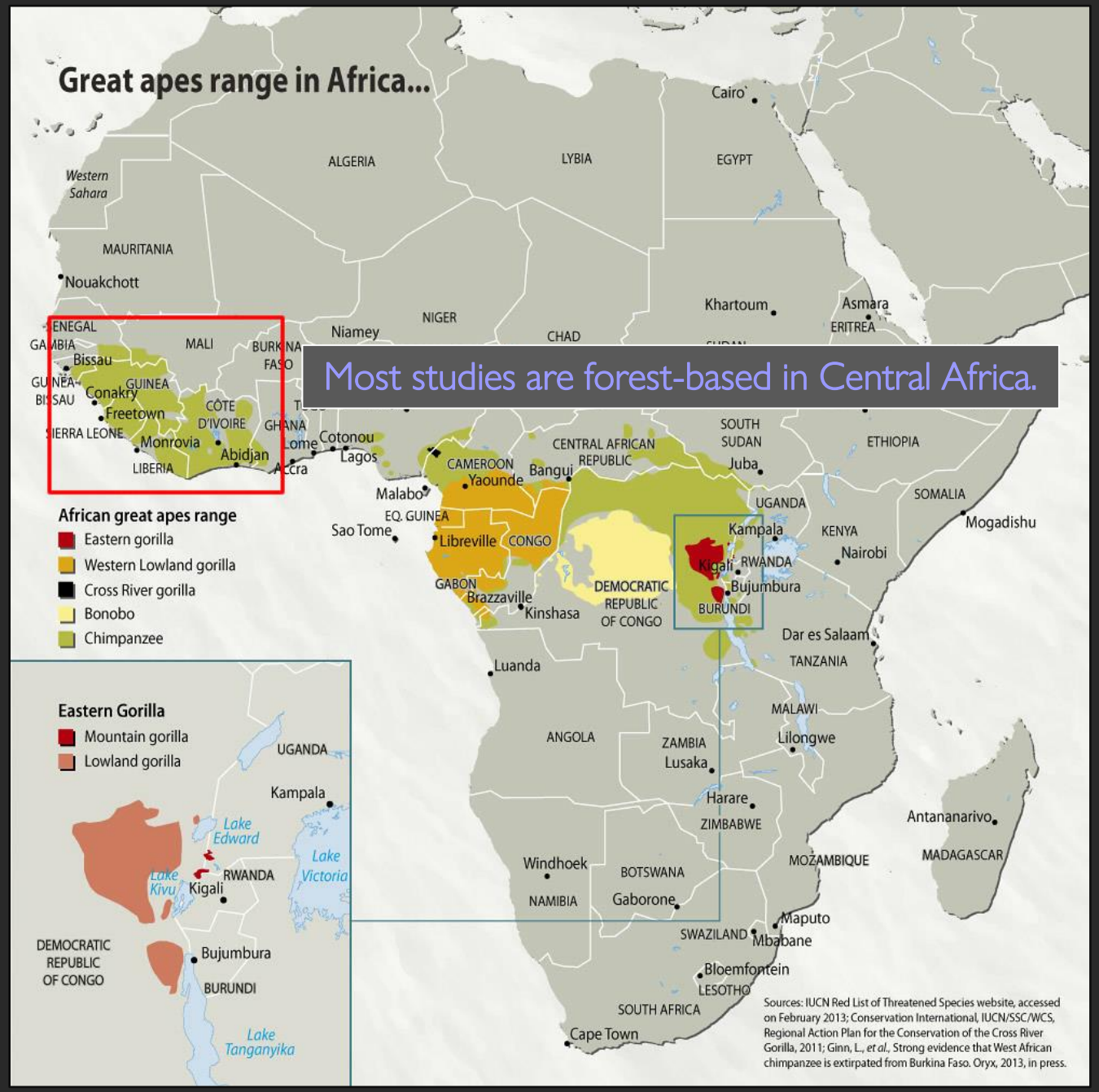
Background

Great Ape Distribution In Africa

There are four officially recognized chimpanzee subspecies:

- Western chimpanzee or Savanna Chimpanzee *(Pan troglodytes verus)* in the red box covering eight West African countries.

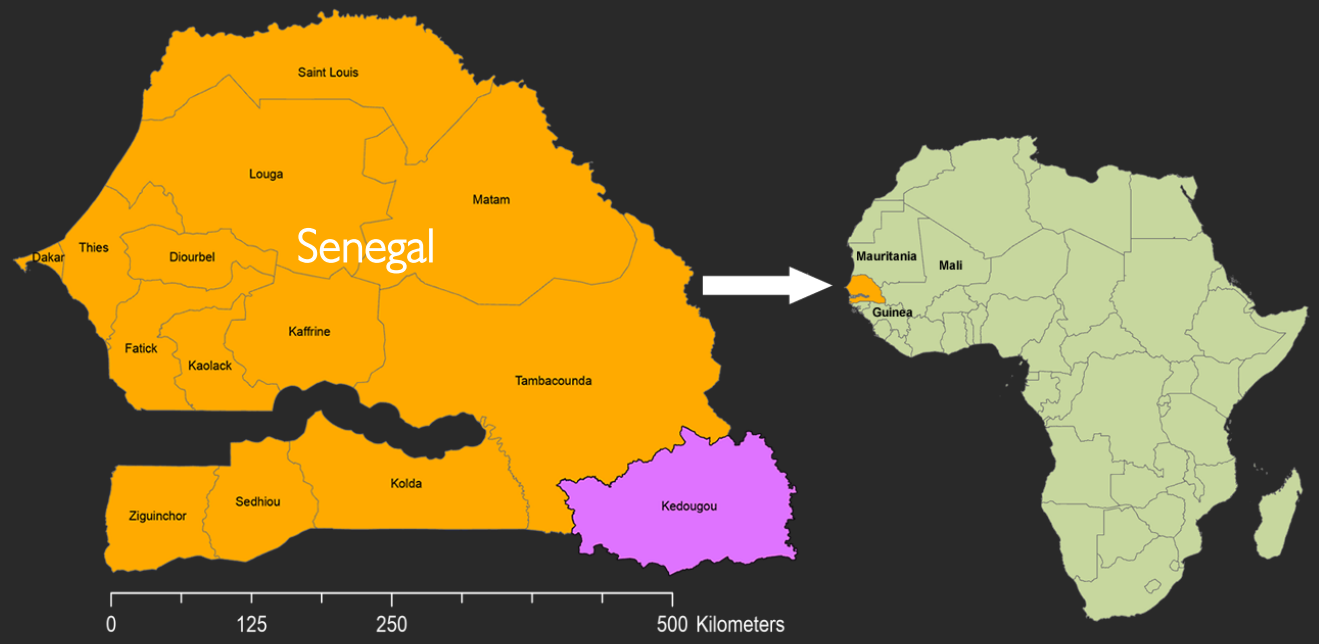
- Central chimpanzee *(Pan troglodytes troglodytes)*
- Nigeria-Cameroon chimpanzee *(Pan troglodytes ellioti)*
- Eastern chimpanzee *(Pan troglodytes schweinfurthii)*

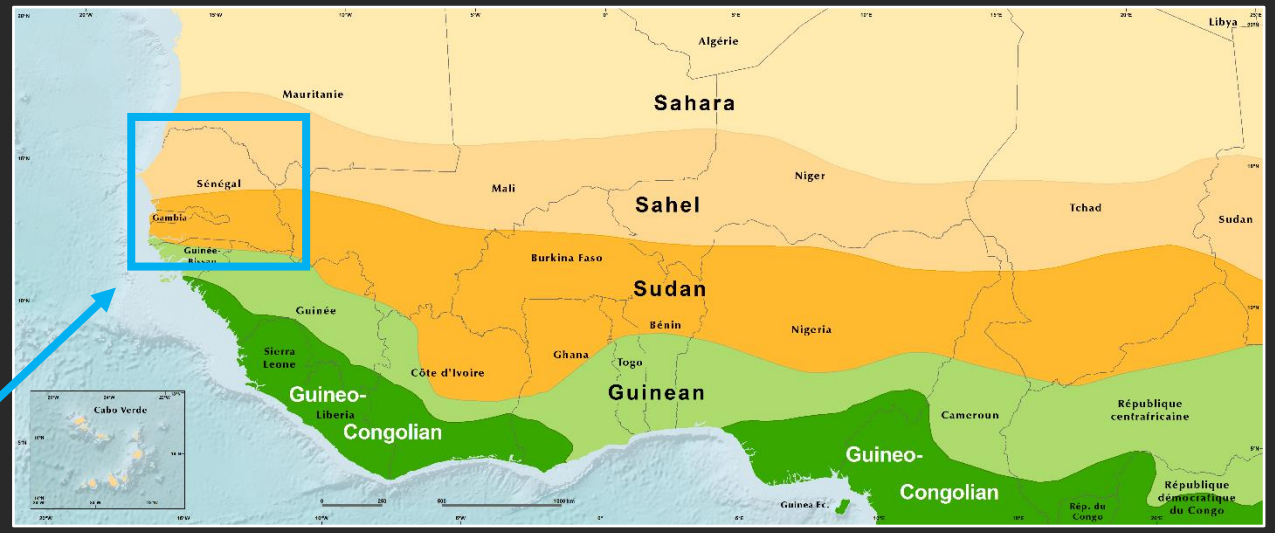


Background

Senegal

- Senegal is slightly larger than South Dakota!
- The population is 17.32 million people (2022).
- It is the westernmost country on the African continent.
- Dakar is the capital, and its ports are known as the Gateway to West Africa.
- The region of Kedougou is in the Sudanian Zone and it is characterized as the domain of the savannas.





The Bioclimatic Zones of West Africa, the Sahara, Sahel, Sudan, Guinean, and Guineo-Congolian (CILSS, USGS, & USAID, 2016).

Background

Savanna Chimpanzee

(Pan troglodytes verus)

- They were listed as critically endangered in 2016 by the IUCN Red List. The next categories are Extinct in the Wild and Extinct. The population est. is 18,000 to 65,000, an 80% decline since the 90s.
- Senegal is the northernmost limit and the harshest environment for chimpanzees. The dry season temperatures can reach 40 °C (104 °F).
- They have a unique suite of behaviors adapted for an open, hot, dry, and mosaic environment.
- They termite fish, and hunt galagoes with a spear that they fashion themselves!
- They utilize microclimates such as gallery forests, caves, and pools to cool off during the dry season.
- Only 2% of their habitat is forested.
- They would rather be in a gallery forest during the hottest time of the dry season because this is where water, food, shade, and tall evergreen trees are for nesting and protection from predators.
- Also, the savanna chimpanzee adaptations help us to understand how our last common ancestor survived in an open, hot, dry and mosaic environment.



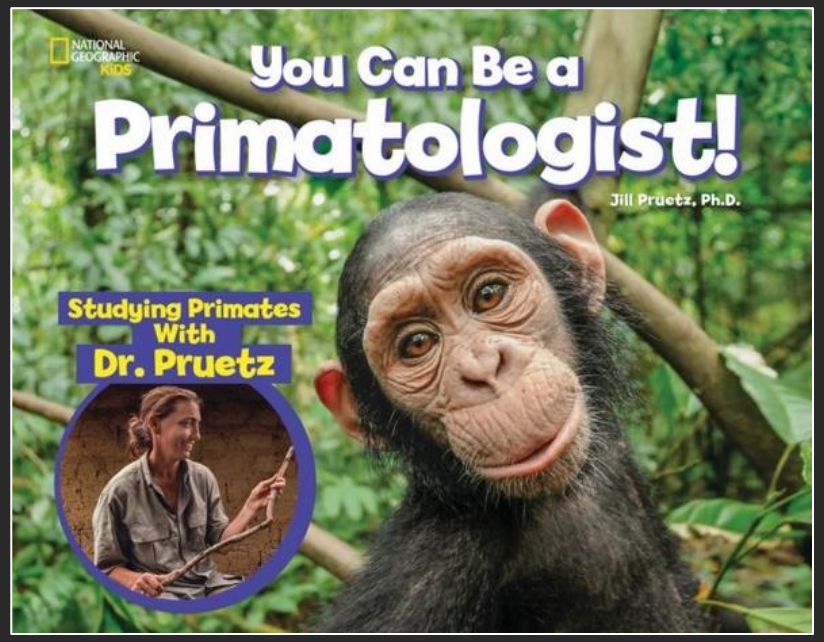



Photo Credit: Jill D. Pruetz

Background

The Famed Fongoli Chimpanzees

As seen on BBC Earth and Max. https://youtu.be/SN7CLg2LixY



Dr. Jill Pruetz from Iowa State University to Texas State University is a biological anthropologist who studies savanna chimpanzees at the Fongoli Savanna Chimpanzee Project and the founder.

This project used her nesting data, topography maps, and knowledge.

Background

Gold Mining in Kedougou, Senegal

- There has been a gold mining boom in Senegal for over 14 years.
- The gold mining boom presents a great challenge for primate conservation because the mining brings new levels of anthropogenic disturbances and ecological pressures.
- The disturbances can include loss of group connectivity and loss of connectivity to habitat preference and protected areas — due to road construction, mining pits, pond tailings, fencing, settlement development, and forest degradation.

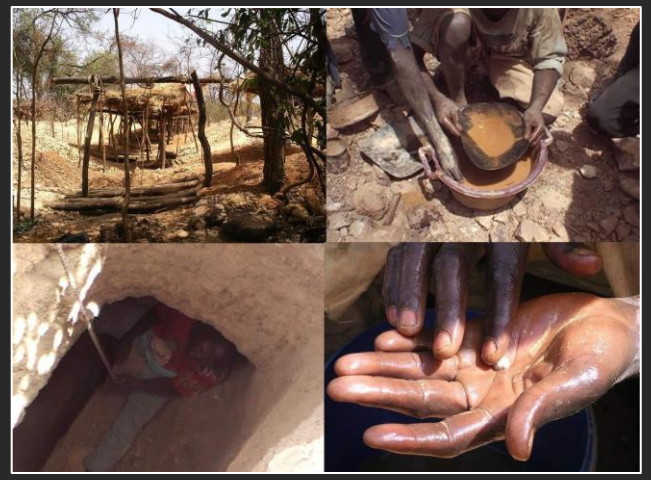
Gold Price Tracker: https://goldbroker.com/widget/historical/XAU?height=500&currency=USD

Background

Types of Mining

- Large-scale Gold Mine
  - Industrial mining with trained employees, using large-scale mechanized tools to extract the gold quickly.
  - Investors are foreign and West African.
- Intermediate-scale Artisanal Gold Mine
  - Large-scale Artisanal Mine that has more infrastructure.
- Small-scale Artisanal Gold Mines (Djouras)
  - Is cultural subsistence mining.
  - This is gold panning with iron tools or small power machines.
  - Investors are traditional local people.
  - Dijouras have been culturally present for millennia with local rules.

Large-scale: Mako gold mine, photo credit: Resolute, reproduced for educational purposes only.



Intermediate-scale Artisanal Mine: Bantakocouta gold mine, photo credit: niokolo.com, reproduced for educational purposes only.

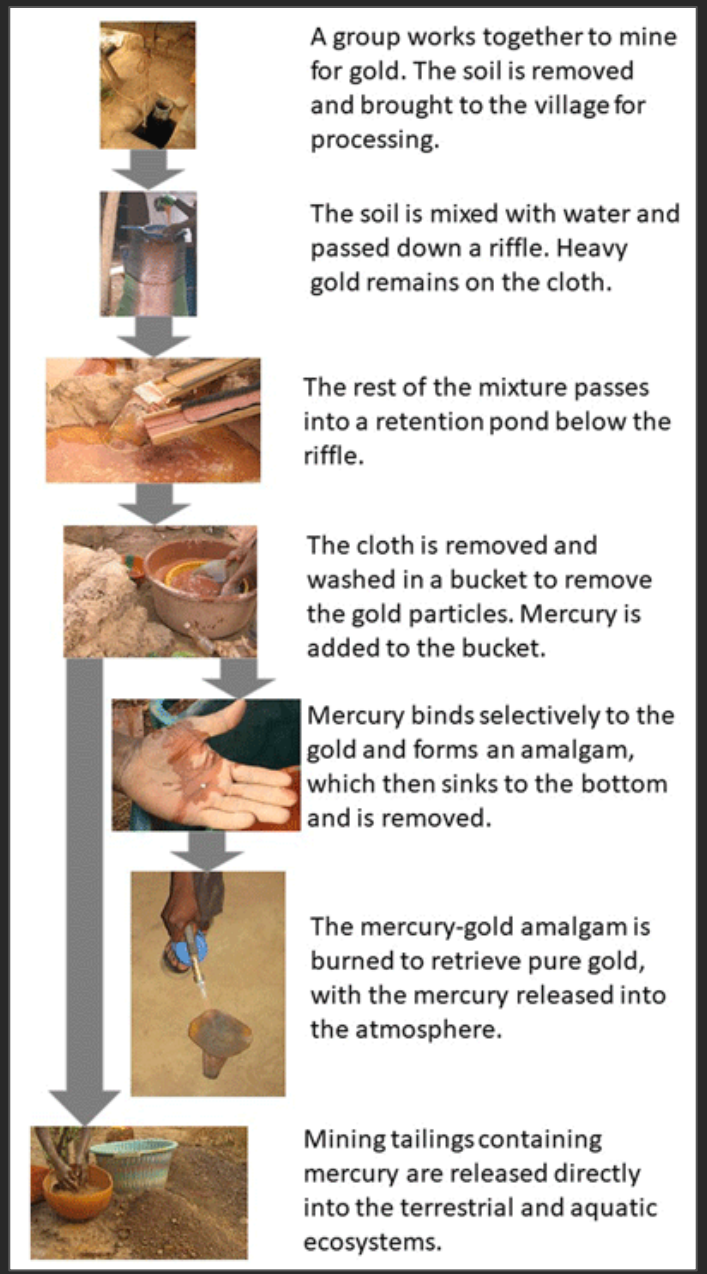
Small-scale Artisanal Mine: Open pit gold mine, photo credit: rivergambiaexpedition, reproduced for educational purposes only.

Background

Small-scale Process

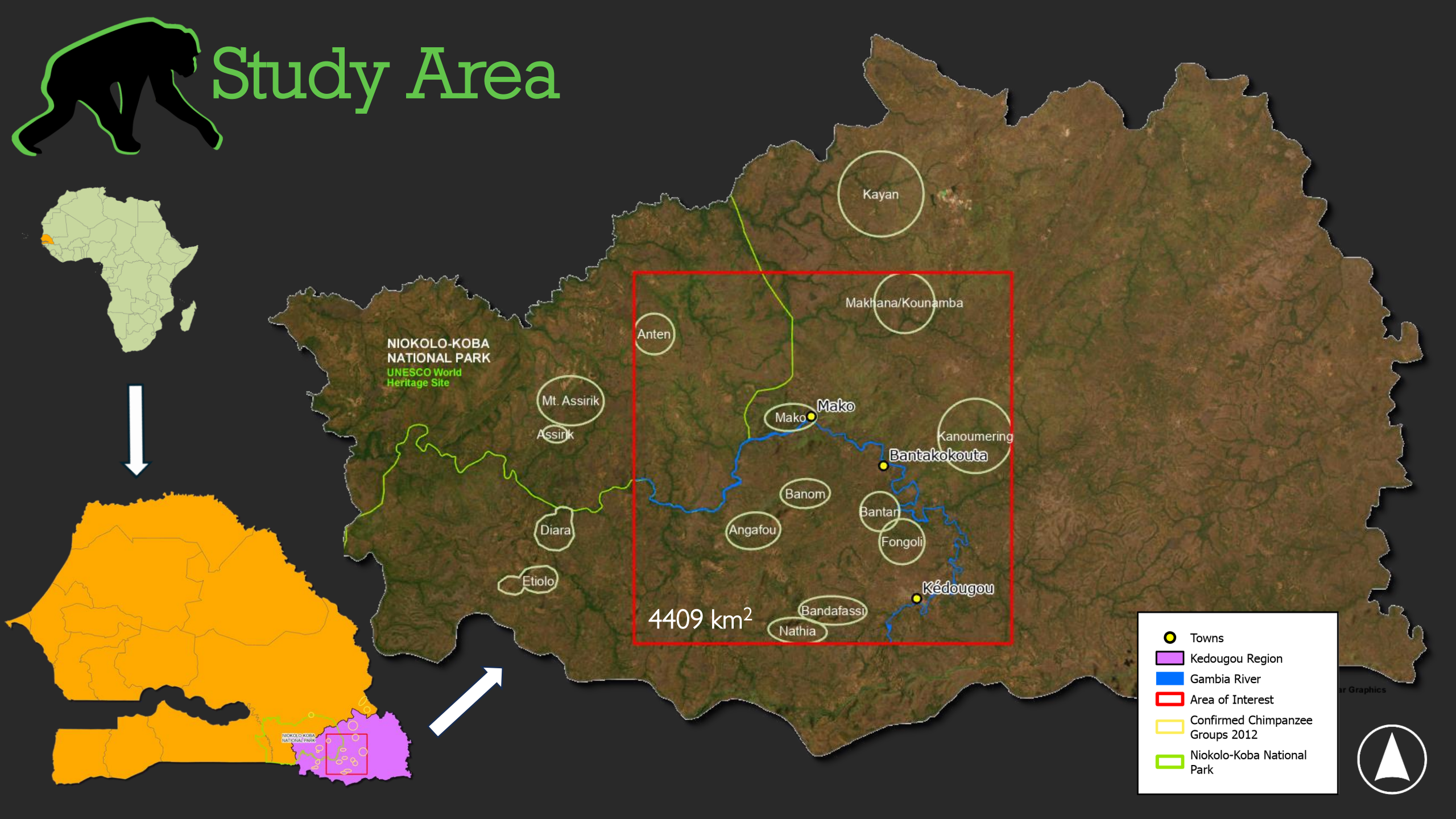
Furthermore, gold mining brings mercury-contaminated water to terrestrial and aquatic ecosystems.

