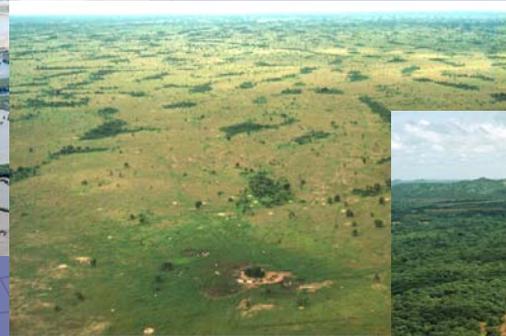




# Monitoring and Assessment of Land Use and Land Cover in West Africa



Training Center  
U.S. Geological Survey  
Center for Earth Resources  
Observation and Science (EROS)  
Sioux Falls, South Dakota, USA



# Monitoring and Assessment of Land Use/Land Cover in West Africa

Gray Tappan – SAIC / USGS EROS



Bamako , Mali

6 - 17 February, 2006

A satellite mosaic of West Africa, showing a gradient from arid, yellowish-brown terrain in the north to lush green vegetation in the south. The text is overlaid on the central part of the image.

# **Suivi et Evaluation de l'Occupation du Sol en Afrique de l'Ouest**

---

## **Monitoring and Assessment of Land Use/Land Cover in West Africa**

Mosaïque MODIS:  
Afrique du Nord et Ouest

# Presentation Outline

- Land Use and Land Cover Definitions
- Mapping LULC in Senegal
- Monitoring LULC Trends in Senegal
- LULC Monitoring at the Regional Scale
- Some West Africa LULC Trends
- Examples of Landsat imagery across the Region



## **Assumptions & General Objectives**

- **Natural resources – land, soils, vegetation, wildlife and water – are central to the livelihoods of the majority of people**
- **Natural resources represent capital – their condition is important**
- **Natural resources are constantly changing**
- **Human livelihoods are closely linked to environmental sustainability**
- **Natural resources are a key to rural development**
- **Monitoring the distribution and condition of natural resources is essential for good management and planning**

## Land Use and Land Cover: Definitions

- **Land cover:** refers to the attributes of a part of the Earth's land surface, including biota, soil, topography, water, and human structures
- **Land use:** refers to the purposes for which humans exploit the land cover

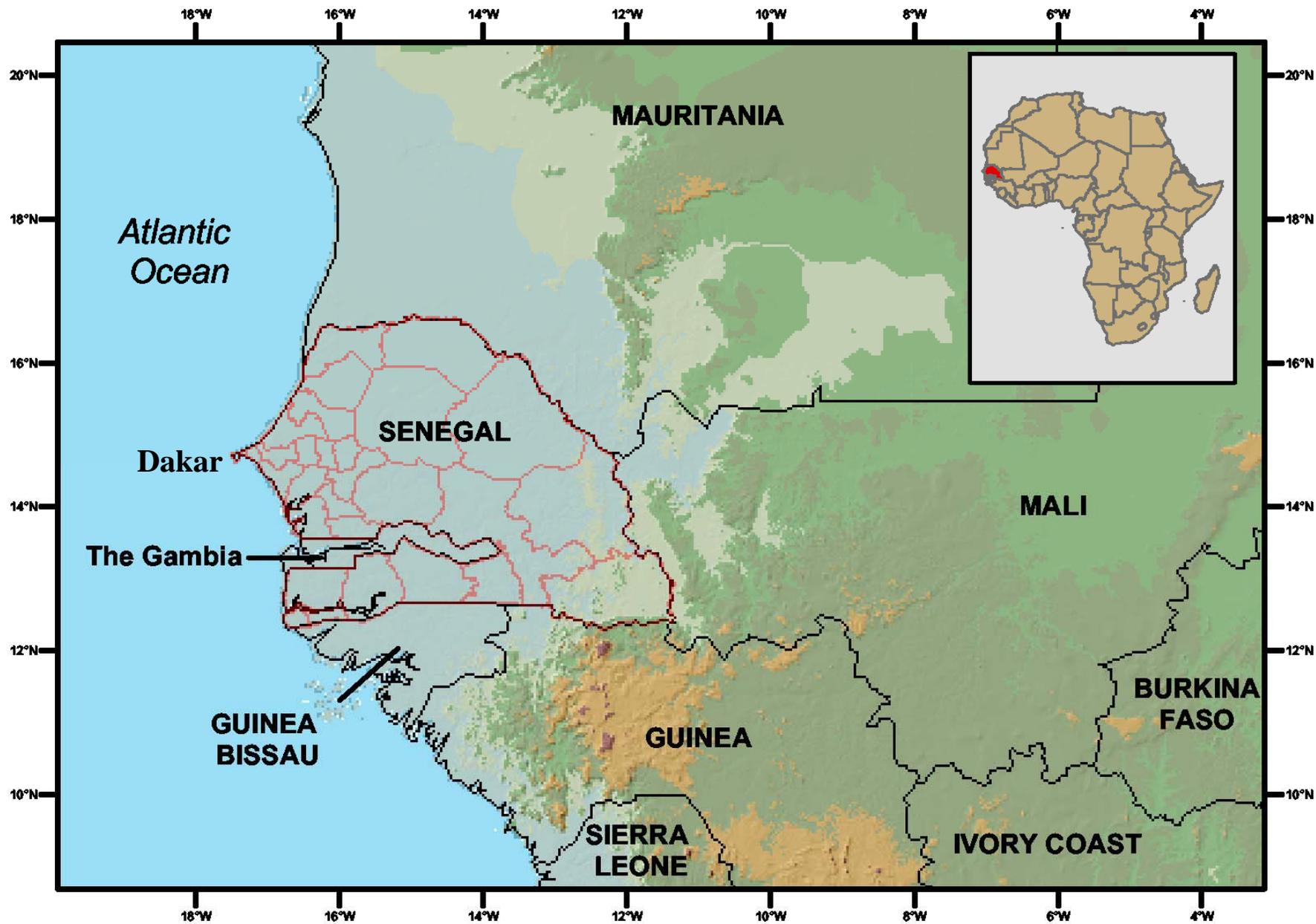
# Why examine land use and land cover dynamics?