Fongoli savanna chimpanzees drink water from a polluted artisanal mining pit.



The Small-scale Artisanal Gold Mining Process in Kedougou, Senegal (Gerson, Driscoll, Hsu-Kim, & Bernhardt, 2018).

Study Area


Kayan
Makhana/Kounamba
Anten
NIOKOLO-KOBA
NATIONAL PARK
UNESCO World
Heritage Site
Mt. Assirik
Assirik
Mako
Mako
Kanoumering
Bantakokouta
Banom
Bantan
Angafou
Fongoli
Diara
Etiolo
Kédougou
Bandafassi
Nathia
4409 km²
Towns
Kedougou Region
Gambia River
Area of Interest
Confirmed Chimpanzee Groups 2012
Niokolo-Koba National Park

Methodology

Workflow

STAGE 1

Data Acquisition

- SRTM DEM (NASA EarthData), PlanetScope (Planet NICFI Program), Sentinel 2A (ESA Copernicus), Landsat 8, 7, 5 (EarthExplorer).

Pre-processing

- Composite Landsat and Sentinel 2A.
- Mosaic Sentinel 2A, PlanetScope, and SRTM DEM.
- Subset all to the Area of Interest (AOI) and adjust the spatial reference to WGS 1984 UTM Zone 28N.
- Data Exploration

STAGE 2

Build Layers

- Create stream network vector and raster and local and subregional watershed boundaries using ArcGIS Pro and Arc Hydro Toolbox.
- Create soils vector, raster, tables and maps from World Soil Information.
- Create Principal Component Analysis for the AOI in 2023, 2010, 2000, and 1988.
- Create indices for NDWI, NDVI, and SAVI for the AOI for all 4 years in eCognition and export out to save and import back into eCognition.

Build Remotely Sensed Meteorological Data

- Create CHIRPS monthly mean rainfall esitmates from 1988 to 2023 specifically for the AOI using Google Earth Engine.
- Create MODIS Land Surface Temperature estimates from 2000 to 2023 specifically for the AOI using Google Earth Engine.

STAGE 3

Classification

- Using Trimble eCognition to classify the AOI for 2023, 2010, 2000, and 1988.
- Ruleset refinement for unsupervised classification and multi-threshold segmentation.
- Classification for: Closed-vegetation, Ecotone, Open-vegetation, Bare Soil, Vegetation Degradation, Development, Large-scale Mine, Mine Tailing Pond, Intermediate-scale Artisanal Mine, Small-scale Artisanal Mine, Water Body, Roads, and NoData.
- Export eCognition vector output to ArcGIS Pro to process and create tables, charts, and maps for the AOI, subregional watershed, and local watershed.

STAGE 4

Accuracy Assessment

- For 2023 classification using ArcGIS Pro and PlanetScope as the reference data.

Change Detection

- Using ArcGIS Pro Change Detection Wizard for 1988 to 2023.

Presence-only Prediction

- Using ArcGIS Pro Presence-only Prediction Tool to predict where the savanna chimpanzee habitat was suitable in 2023.
- Based on savanna chimpanzee nesting data, the classified 2023 AOI, stream network, dominate soils, parent soils, land forms, elevation, aspect, and OpenStreetMap roads.

Methodology

Data

January	February	March	April	May	June	July	August	September	October	November	December
Dry	Dry	Dry	Dry	Transitional	Wet	Wet	Wet	Wet	Transitional	Dry	Dry





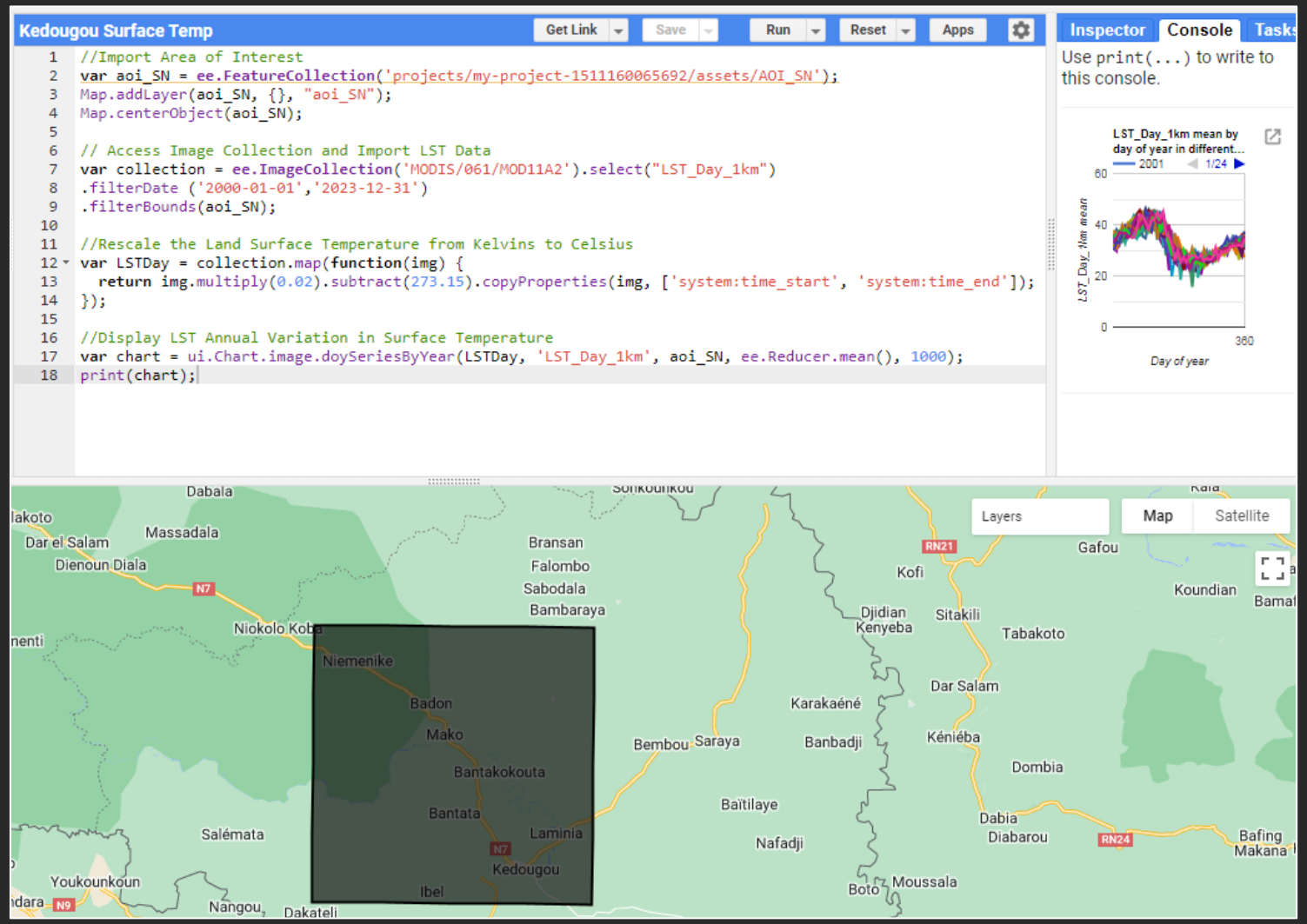

Photo Credit: Gray Tappan

- Senegal's landscape is a highly mosaic environment. Which can make it very difficult to classify the land cover and land use.
- Dry season is from November to April and May is a transitional month.
- Wet season (rain and clouds) is from June to September and October is a transitional month.
- Senegal's seasons and vegetation growth are highly correlated with annual precipitation.
- Satellite imagery was selected for the month of December.
- December was chosen to get a snapshot of the gallery forests when the highest and lowest growth does not interfere with capturing the classification … in theory.

Methodology

Google Earth Engine Data

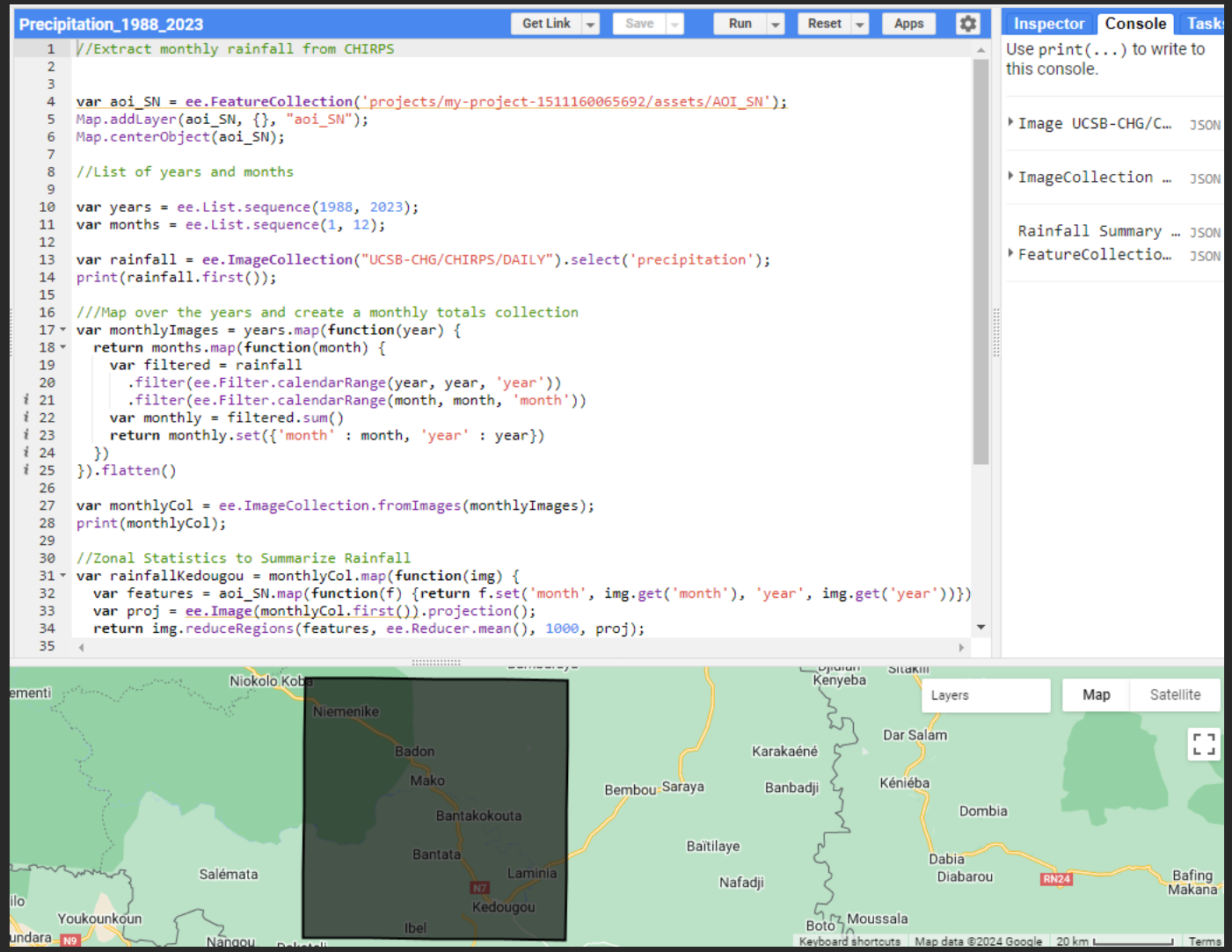
- I used Google Earth Engine (GEE) to analyze land surface temperature and precipitation, which allowed me to observe seasonality over time. This analysis also guided my decision to select December for my imagery.
- Accessing large datasets on GEE can be accomplished with some simple code.
- Here is an example of how to retrieve land surface temperature data using MODIS.
- I did not write this JavaScript code myself; instead, I followed a video tutorial and made some adjustments.



Methodology

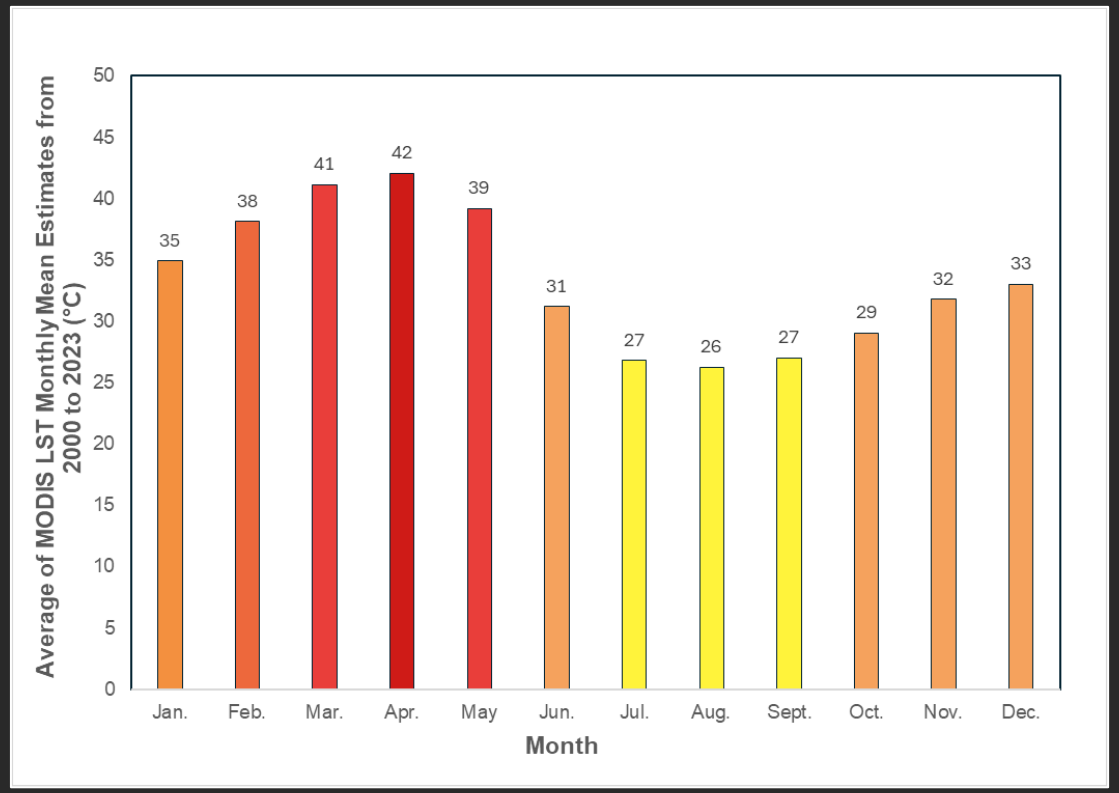
Google Earth Engine Data

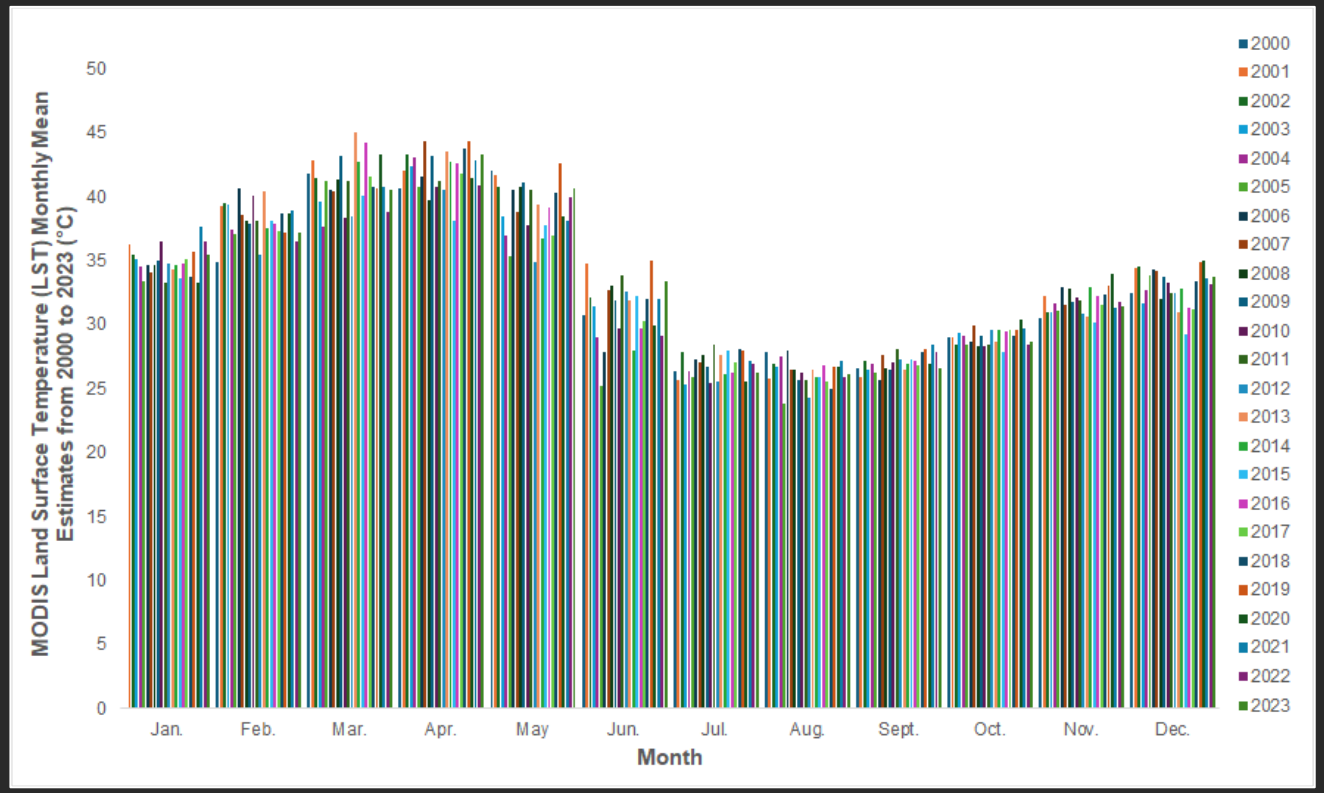
- Here is an example of the code for CHIRPS Precipitation.
- You can use the QR Code below to access this information.



Methodology

MODIS Land Surface Temperature Data from 2000 to 2023



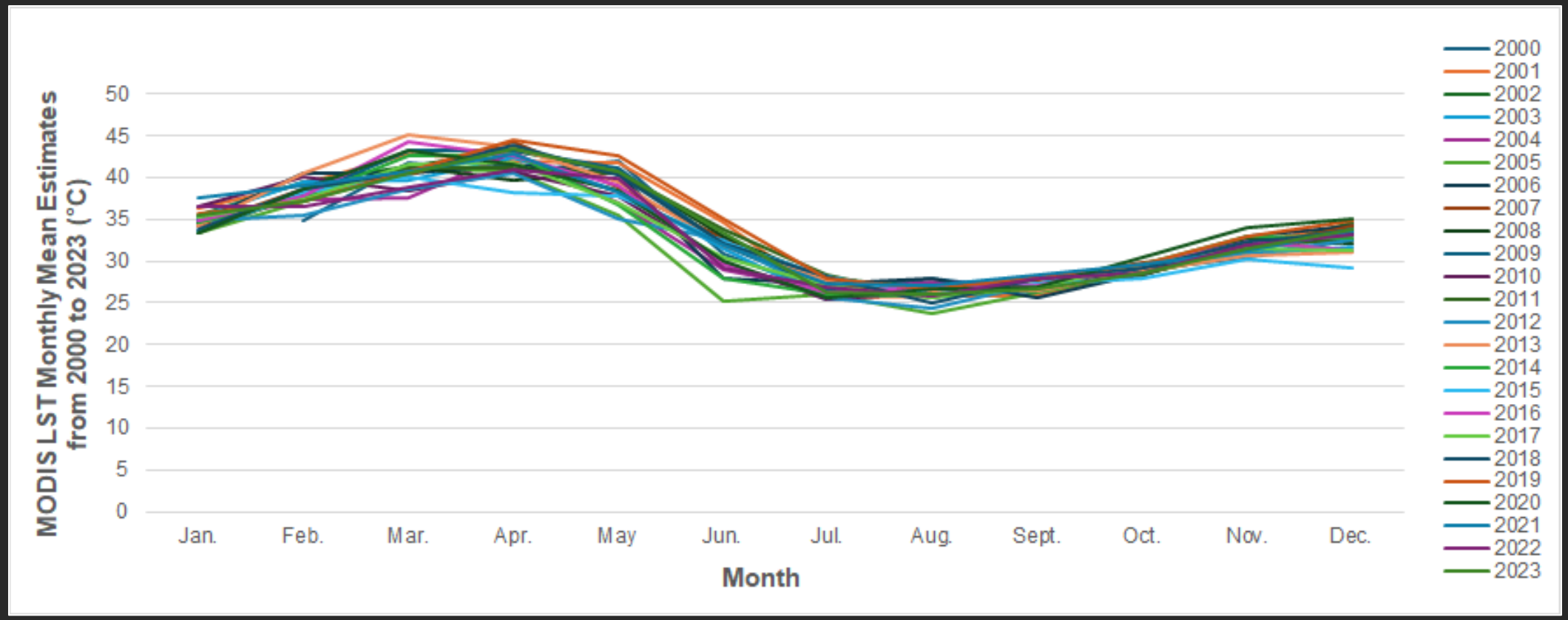


It is hot in Senegal! Hot in the dry season and then it cools down a bit in the wet.

MODIS LST takes an 8-day average of the surface temperature every 8 days.

Methodology

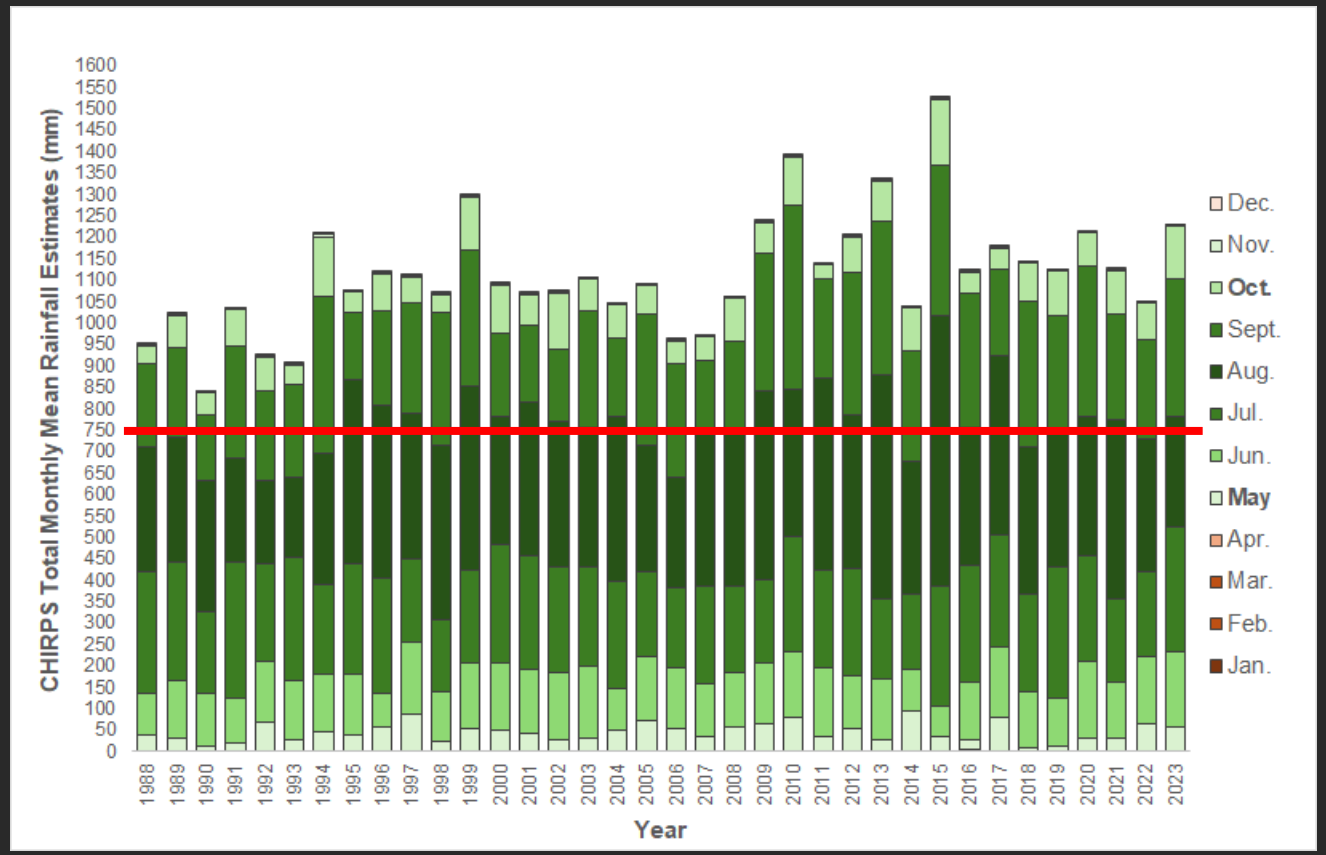
MODIS Land Surface Temperature Data from 2000 to 2023

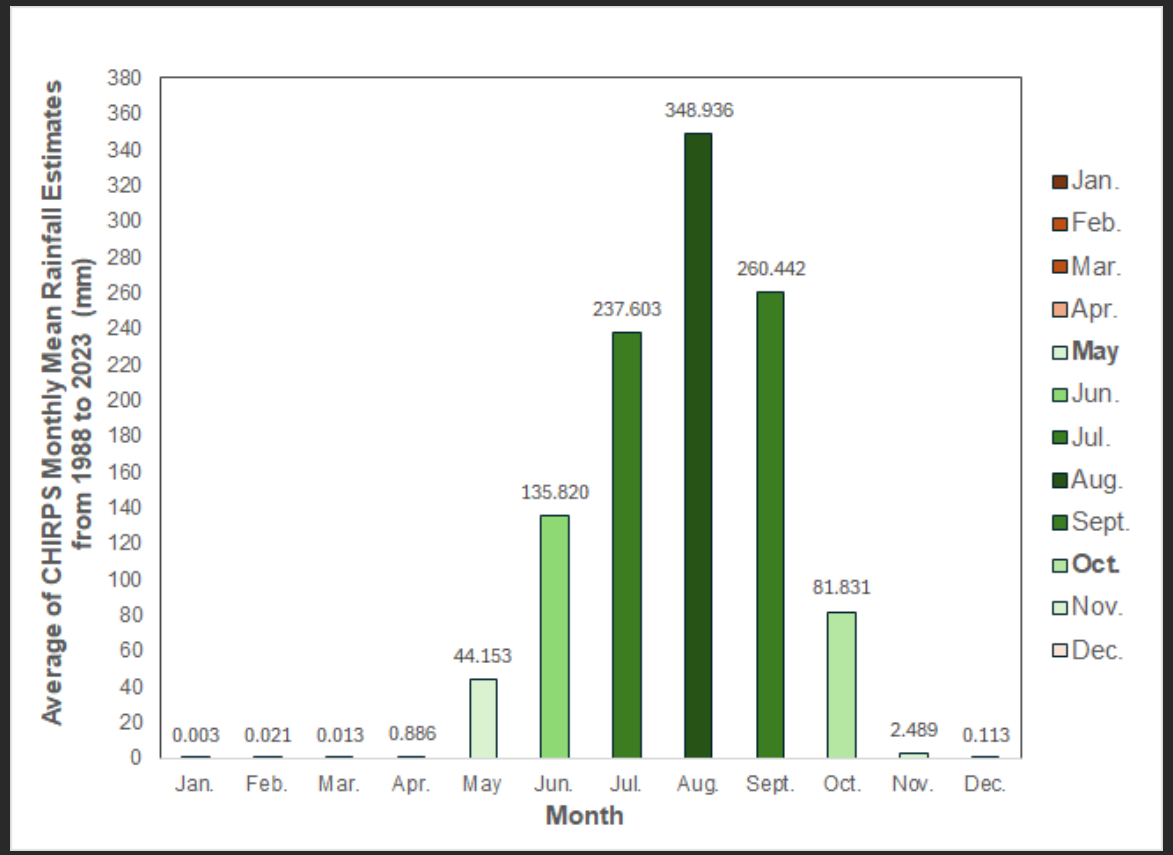


Here is another interpretation that is essentially the same seasonal curve.

Methodology

CHIRPS Precipitation Data for 1988 to 2023



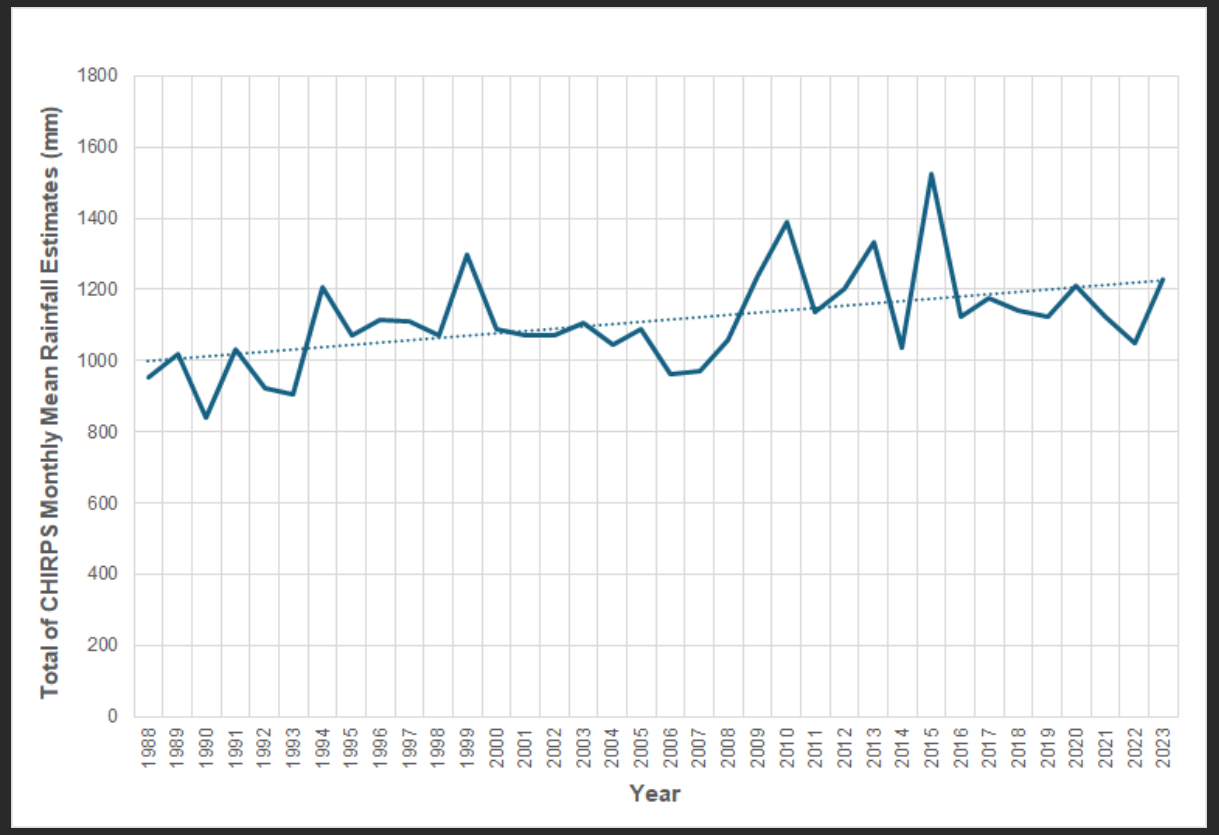


As a reference, chimpanzees have not been observed in areas where the average annual rainfall is less than 750 mm (Lindsheild, et al., 2021).

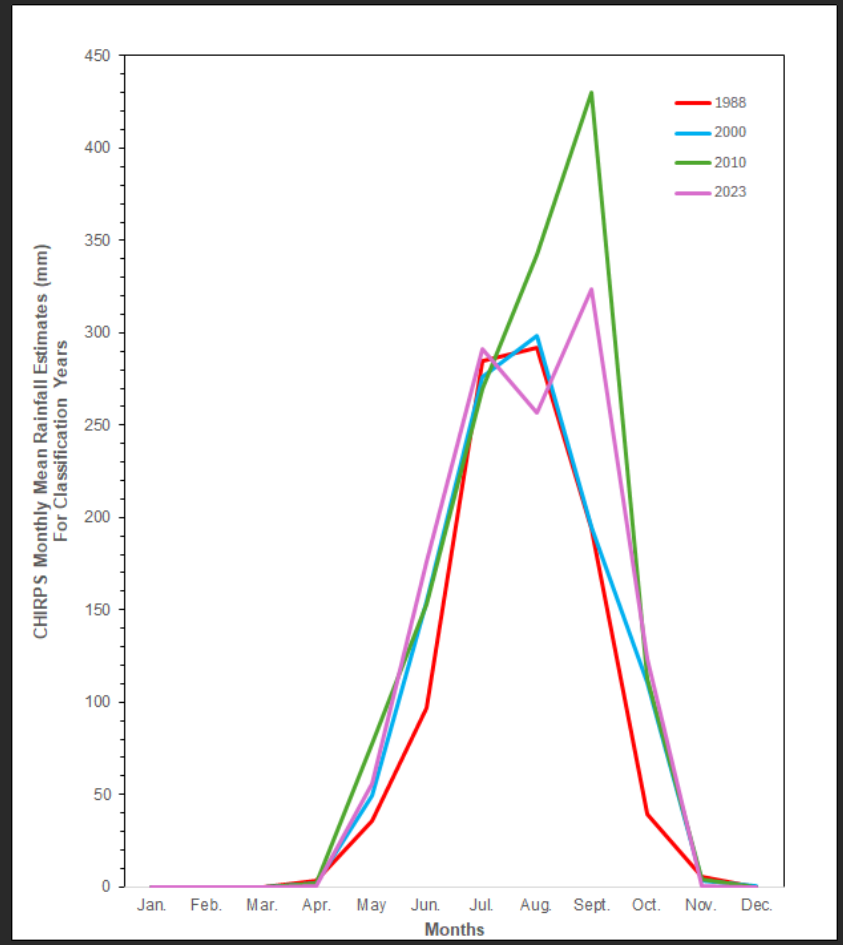
The rainfall and vegetation growth are closely correlated so you can infer some seasonality with precipitation.

Methodology

CHIRPS Precipitation Data for 1988 to 2023



It looks like they are getting more rain perhaps flooding.

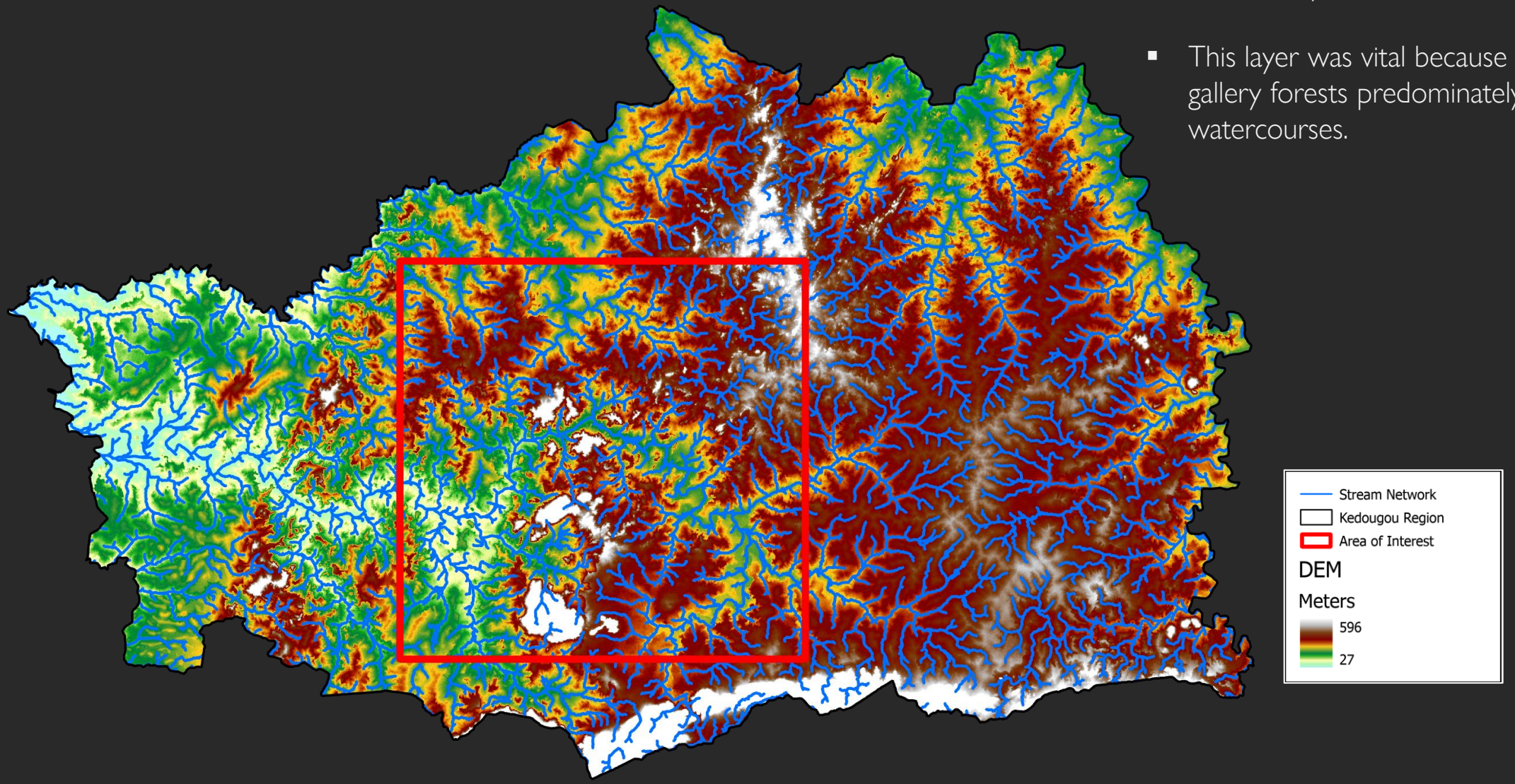


These data are specific to the study area. The 1988, 2000, 2010, and 2023 study areas show three different patterns.

Methodology

Layer Creation: Stream Network

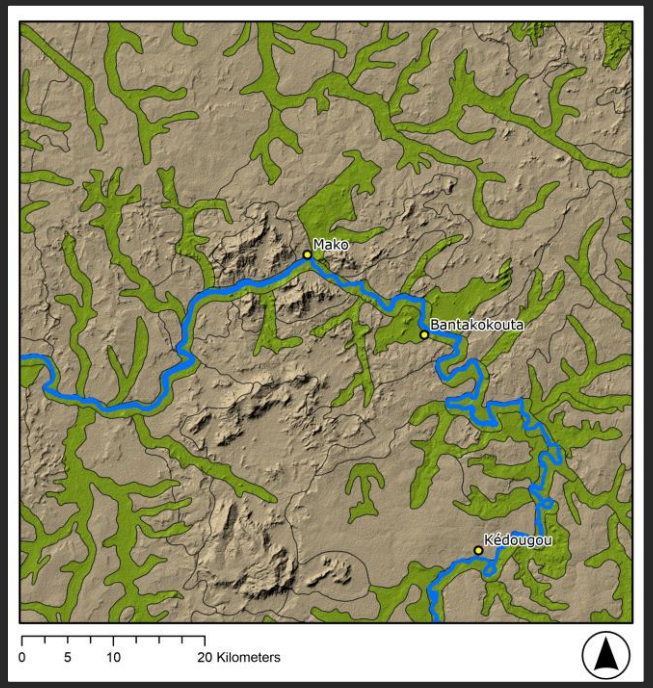
- The stream network was derived from the 30-meter SRTM DEM using ArcGIS Pro and Arc Hydro Toolbox.
- This layer was vital because it helped locate gallery forests predominately found along watercourses.