## A perspective from the National Research Council:

An interdisciplinary committee of the NRC recently identified the most important environmental research challenges over the next 20 to 30 years. One of eight grand challenges is Land Use Dynamics, which calls for the development of a comprehensive understanding of changes in land use and land cover that are critical to biogeochemical cycling, ecosystem functioning and services, and human welfare. The report concluded that “... improved information on and understanding of land use and land cover dynamics are essential for society to respond effectively to environmental changes and to manage human impacts on environmental systems” (NRC, 2001).

# Mapping Land Use and Land Cover in Senegal

- Project timeframe: 1982 - 1985
- Funding: USAID / Senegal
- Implementation: SDSU and GOS
- Natural Resource Inventory of Senegal
- National Plan for Land Use and Development
- Multi-thematic maps; single point in time
- One of the early Landsat projects in Africa



# Natural Resource Diversity



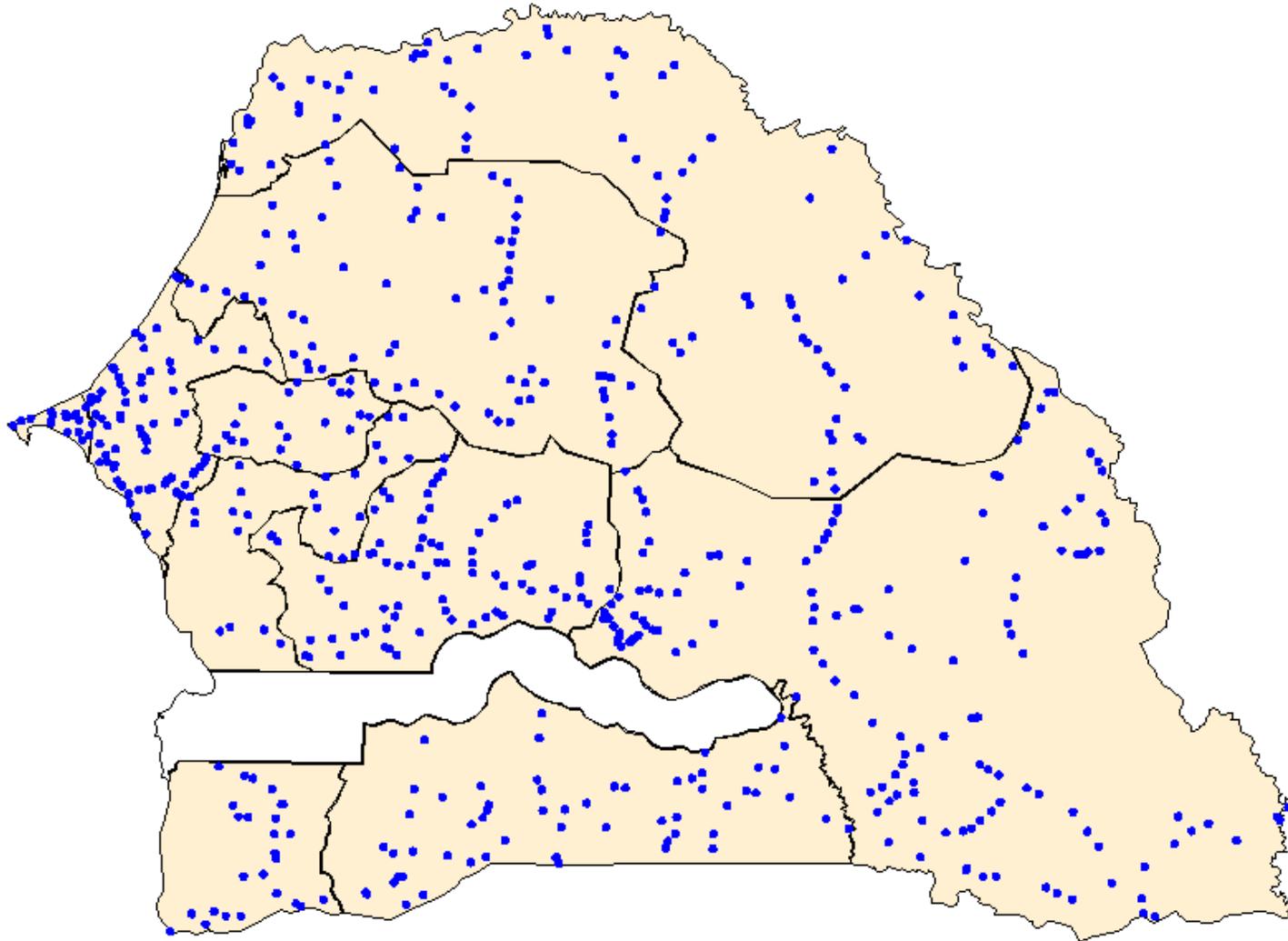
Field Data Collection:  
1982 – 1984



*Dicrostachys  
glomerata*

# Field Sites Established 1982-84

## Field Data Collection Sites



# Vegetation Inventory in an Agricultural Parkland (Site 57)

## Woody Species at Site 57 – January 1983

*Combretum micranthum*