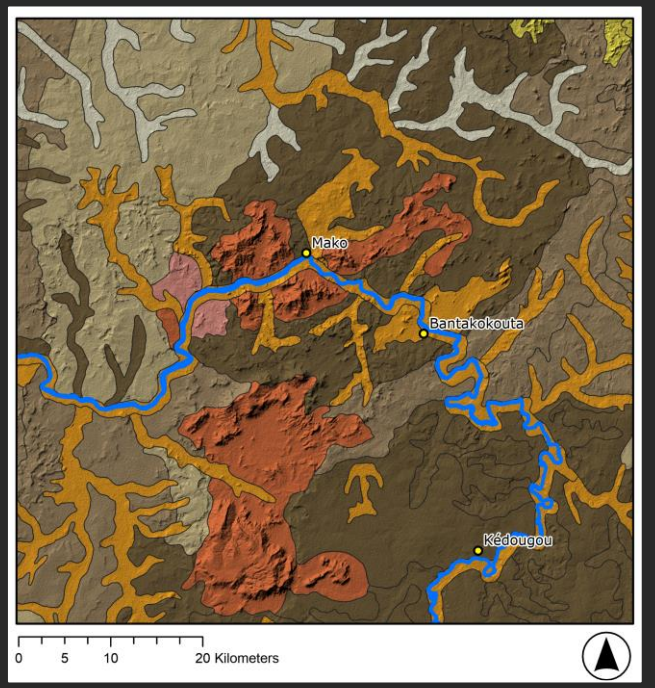


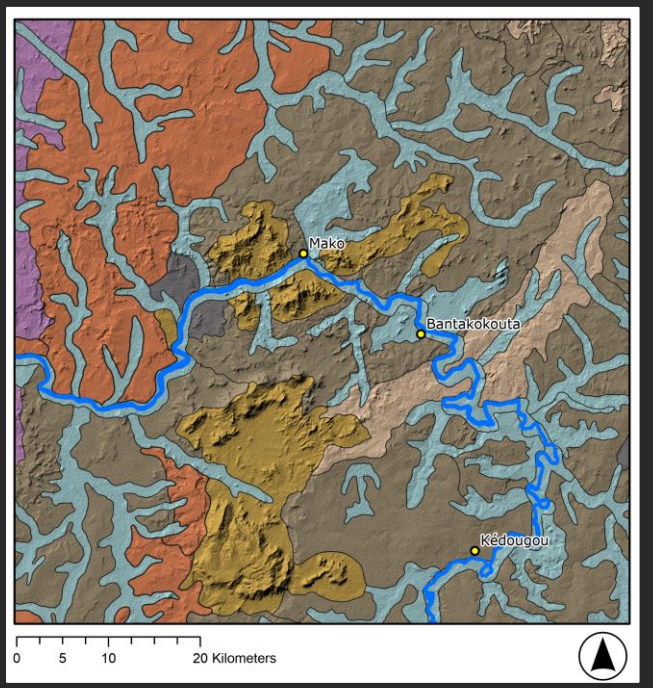
Methodology

Layer Creation: Soils

The soils data was acquired from the Soil and Terrain Database (SOTER) for Senegal and the Gambia.







Towns
Gambia River
Area of Interest
Senegal 2008 SOTER Soils:
Landforms
Plain
Valley Floor

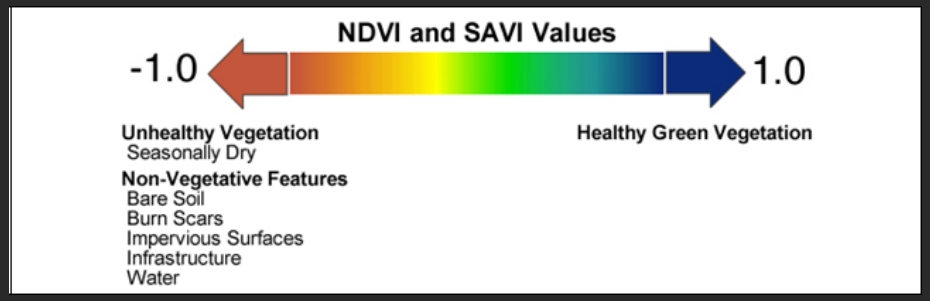
Towns
Gambia River
Area of Interest
Senegal 2008 SOTER Soils:
Dominant Soils
Dystric REGOSOLS
Eutric GLEYSOLS
Eutric LEPTOSOLS
Eutric REGOSOLS
Eutric VERTSOLS
Ferric ACRISOLS
Lithic LEPTOSOLS
Plinthic ACRISOLS

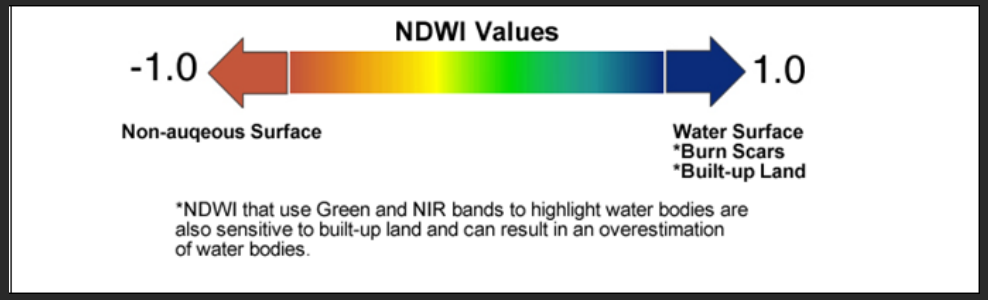
Towns
Gambia River
Area of Interest
Senegal Soils 2008:
Dominant Parent Materials
Basic igneous rock
Colluvial
Fluvial
Granite
Sandstone, greywacke, arkose
Schist
Slate, phyllite (peltic rocks)

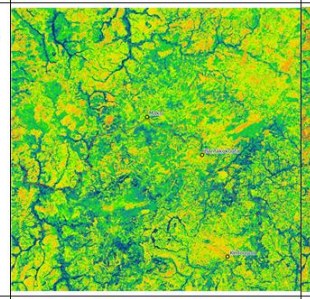
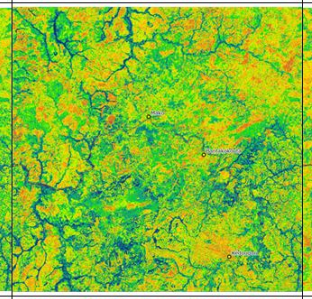
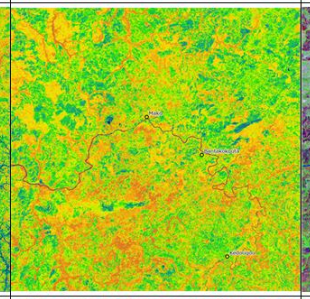
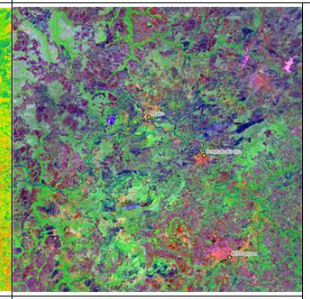
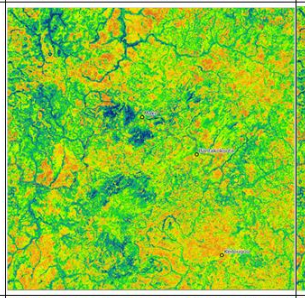
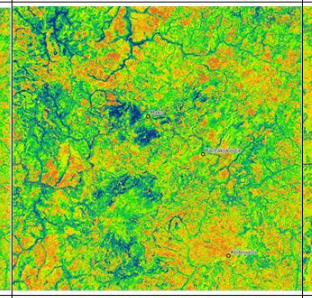
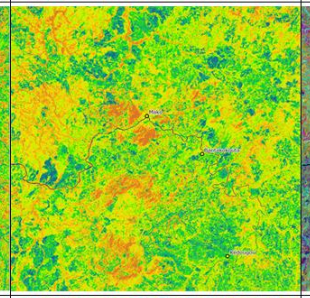
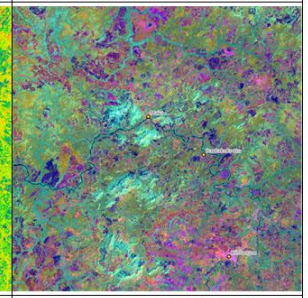
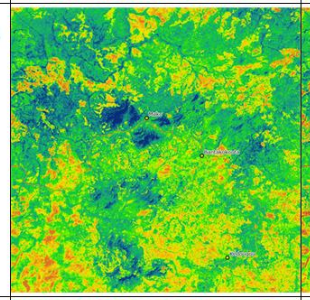
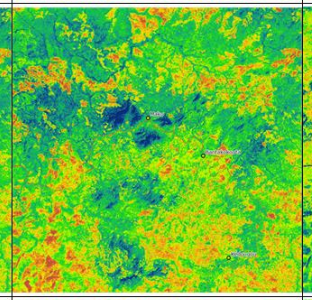
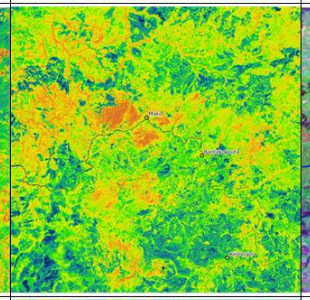
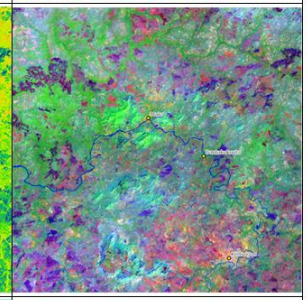
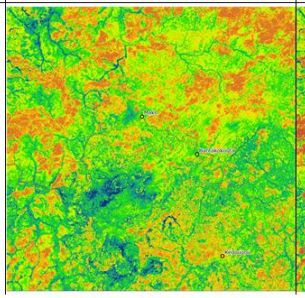
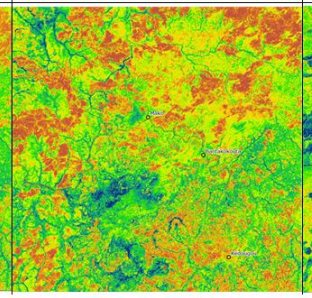
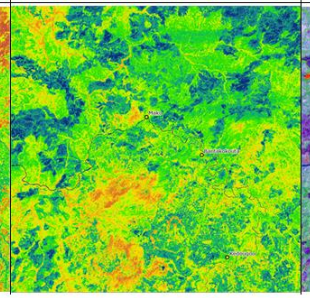
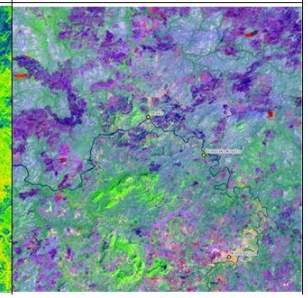
Methodology

Layer Creation: Indices and PCA

- The PCA colors are random, and feature information is clustered and extruded to show the most dominant features in the scene.
- The indices were built within eCognition by using its canned formulas.



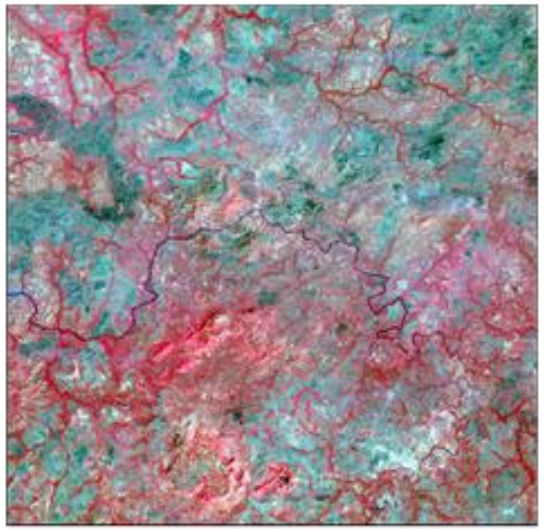


Year	Res.	NDVI (NIR-Red)/(NIR+Red)	SAVI ((NIR-Red)/(NIR+Red+L)) * (1+L) L=0.75	NDWI (Green-NIR)/(Green+NIR)	Principal Component Analysis (PCA)
Dec 2023 Sentinel 2A	10 meters				
Dec 2010 Landsat 5 TM	30 meters				
Dec 2000 Landsat 7 ETM	15 meters				
Dec 1988 Landsat 5 TM	30 meters				

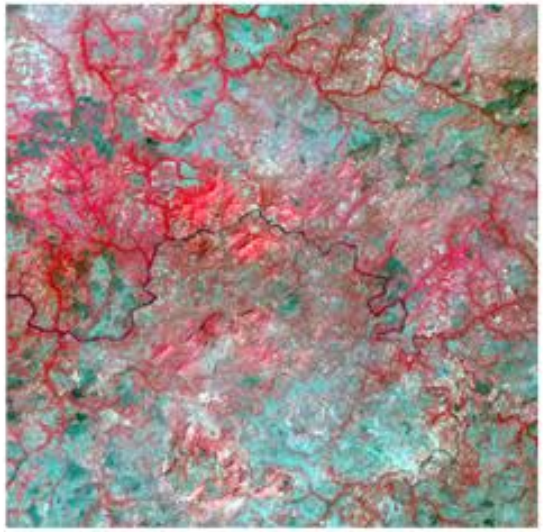
Methodology

eCognition Data Fusion

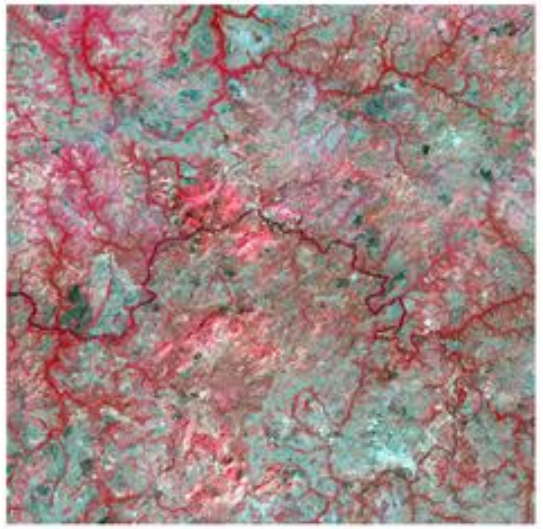
10 December 1988
Landsat 5 TM, C2L2
30 meters



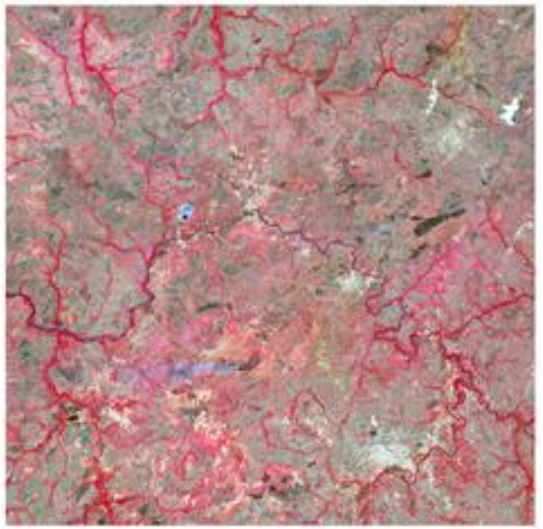
19 December 2000
Landsat 7 ETM, C2L1
15 meters



23 December 2010
Landsat 5 TM, C2L2
30 meters



27 December 2023
Sentinel-2A
10 meters



This is the primary satellite imagery used to set the resolution for each eCognition project. Landsat 7 ETM and Landsat 5 TM used B4, B3, and B2, and Sentinel 2A used B8, B4, and B3 (RGB) to display healthy vegetation in color infrared.

Methodology

eCognition Data Fusion

eCognition Data for 1988	eCognition Data for 2000	eCognition Data for 2010	eCognition Data for 2023
Landsat 5 TM, C2L2 Tier 1, 16 Bit, **30 m**, Date: 12/10/1988 PCA of Landsat 5	Landsat 7 ETM C2L1,**15 m**, Date: 12/19/2000 Panchromatic PCA of Landsat 7 C2L2 Pansharpened Landsat 7 ETM C2L2 Tier 1, 16 Bit, 30 m, Date: 12/19/2000 PCA of Landsat 7 C2L2	Landsat 5 TM, C2L2 Tier 1, 16 Bit, **30 m**, Date: 12/23/2010 PCA of Landsat 5	Sentinel2A, **10 m** Date: 12/27/23 PCA of Sentinel2A
DEM, 30 m, Date: 2/11/2000	DEM, 30 m, Date: 2/11/2000	DEM, 30 m, Date: 2/11/2000	DEM, 30 m, Date: 2/11/2000
Constructed in eCognition with Landsat SAVI_1988.tif NDVI_1988.tif NDWI_1988.tif	Constructed in eCognition with Landsat SAVI_2000.tif NDVI_2000.tif NDWI_2000.tif	Constructed in eCognition with Landsat SAVI_2010.tif NDVI_2010.tif NDWI_2010.tif	Constructed in eCognition with Sentinel SAVI_2023.tif NDVI_2023.tif NDWI_2023.tif
Overlays in eCognition for Classifying Soils, Vector, Date: 2008 Stream Network, Vector, Date: 2/11/2000 Artisanal Mines, Vector, 2014 OpenStreetMap Roads Fishnet Guide	**Overlays in eCognition for Classifying** Soils, Vector, Date: 2008 Stream Network, Vector, Date: 2/11/2000 Artisanal Mines, Vector, 2014 OpenStreetMap Roads Fishnet Guide	**Overlays in eCognition for Classifying** Soils, Vector, Date: 2008 Stream Network, Vector, Date: 2/11/2000 Artisanal Mines, Vector, 2014 OpenStreetMap Roads Fishnet Guide	**Overlays in eCognition for Classifying** Soils, Vector, Date: 2008 Stream Network, Vector, Date: 2/11/2000 Artisanal Mines, Vector, 2014 OpenStreetMap Roads Fishnet Guide
Reference Data: N/A	**Reference Data: N/A**	**Reference Data: N/A**	**Reference Data:** PlanetScope 4.47 m Date: 12/27/23

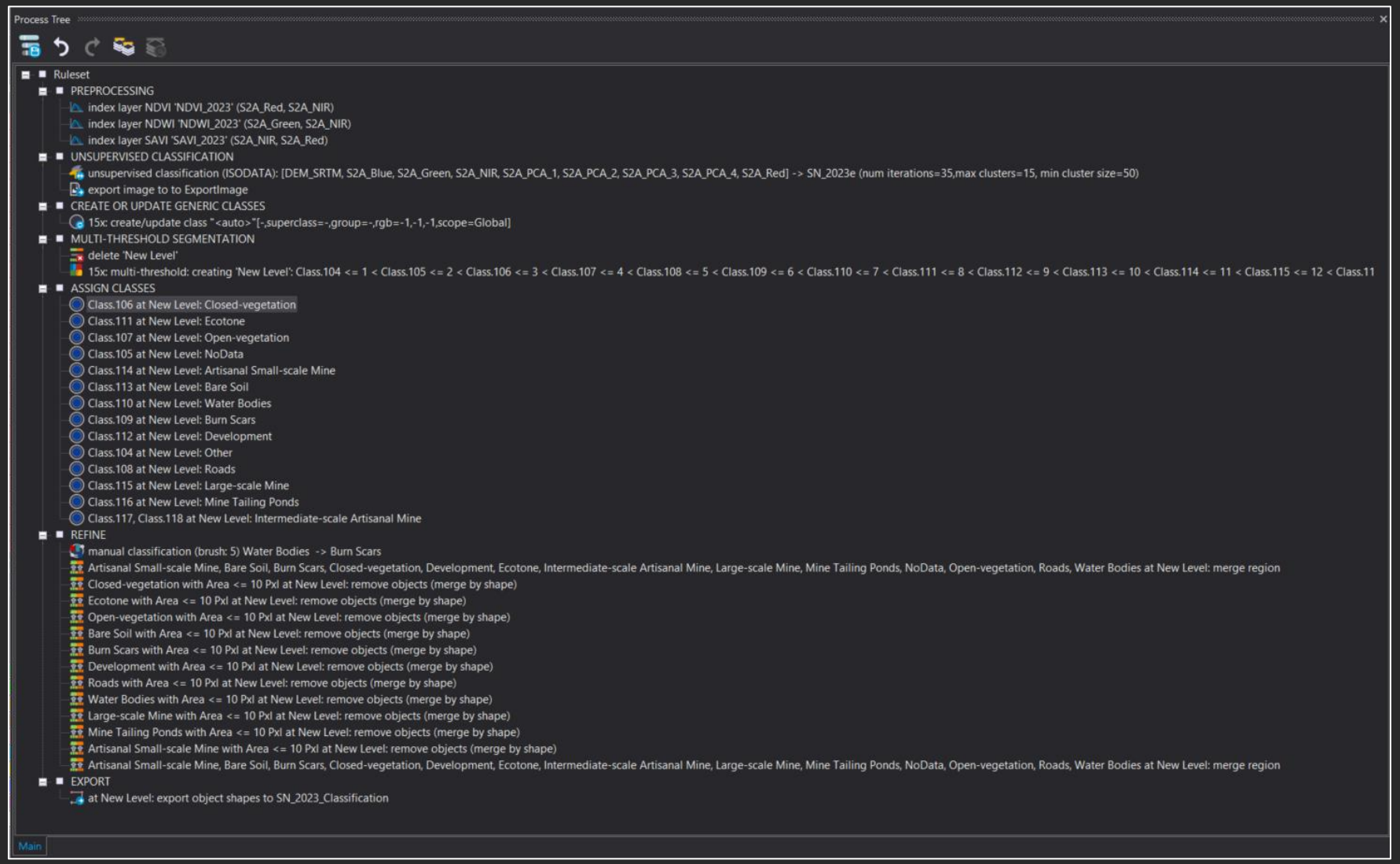
This is like supercharging an unsupervised classification!

Remember, mosaic landscapes are difficult to classify.

An unsupervised classification may be a better choice if you are unfamiliar with the area.

Methodology

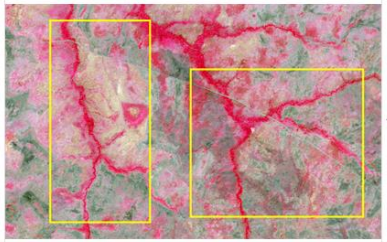
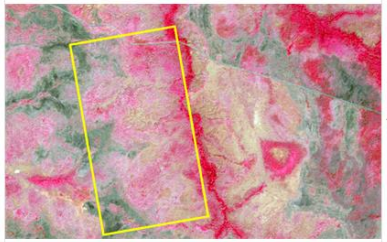
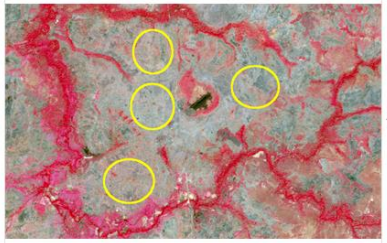
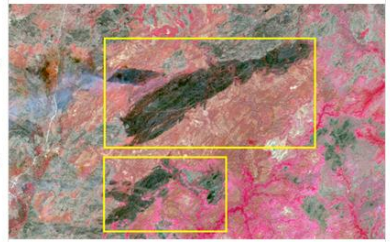
eCognition Classification Ruleset



1. Preprocessing indices.
2. Run unsupervised classification. This can take 20 to 30 minutes.
3. Run Create /Update Generic Classes.
4. Run Multi-threshold Segmentation with the layer produced from the unsupervised classification. This creates the number of clusters (or classes) you assign.
5. Manually assign classes.
6. Refine the classification.
7. Export.

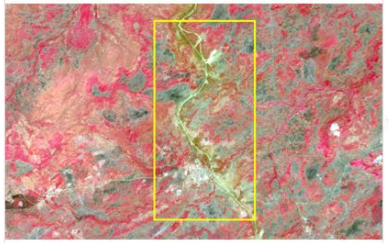
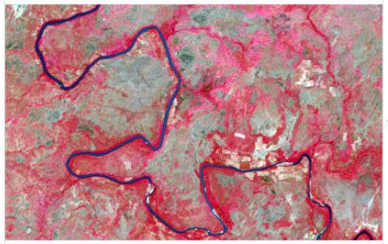
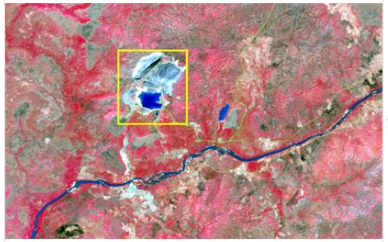
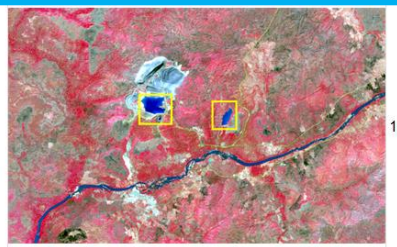
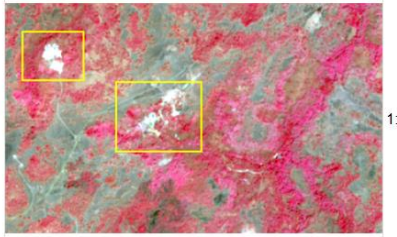
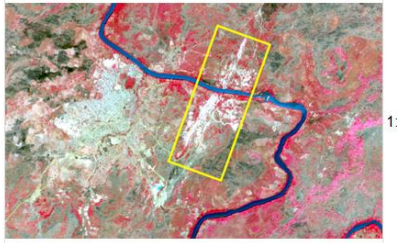
Methodology

eCognition Visual Classification Key

	Classification	Description	Imagery Examples in Infrared	Scale	1988	2000	2010	2023
1	**Closed-vegetation (Gallery Forest)**	"Closed and evergreen (e.g., gallery/riparian or thicket forest;hereafter "closed vegetation")" (Lindshield, et al., 2021).		1:38,000	✓	✓	✓	✓
2	**Ecotone**	"A transitional "ecotone" category for vegetation that is neither mostly open nor mostly closed" (Lindshield, et al., 2021).		1:24,000	✓	✓	✓	✓
3	**Open-vegetation**	"Open and deciduous(e.g., woodland, wooded grassland, and grassland; refered to as "open vegetation")" (Lindshield, et al., 2021).		1:38,000	✓	✓	✓	✓
4	**Bare Soil**	Land with little or no vegetation cover exposing soil, and sandy areas (CILSS, 2016).		1:24,000	✓	✓	✓	✓
5	**Vegetation Degradation**	"The temporary or permanent reduction in the density, structure, species composition or productivity of vegetation cover (Conacher & Sala, 1998). Such as burn scars after natural brush fires or those ignited to clear the land for agriculture. These can also be new or old burn scars and seasonally dry or dead vegetation (CILSS, 2016).		1:38,000	✓	✓	✓	✓
6	**Development**	Settlements such as villages, towns, cities and local roads (CILSS, 2016).		1:38,000	✓	✓	✓	✓

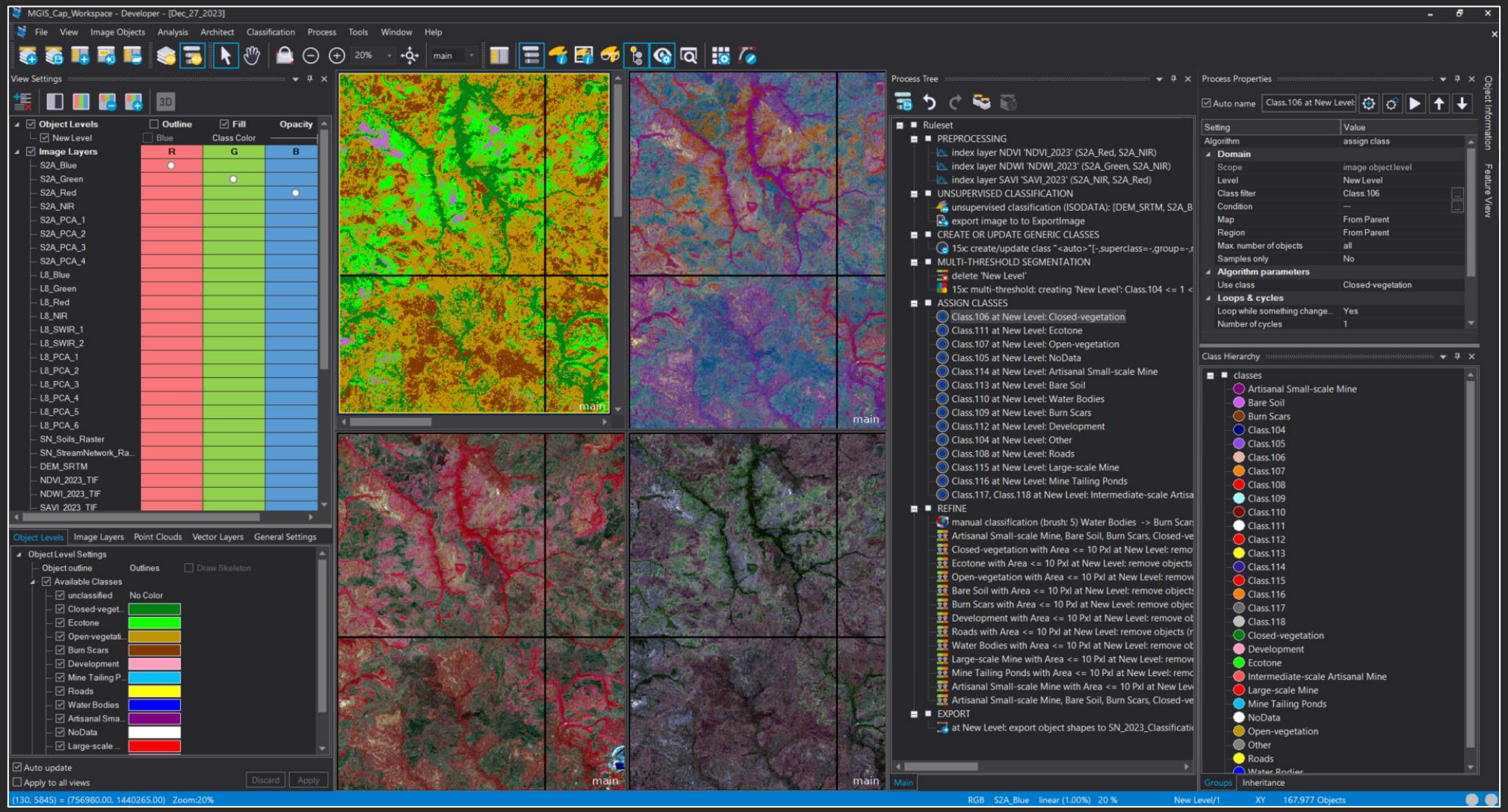
Methodology

eCognition Visual Classification Key

	Classification	Description	Imagery Examples in Infrared	Scale	1988	2000	2010	2023
7	**Roads**	Major roads.		1:24,000	X	X	X	✓
8	**Water Bodies**	Areas with permanent or semi-permanent surface water such as the Gambia River and smaller waterways (CILSS, 2016).		1:38,000	✓	✓	✓	✓
9	**Large-scale Mine**	Open pit where gold is mined (CILSS, 2016).		1:38,000	X	X	X	✓
10	**MineTailing Ponds**	Structure or embankment that is built to retain gold mining waste or the byproduct of open pit mining such as fine-grained particles, waste water, arsenic and mercury (Adapted from Morrill, et al., 2020).		1:38,000	X	X	X	✓
11	**Small-scale Artisanal Mine**	Shallow-pocked mining locales usually near a water source where mineral extractions are mined from surface sand or gravel with little need for sophisticated tools (Allan, 2015).		1:15,000	X	✓	✓	✓
12	**Intermediate-scale Artisanal Mine**	The intermediate-scale gold mine that is not as expansive as a large-scale mine but also not as small as an ASGM mine either. The intermediate-scale mine has more infrastructure than an ASGM and is adjacent to a village or town		1:24,000	✓	X	✓	✓
13	**Other**	Unidentified class or pixels, shadows, smoke, clouds, reflections of clounds in the water.	To be decided as needed.		X	X	X	X
14	**NoData**	Frame border in eCognition.	To be decided as needed.		✓	✓	✓	✓
	Class Count				**8**	**9**	**10**	**13**

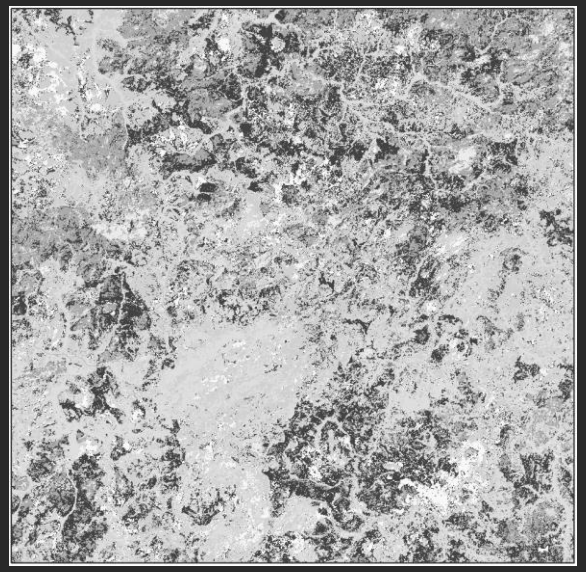
Methodology

eCognition Workspace

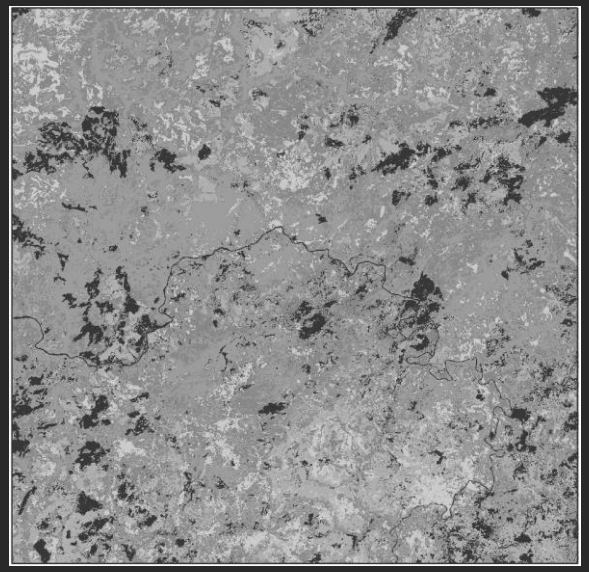


Methodology

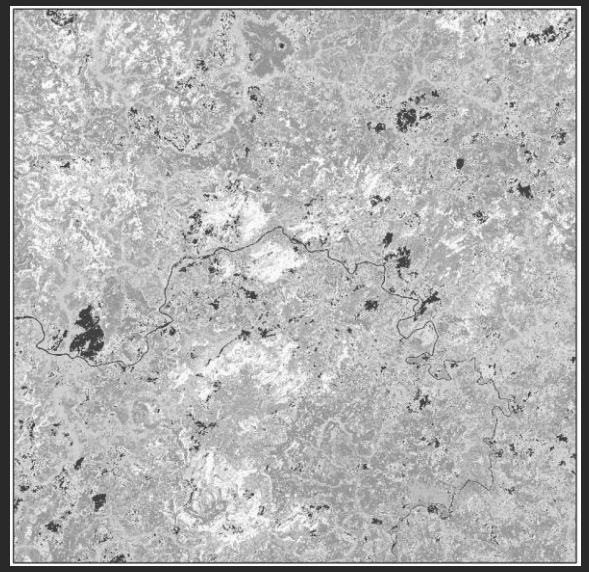
eCognition Unsupervised Classification with Data Fusion for Each Year



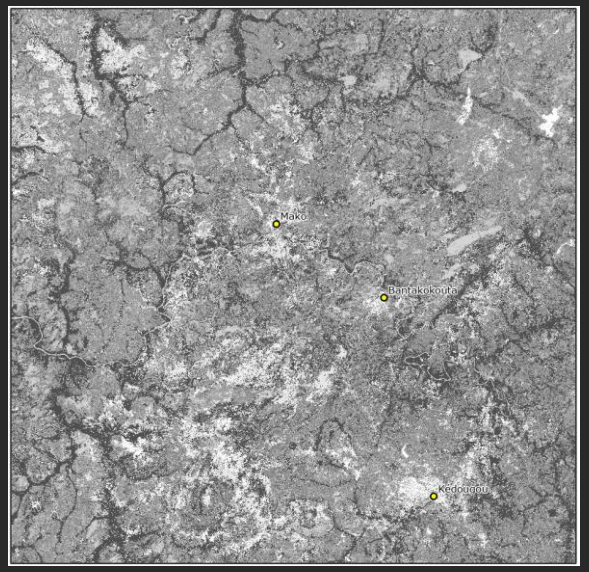
1988
30 meters



2000
15 meters



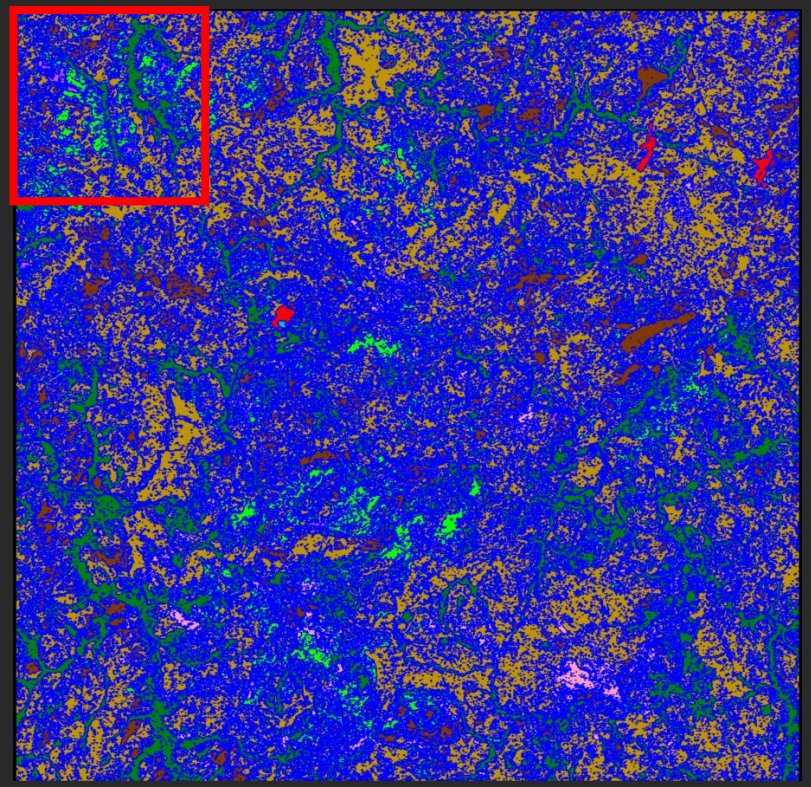
2010
30 meters



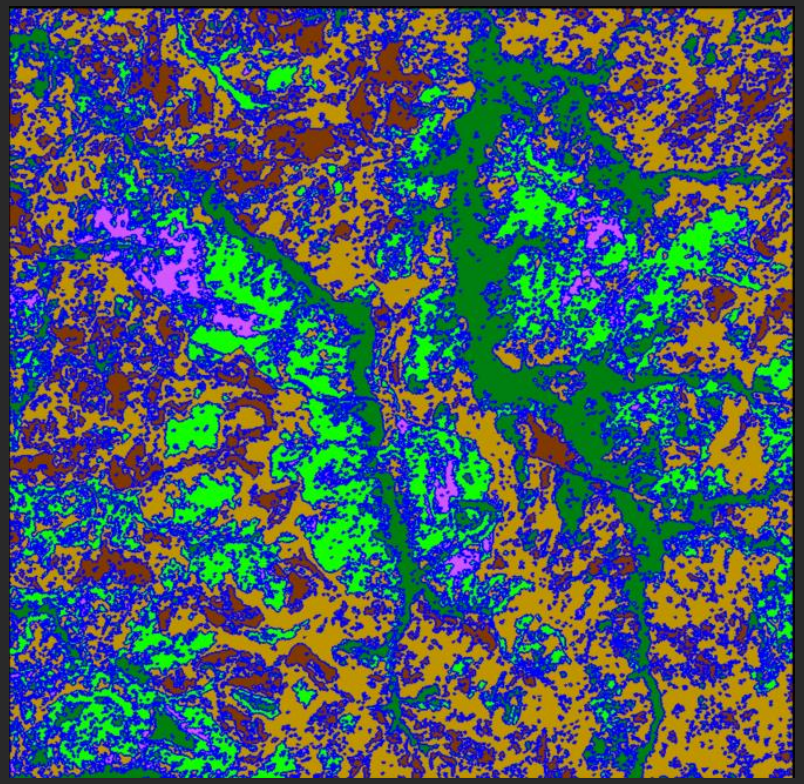
2023
10 meters

Methodology

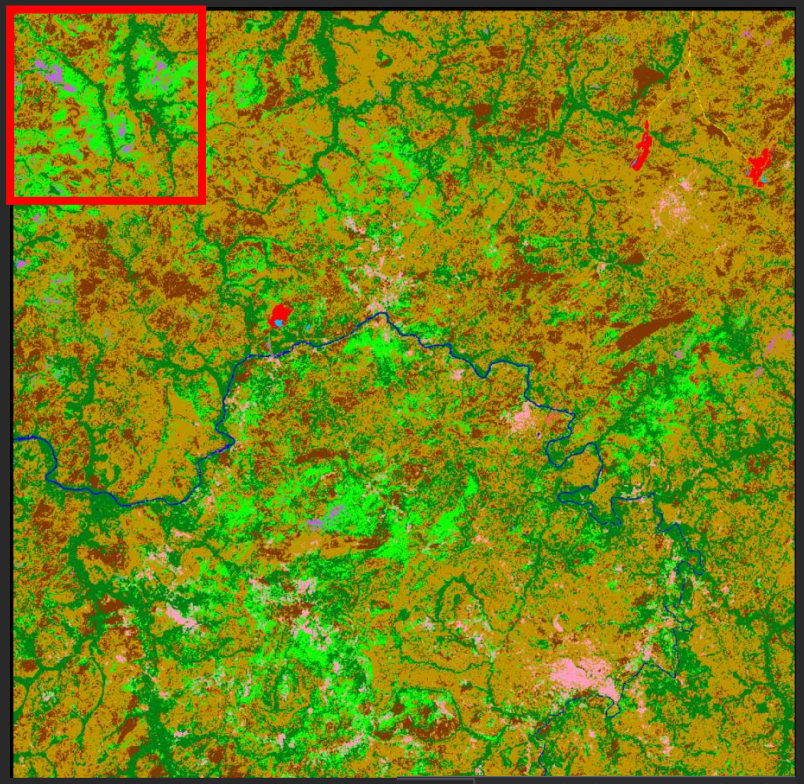
Example of the Results After Running the Multi-threshold Segmentation



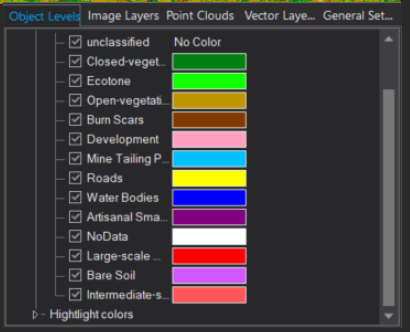
The vector results after running the multi-threshold segmentation algorithm in eCognition for 10-meter resolution (2023).



An up-close view of the segmentation results.



Results after classification and refinement steps.



Methodology

Post-processing in ArcGIS Pro

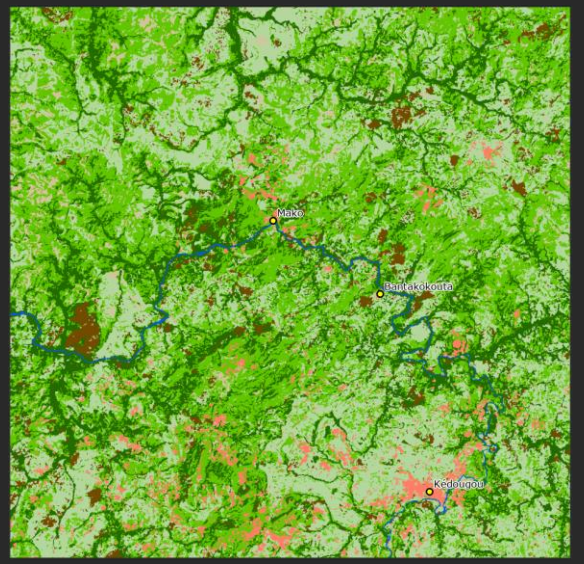
- Performed an accuracy assessment in ArcGIS Pro for the 2023 classification using stratified random sampling for 663 points.
- Performed a change detection analysis to track closed-vegetation (gallery forest) from 1988 to 2023.
- Last, the presence-only prediction tool in ArcGIS Pro was used to predict where the savanna chimpanzee habitat was suitable in 2023.

Results

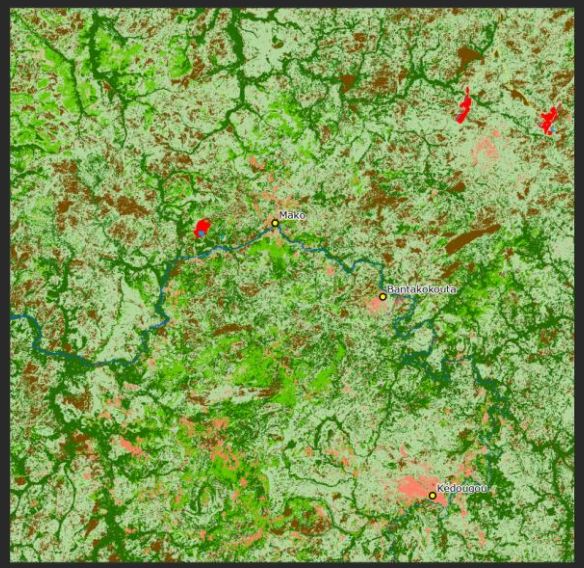
eCognition Classification for Area of Interest

1988

2000



2010



2023

4409 **km²**

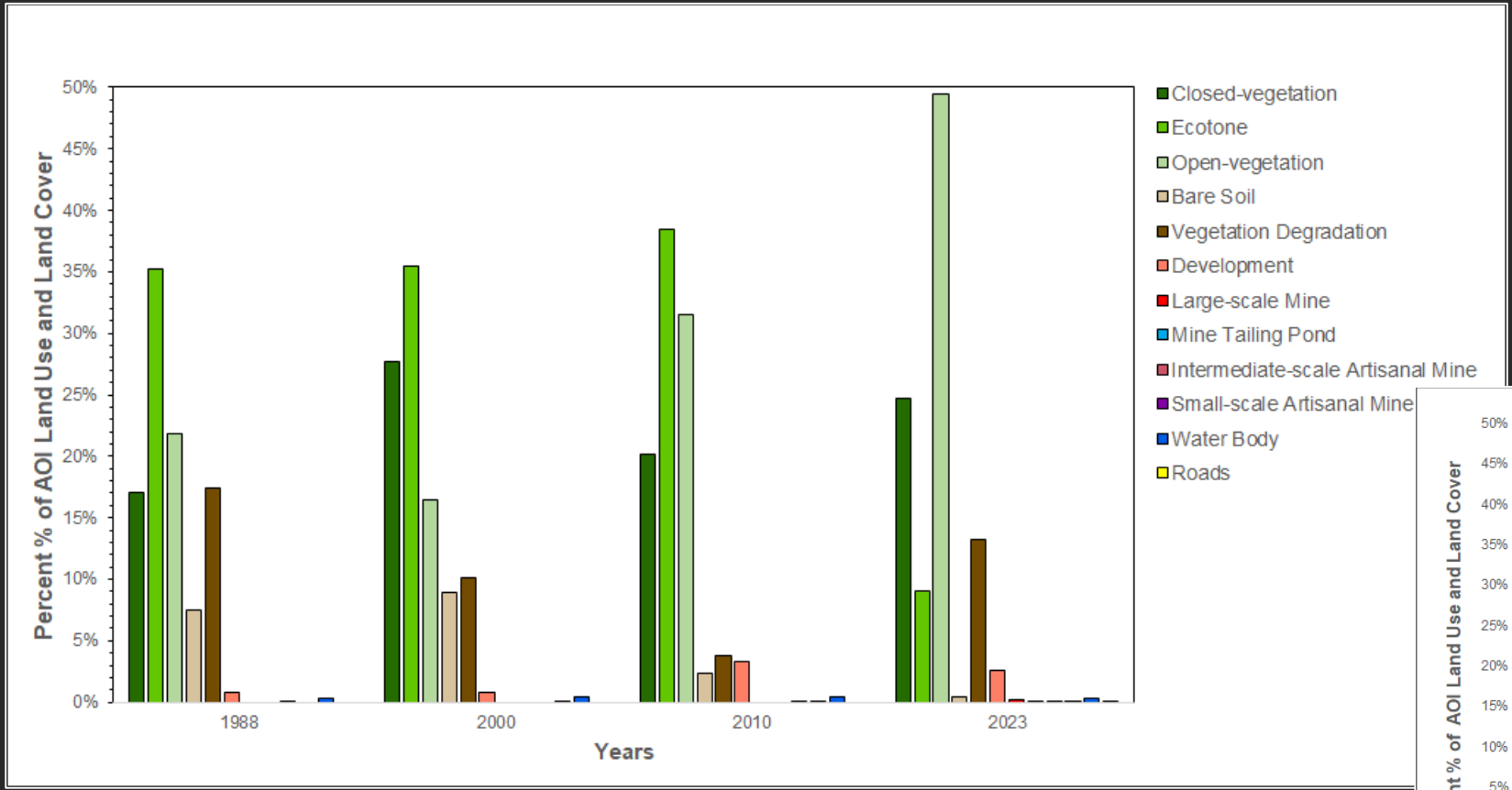
Towns

Class Names

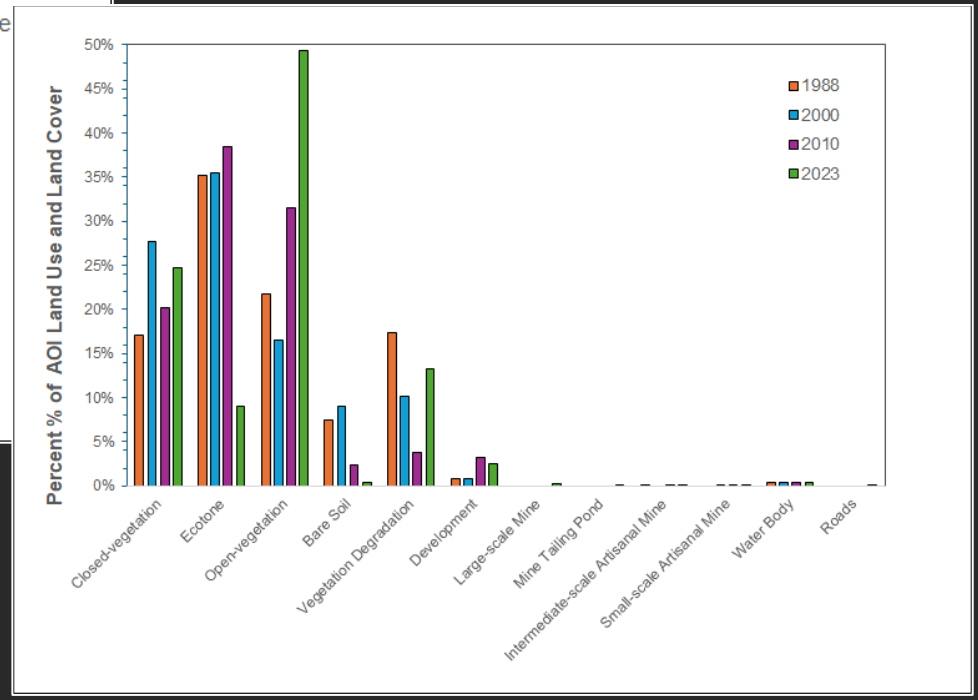
- Closed-vegetation
- Ecotone
- Open-vegetation
- Bare Soil
- Vegetation Degradation
- Development
- Large-scale Mine
- Mine Tailing Pond
- Intermediate-scale Artisanal Mine
- Small-scale Artisanal Mine
- Water Body
- Roads
- NoData

Results

eCognition Classification for Area of Interest



- From 1988 to 2023, the LULC has shifted to predominately open-vegetation. Ecotone increased from 1988 to 2010; however, in only 13 years, from 2010 to 2023, the ecotone has dramatically declined, and closed-vegetation (Gallery Forests) has increased.



- This time interval from 2010 to 2023 corresponds with the gold mining boom in the study area.

Results

eCognition Classification for Subregional Watershed

1988

2000

2010

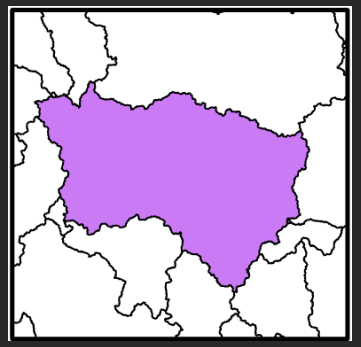
2023

1291 **km²**

Towns

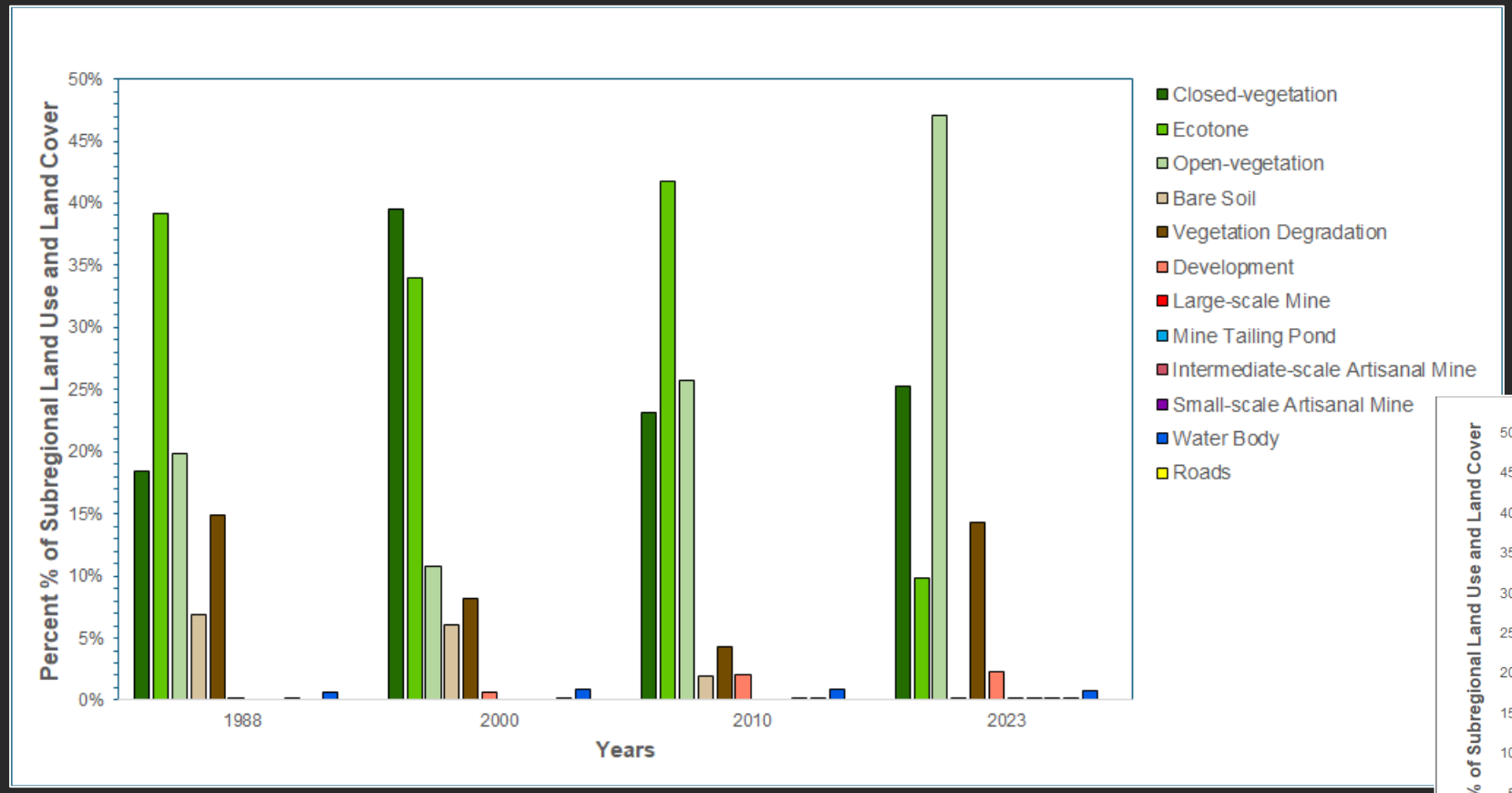
Class Names

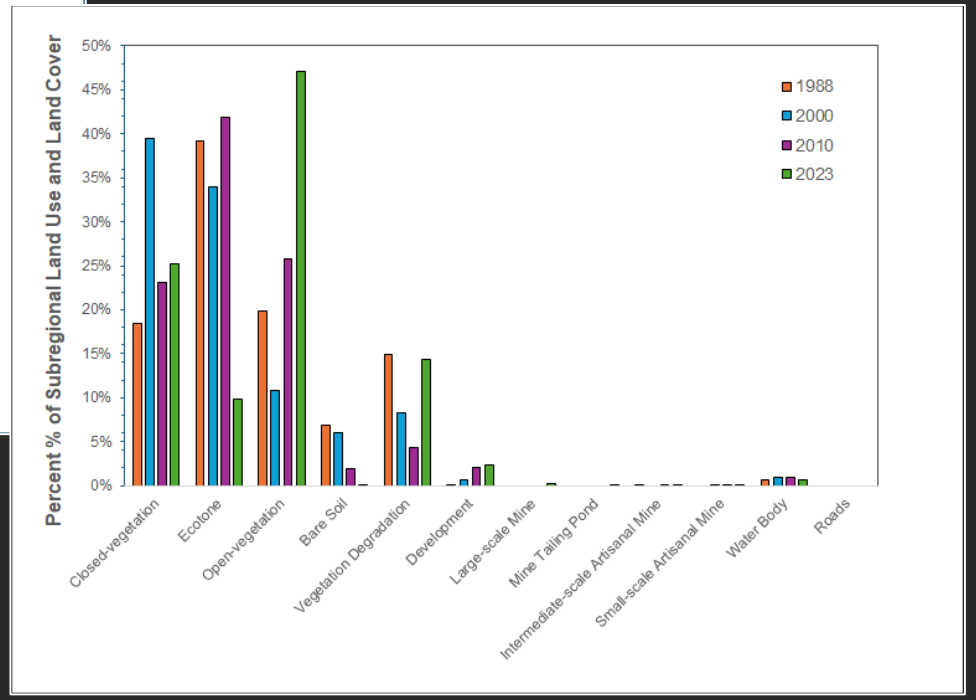
- Closed-vegetation
- Ecotone
- Open-vegetation
- Bare Soil
- Vegetation Degradation
- Development
- Large-scale Mine
- Mine Tailing Pond
- Intermediate-scale Artisanal Mine
- Small-scale Artisanal Mine
- Water Body
- Roads
- NoData



Results

eCognition Classification for Subregional Watershed





Results

eCognition Classification for Local Watershed (this is Fongoli)

1988

2000

2010

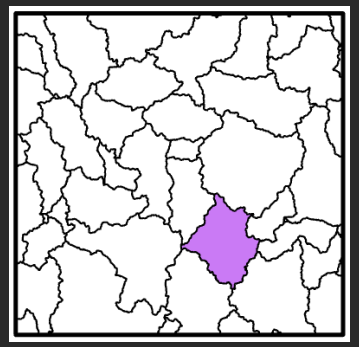
2023

157 **km²**

Towns

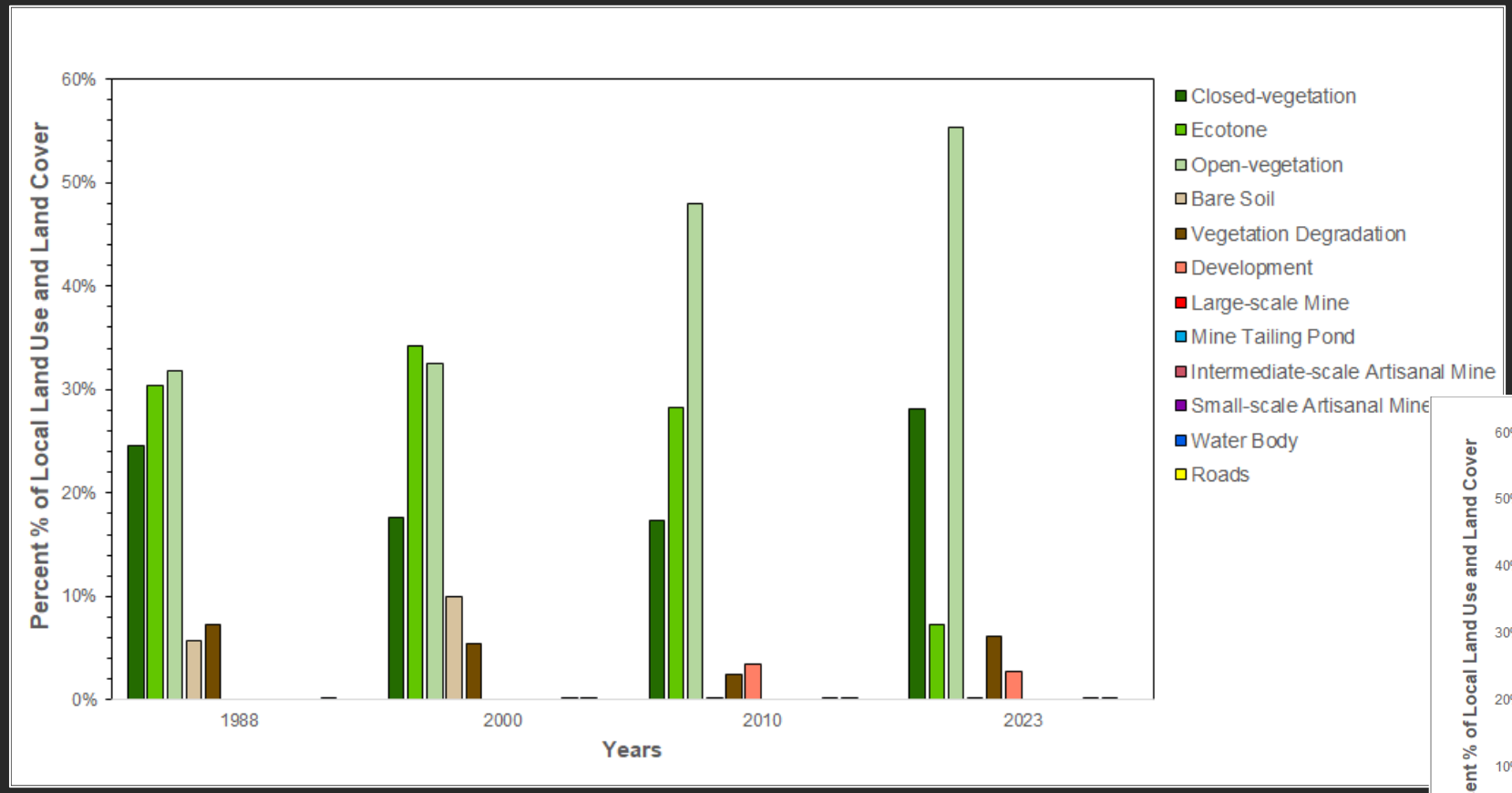
Class Names

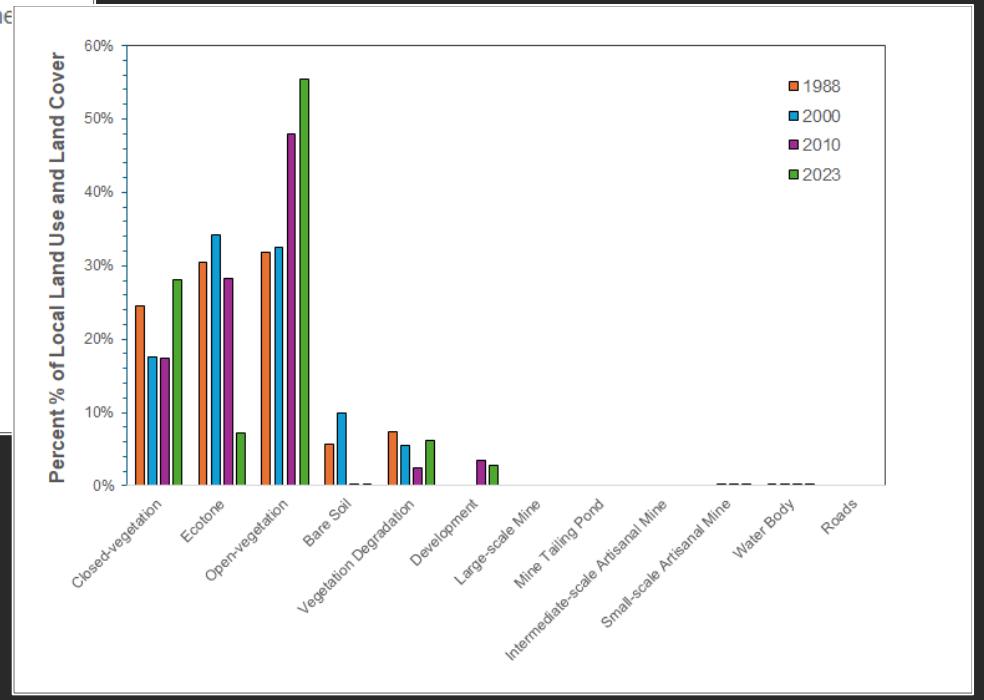
- Closed-vegetation
- Ecotone
- Open-vegetation
- Bare Soil
- Vegetation Degradation
- Development
- Large-scale Mine
- Mine Tailing Pond
- Intermediate-scale Artisanal Mine
- Small-scale Artisanal Mine
- Water Body
- Roads
- NoData



Results

eCognition Classification for Local Watershed





Results

ArcGIS Pro Accuracy Assessment for 2023

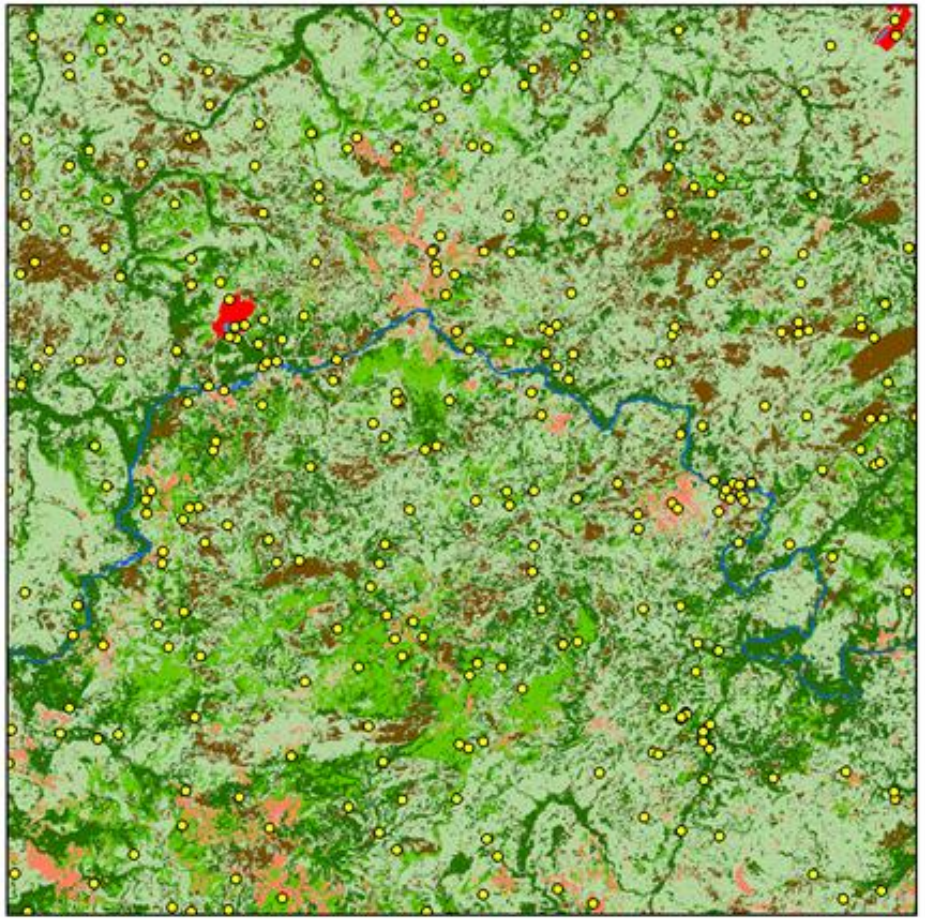
663 points using stratified random sampling and PlanetScope (4.77 meters) as the reference data for the same day and year.

Reference Data (User's Data)

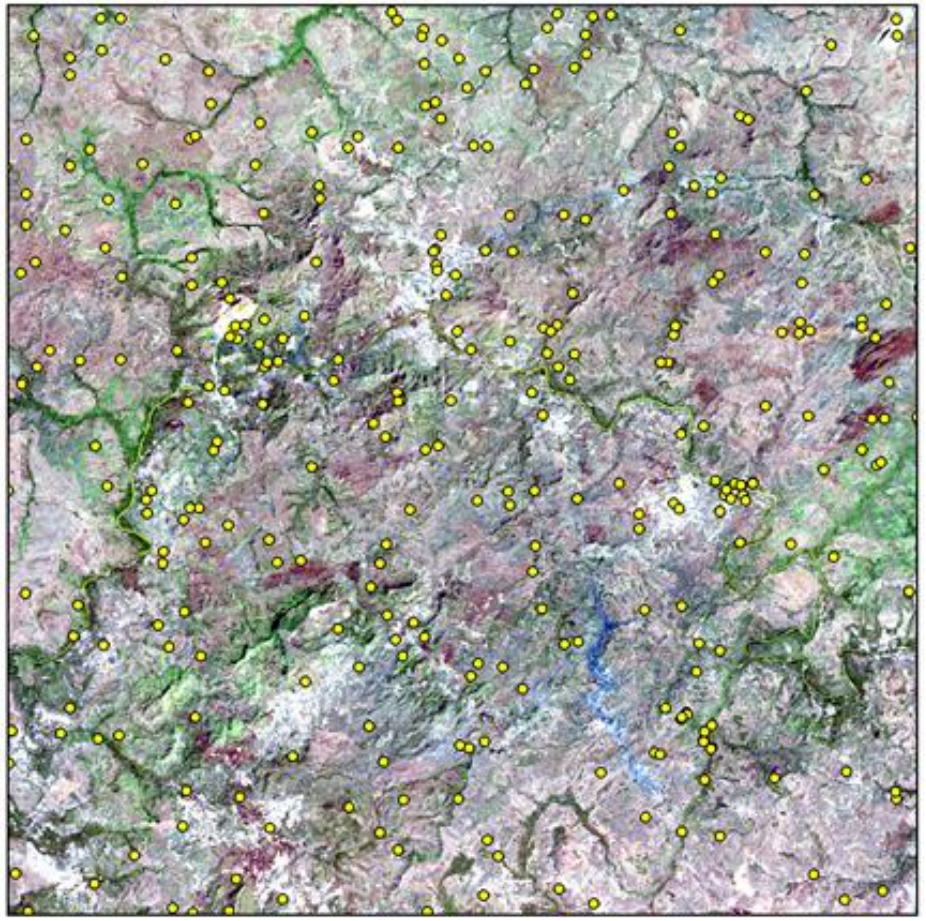
Map Classified Data (Producer's Data)	Class For 2023	Small-scale Artisanal Mine	Bare Soil	Vegetation Degradation	Closed-vegetation	Development	Ecotone	Intermediate-scale Artisanal Mine	Large-scale Mine	Mine Tailing Pond	Open-vegetation	Roads	Water Body	Total	User's Accuracy
	Small-scale Artisanal Mine	10	0	0	0	0	0	0	0	0	0	0	0	10	100%
	Bare Soil	0	10	0	0	0	0	0	0	0	0	0	0	10	100%
	Vegetation Degradation	0	1	74	1	0	1	0	0	0	3	0	0	80	93%
	Closed-vegetation	0	1	1	93	3	44	0	0	0	6	0	0	148	63%
	Development	0	3	0	1	11	0	0	0	0	0	0	0	15	73%
	Ecotone	0	4	0	8	2	38	0	0	0	2	0	0	54	70%
	Intermediate-scale Artisanal Mine	0	0	0	0	0	0	10	0	0	0	0	0	10	100%
	Large-scale Mine	0	0	0	0	0	0	0	10	0	0	0	0	10	100%
	Mine Tailing Pond	0	0	0	0	1	0	0	0	9	0	0	0	10	90%
	Open-vegetation	0	3	12	8	3	14	1	0	0	254	1	0	296	86%
	Roads	0	0	0	0	0	2	0	0	0	2	6	0	10	60%
	Water Body	0	0	1	1	0	0	0	0	0	0	0	8	10	80%
	Total	10	22	88	112	20	99	11	10	9	267	7	8	663	
	Producer's Accuracy	100%	45%	84%	83%	55%	38%	91%	100%	100%	95%	86%	100%		Overall Accuracy 80%
															Kappa 74%

Results

ArcGIS Pro Accuracy Assessment for 2023



Producer's Map



User's Map

The distribution of 663 random points on the producer's map (left) and the user's reference data (right).

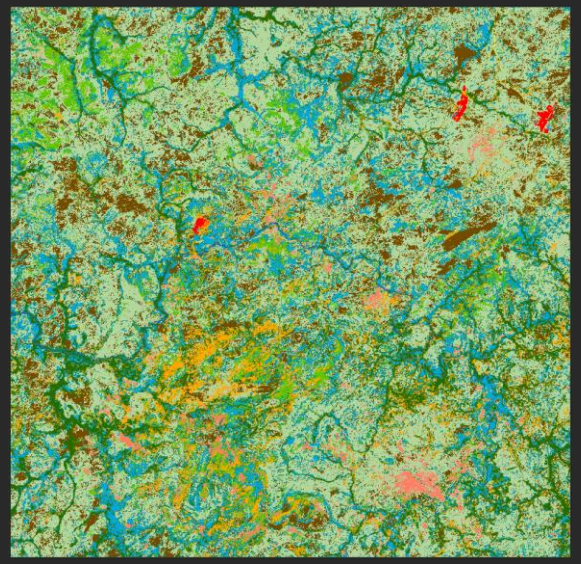
The producer's map is 10 meter resolution (Sentinel 2A).

The user's map is PlanetScope (NICFI) 4.77 meter resolution.

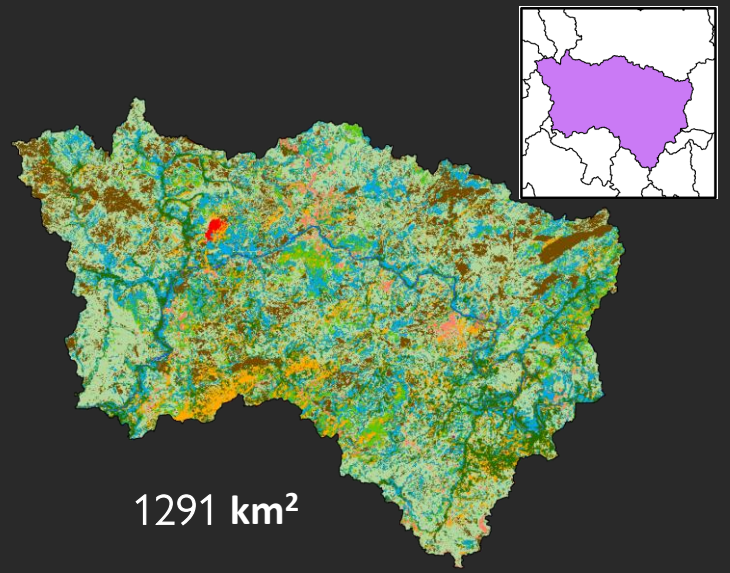
Both are on the same day, December 27, 2023.

Results

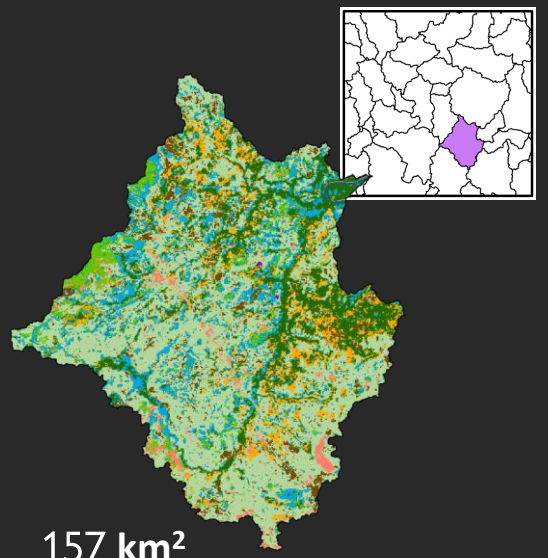
ArcGIS Pro Change Detection for 1988 to 2023



4409 **km²**



1291 **km²**



157 **km²**

Closed-vegetation Survey Scale	**A** No Change from 1988 to 2023 Color Code: Forest Green	**B** LULC from 1988 to Closed-vegetation in 2023 (Added) Color Code: Morea Blue	**C** Closed-vegetation from 1988 to LULC in 2023 (Subtracted) Color Code: Electron Gold	A + B = 2023 Total km²	A + C = 1988 Total km²	Closed-vegetation Gain/Loss from 1988 to 2023
AOI Change from 1988 to 2023	443	642	267	1,086	710	376
Subregional Change from 1988 to 2023	121	205	102	327	223	103
Local Change from 1988 to 2023	24	21	14	44	37	7

Change Designation

- Bare Soil->Closed-vegetation
- Closed-vegetation->Bare Soil
- Closed-vegetation->Closed-vegetation
- Closed-vegetation->Development
- Closed-vegetation->Ecotone
- Closed-vegetation->Intermediate-scale Artisanal Mine
- Closed-vegetation->Large-scale Mine
- Closed-vegetation->Mine Tailing Ponds
- Closed-vegetation->Open-vegetation
- Closed-vegetation->Roads
- Closed-vegetation->Small-scale Artisanal Mine
- Closed-vegetation->Water Body
- Ecotone->Closed-vegetation
- Intermediate-Scale Artisanal Mine->Closed-vegetation
- Open-vegetation->Closed-vegetation
- Vegetation Degradation->Closed-vegetation
- Water Body->Closed-vegetation

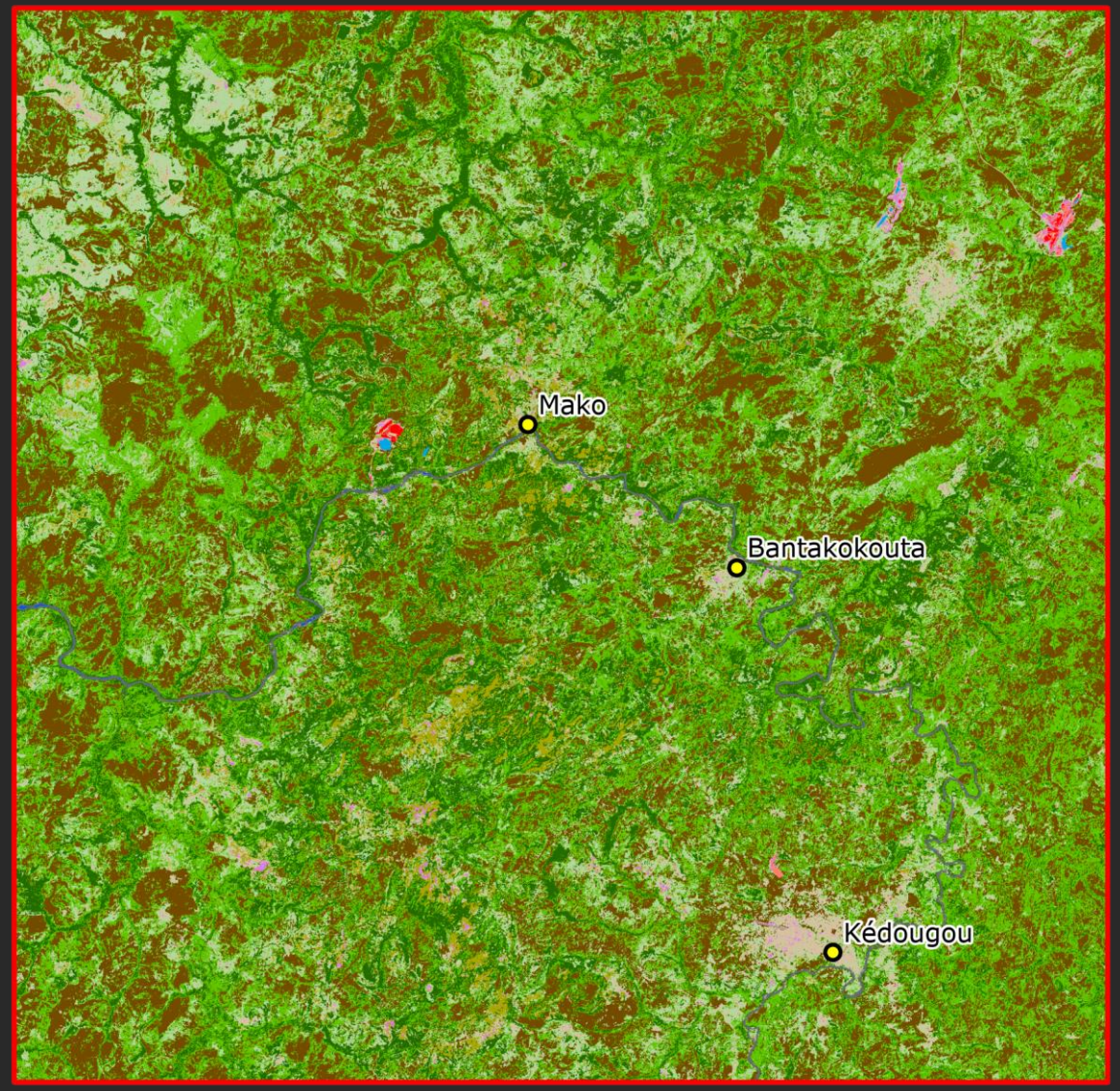
Results

ArcGIS Pro Presence-only Prediction for 2023

- AUC = 0.8242, Omission Rate = 0.2748
- Applied 296 opportunistic chimpanzee nesting points, and the model used 262, and 190 classified as presence.
- Used the 2023 classified imagery, along with the 3 different soils tables, elevation, aspect, slope, the stream network, and roads from OpenStreetMap.
- It is interesting that it started to include the gallery forests surrounding the nest point cluster. If the points were distributed throughout the area, it may have shown more habitat.

Results

Extra: PlanetScope Classification



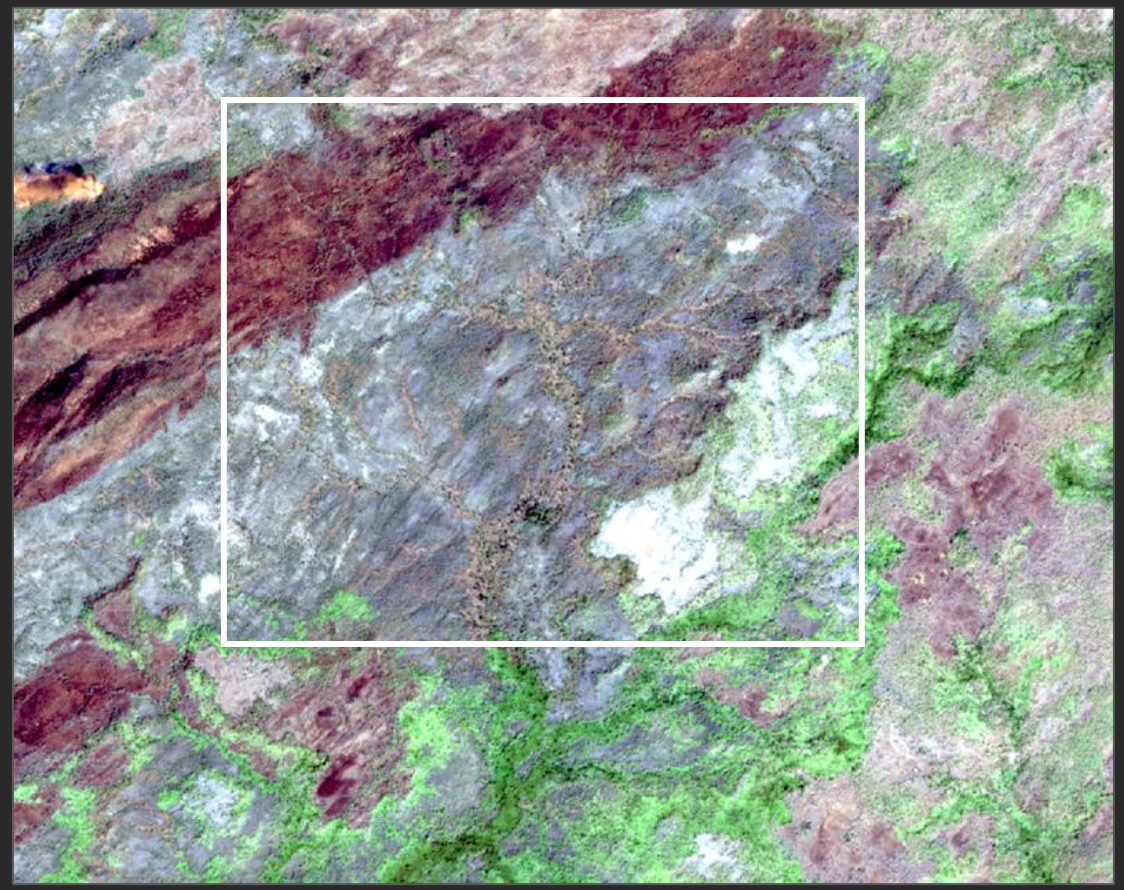
- The resolution for PlanetScope is 4.77 meters, and it took about 4 hours to run the unsupervised classification.
- But there is a lot more detail in the classification.

PlanetScope 2023 Classification

- Closed-vegetation
- Ecotone 1
- Ecotone 2
- Open-vegetation
- Bare Soil
- Vegetation Degradation
- Built-up/Bare
- Erosion/Bare
- Large-scale Mine
- Mine Tailing Pond
- Water Body

Senegal Land Cover Classes
Agriculture
Agriculture in shallows and recession
Bare soil
Bowe
Forest
Gallery forest and riparian forest
Irrigated agriculture
Mangrove
Open Mine
Plantation
Rocky land
Sahelian short grass savanna
Sandy Area
Savanna
Settlements
Steppe
Swamp Forest
Thicket
Water Bodies
Wetland - floodplain
Woodland

The new extension of the Sabodala mine north of the area of interest in this project. The picture depicts the mining infrastructure cutting through a gallery forest in two locations and the position of the mine tailing ponds next to the gallery forest watercourse (Photo credit to Google Earth).



PlanetScope (4.77 meters), December 27, 2023, natural bands (RGB 321). Showing an unhealthy, likely burned, or degrading gallery forest branch.

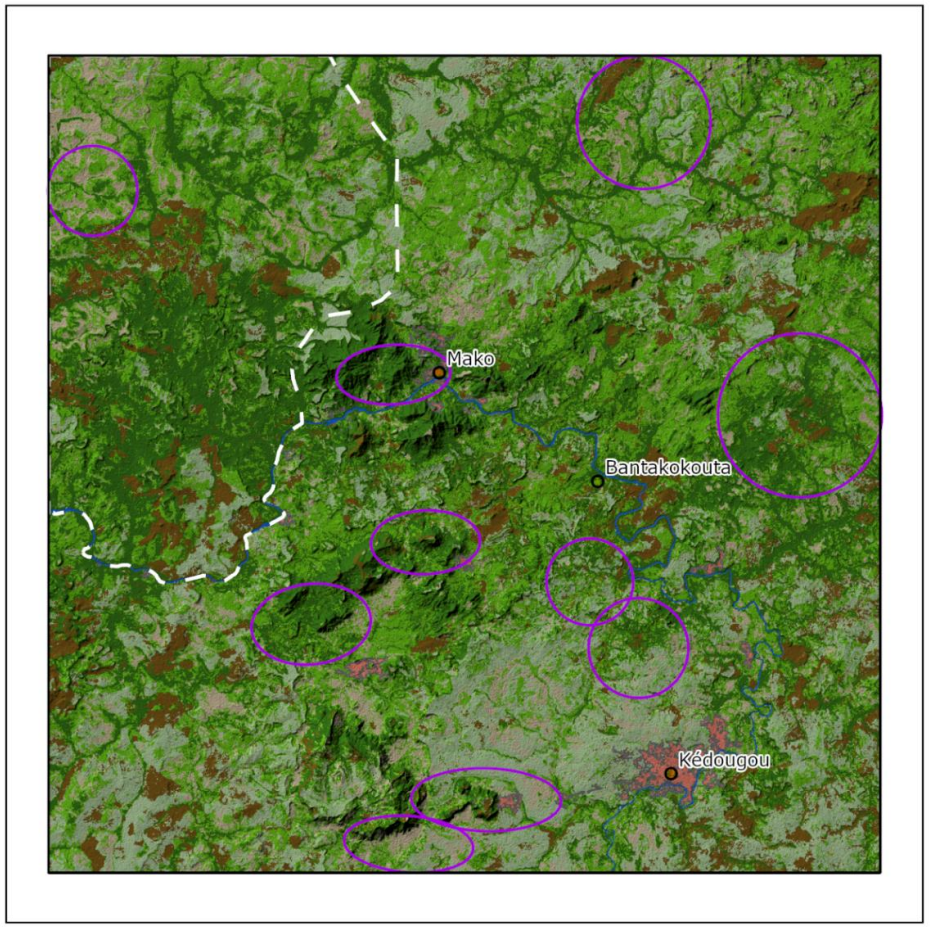
0 5 10 20 Kilometers

1988 Classification

Class Names

- Closed-vegetation
- Ecotone
- Open-vegetation
- Bare Soil
- Vegetation Degradation
- Development
- Intermediate-scale Mine
- Water Body
- Towns
- Area of Interest
- Niokolo-Koba National Park
- 2012 Confirmed Chimpanzee Groups

Constructed by
Claudette Sandoval-Green
28 April 2024
30 meters, Landsat 5 TM, C2L2
Unsupervised Classification
Trimble eCognition
Kedougou, Senegal
WGS 1984 UTM Zone 28 N



0 5 10 20 Kilometers

2000 Classification

Class Names

- Closed-vegetation
- Ecotone
- Open-vegetation
- Bare Soil
- Vegetation Degradation
- Development
- Small-scale Artisanal Mine
- Water Body
- Towns
- Area of Interest
- Niokolo-Koba National Park
- 2012 Confirmed Chimpanzee Groups

Constructed by
Claudette Sandoval-Green
28 April 2024
15 meters, Landsat 7 ETM, C2L2
Unsupervised Classification
Trimble eCognition
Kedougou, Senegal
WGS 1984 UTM Zone 28 N

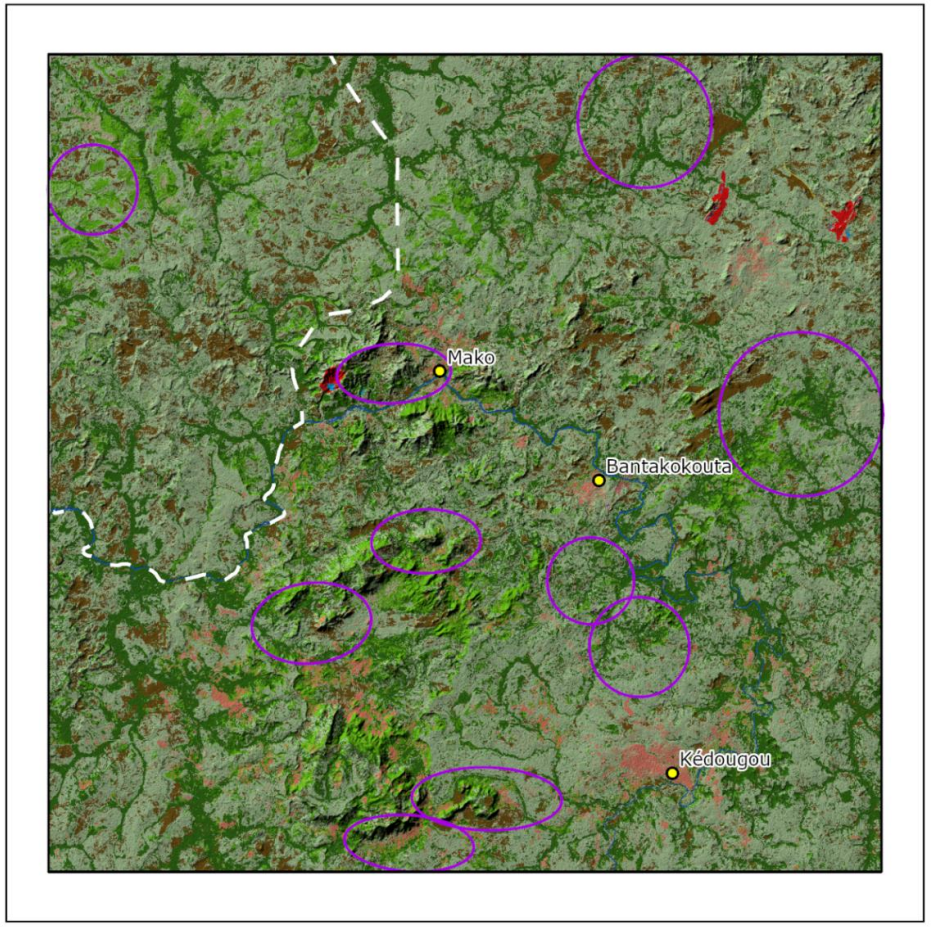
0 5 10 20 Kilometers

2010 Classification

Class Names

- Closed-vegetation
- Ecotone
- Open-vegetation
- Bare Soil
- Vegetation Degradation
- Development
- Intermediate-scale Artisanal Mine
- Small-scale Artisanal Mine
- Water Bodies
- Towns
- Area of Interest
- Niokolo-Koba National Park
- 2012 Confirmed Chimpanzee Groups

Constructed by
Claudette Sandoval-Green
28 April 2024
30 meters, Landsat 5 TM, C2L2
Unsupervised Classification
Trimble eCognition
Kedougou, Senegal
WGS 1984 UTM Zone 28 N



0 5 10 20 Kilometers

2023 Classification

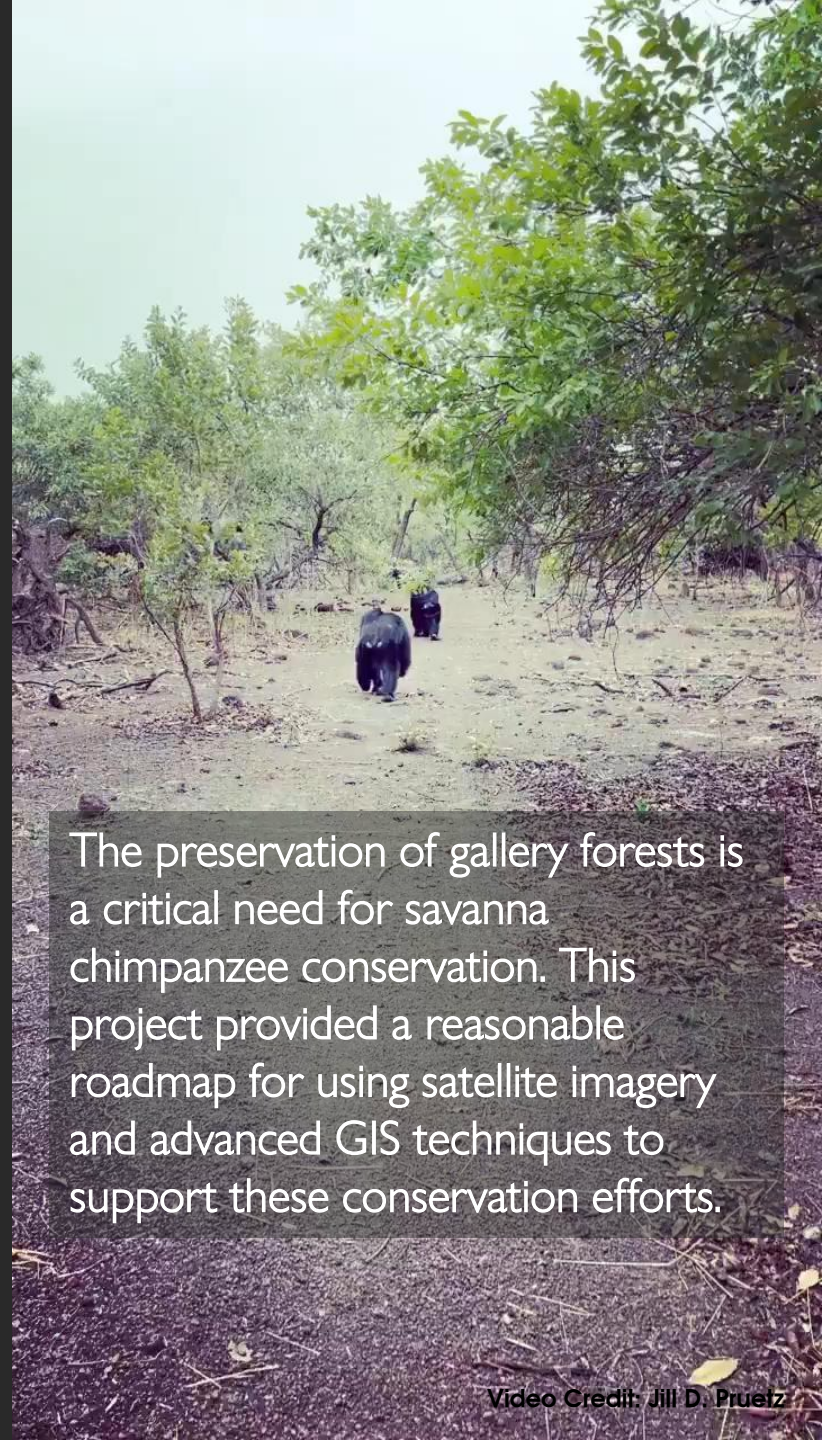
Class Names

- Closed-vegetation
- Ecotone
- Open-vegetation
- Bare Soil
- Vegetation Degradation
- Development
- Large-scale Mine
- Mine Tailing Pond
- Intermediate-scale Artisanal Mine
- Small-scale Artisanal Mine
- Water Body
- Roads
- Towns
- Area of Interest
- Niokolo-Koba National Park
- 2012 Confirmed Chimpanzee Groups

Constructed by
Claudette Sandoval-Green
28 April 2024
10 meters, Sentinel 2A
Unsupervised Classification
Trimble eCognition
Kedougou, Senegal
WGS 1984 UTM Zone 28 N

Lessons Learned

- It's important to remember that all chimpanzees, including the savanna chimpanzee, are dependent on trees for their habitat. This fundamental fact should guide research and conservation efforts.
- The unsupervised classification results were very encouraging. The gallery forests were always the most accessible and most robust cluster to classify. Ecotone is harder.
- Classification should be a two-person job, at the very least, that includes the remote sensing analyst and a partner with intimate knowledge of the area.
- eCognition is a powerful tool. I suspect the PCA is doing the heavy lifting in the data fusion.
- The data fusion works best when the products are made from the same sensor. Other eCognition algorithms will fuse raster and vector data, but not the supervised classification algorithm.
- In the future, I recommend building your own indices outside of eCognition's collection of algorithms. Their NDWI uses the green band to highlight waterbodies but the green is also sensitive to built-up land like burn scars. This can conflict with NBR and NDBI.



The preservation of gallery forests is a critical need for savanna chimpanzee conservation. This project provided a reasonable roadmap for using satellite imagery and advanced GIS techniques to support these conservation efforts.

Video Credit: Jill D. Pruetz

References and Resources

Boyer Ontl, K. M. (2017). Chimpanzees in the Island Of Gold: Impacts of artisanal small-scale gold mining on chimpanzees (Pan troglodytes verus) in Fongoli, Senegal (Doctoral dissertation). Ames, Iowa: Iowa State University.

Diallo, D., Ndiaye, P. I., Badji, L., & Pruetz, D. J. (2024). Savannah chimpanzee (Pan troglodytes verus) nesting behavior in the unprotected area of Tikankali near to a mining exploitation and the Niokolo Koba National Park in Senegal. *Frontiers in Ecology and Evolution, 12*(1228373).

Ndiaye, Y. H., Ndiaye, P. I., Lindshield, S. M., & Pruetz, J. D. (2024). Updating Chimpanzee Nesting Data at Mount Assirik (Niokolo Koba National Park, Senegal: Implications for Conservation. *Animals, 14*(553).

Gold Price Tracker: https://goldbroker.com/widget/historical/XAU?height=500&currency=USD

Google Earth Timelapse for Kedougou, Senegal Mining and Development from 1984 to 2022: https://byclaudette.com/MGIS_assets/Timelapse.html

Mako Gold Mine: 12.85715,-12.3813
Bantakokouta Intermediate-scale Artisanal Mines: 12.76221,-12.22899
New Endeavor Mine: 12.964235, -12.098134
Sabodala Gold Mine: 13.197605,-12.114124
Copy and paste the coordinates into the search field, click Enter, set the speed to 1x and then press Play.

MODIS LST Tutorial:
MODIS Land Surface Temperature (LST) Annual Timeseries using Earth Engine by Spatial eLearning.
https://youtu.be/0ASsr6Hj6NU?si=VHDrmLcHqpeRz1RV

CHIRPS Precipitation Data Tutorial:
Download Climate Data (Rainfall) from 1981-2022 using Earth Engine API by Spatial eLearning.
https://youtu.be/TcpG6SbUiYU?si=IFV7KzxpfBJn7hTX

Questions?

Thank you!

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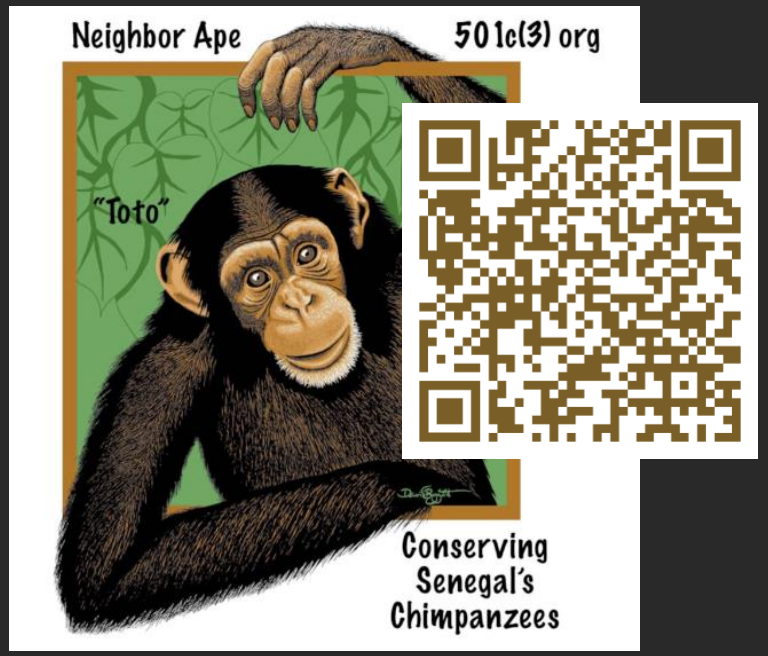
GEE Code and Links



Grassroots Funding

Video Credit: Jill D. Pruetz