*Adansonia digitata*

*Acacia albida*

*Acacia raddiana*

*Guiera senegalensis*

*Maytenus senegalensis*

*Balanites aegyptiaca*

*Tamarindus indica*

*Diospyros mespiliformis*



# Vegetation Characteristics at Site 403 (Open Woodland)

## Woody Species at Site 403 – March 1984

*Combretum micranthum*

*Combretum nigricans*

*Combretum glutinosum*

*Bombax costatum*

*Adansonia digitata*

*Acacia macrostachya*

*Acacia polyacantha*

*Gardenia ternifolia*

*Grewia bicolor*

*Lannea acida*

*Lonchocarpus laxiflorus*

*Sclerocarya birrea*

*Sterculia setigera*

*Strychnos spinosa*

*Feretia apodanthera*

*Boscia angustifolia*

*Guiera senegalensis*

*Pterocarpus lucens*



## Landscapes of West Africa: Dry Season



## Landscapes of West Africa: Wet Season



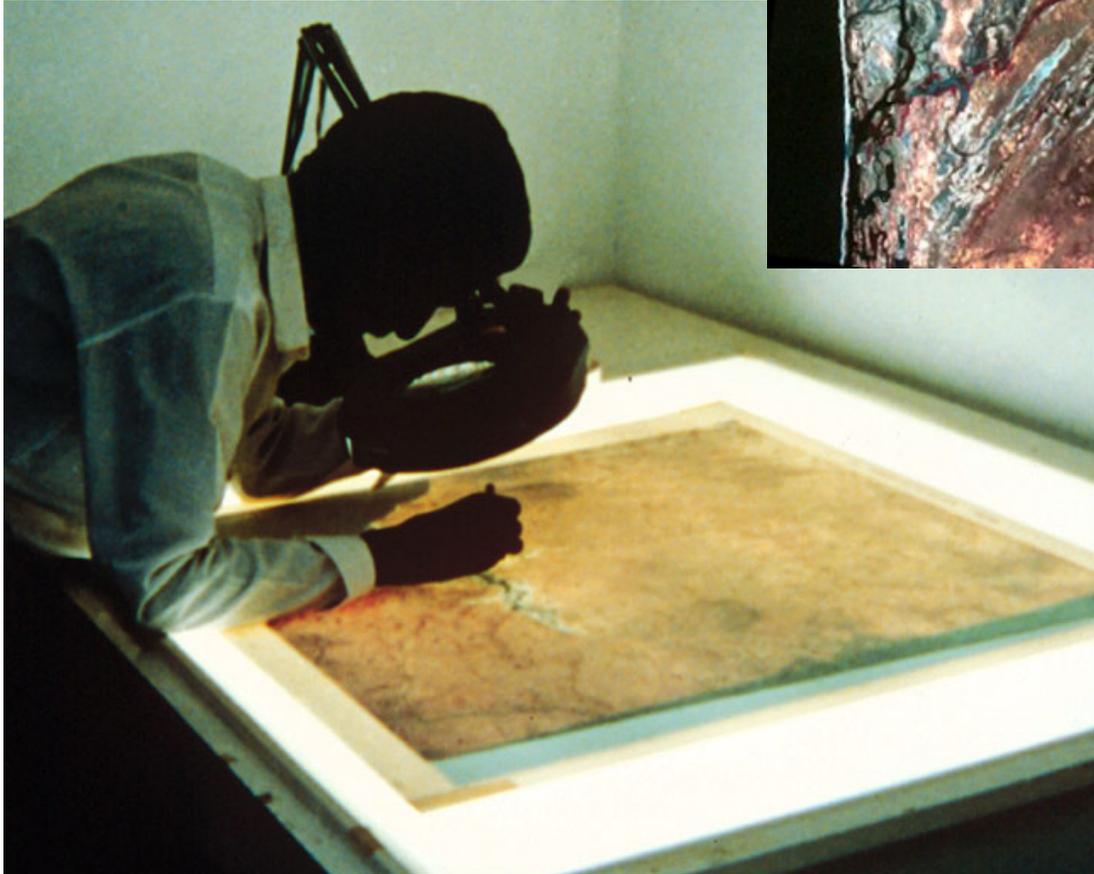
# Dry Season



# Wet Season



# Interpretation of Landsat Images



## Mangroves, Protected areas, and Cropland (Landsat)

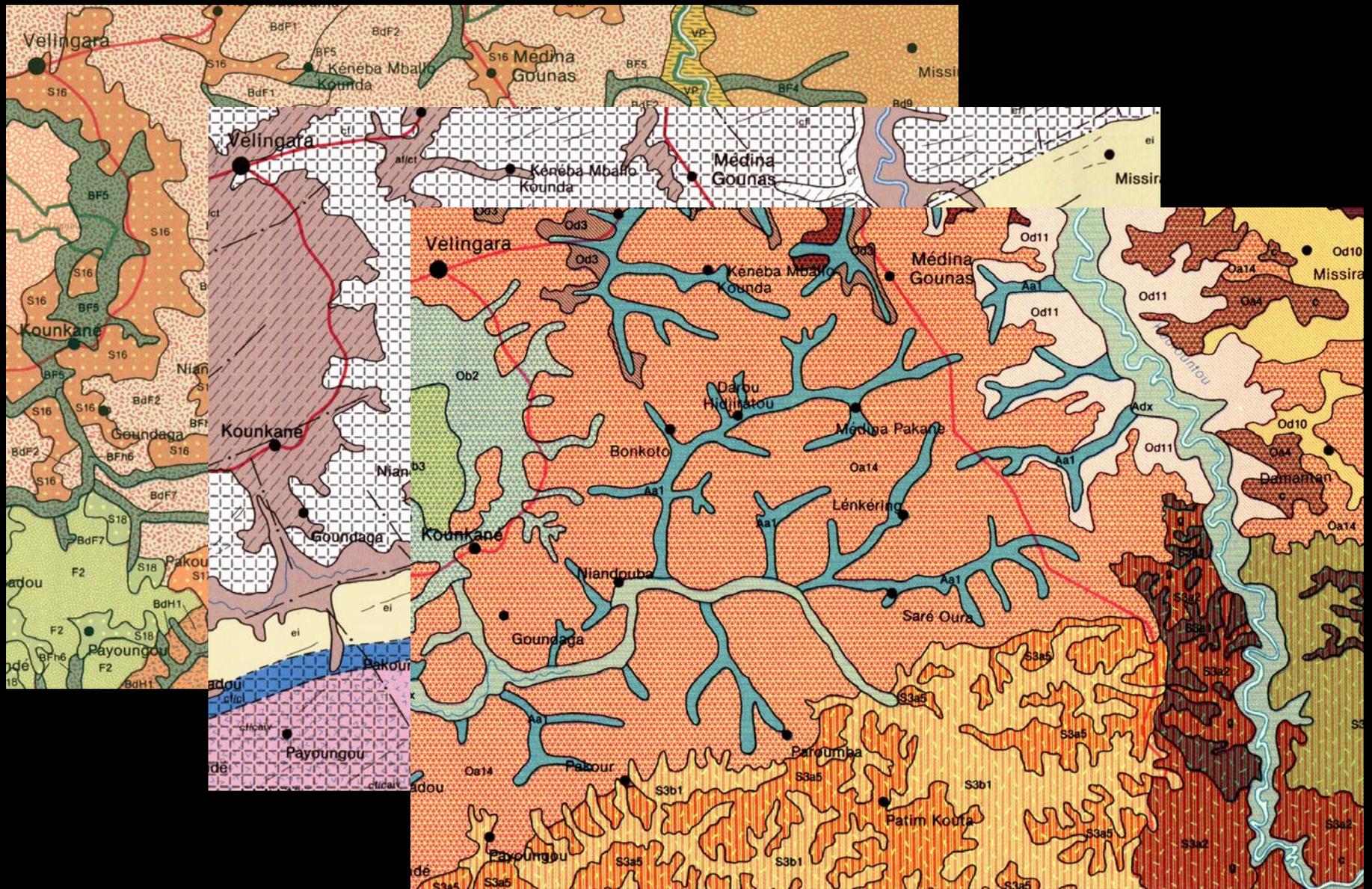


## Protected Areas and Cropland (Aerial perspective)



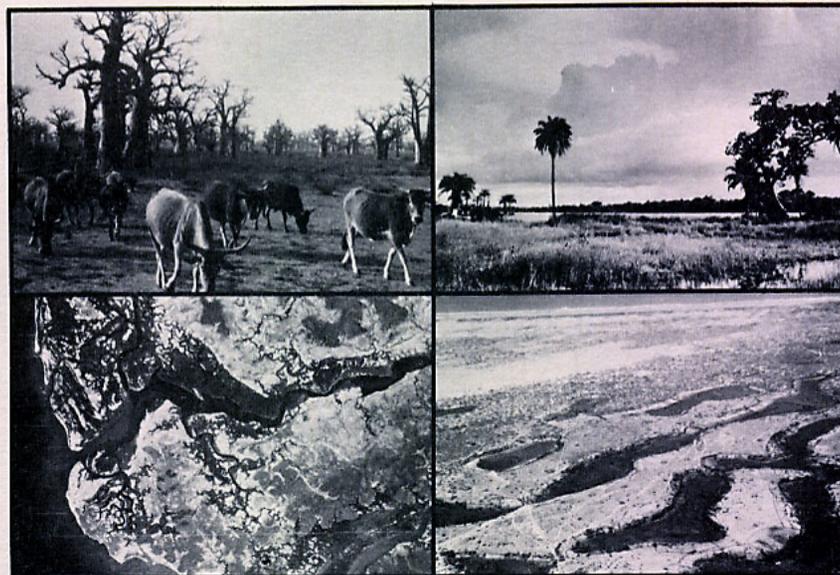


# Cartes Thématiques du Sénégal, 1/500.000



CARTOGRAPHIE ET TELEDETECTION  
DES RESSOURCES DE LA REPUBLIQUE DU SENEGAL  
ETUDE DE LA GEOLOGIE, DE L'HYDROLOGIE, DES SOLS,  
DE LA VEGETATION ET DES POTENTIELS D'UTILISATION DES SOLS

SDSU-RSI-86-01



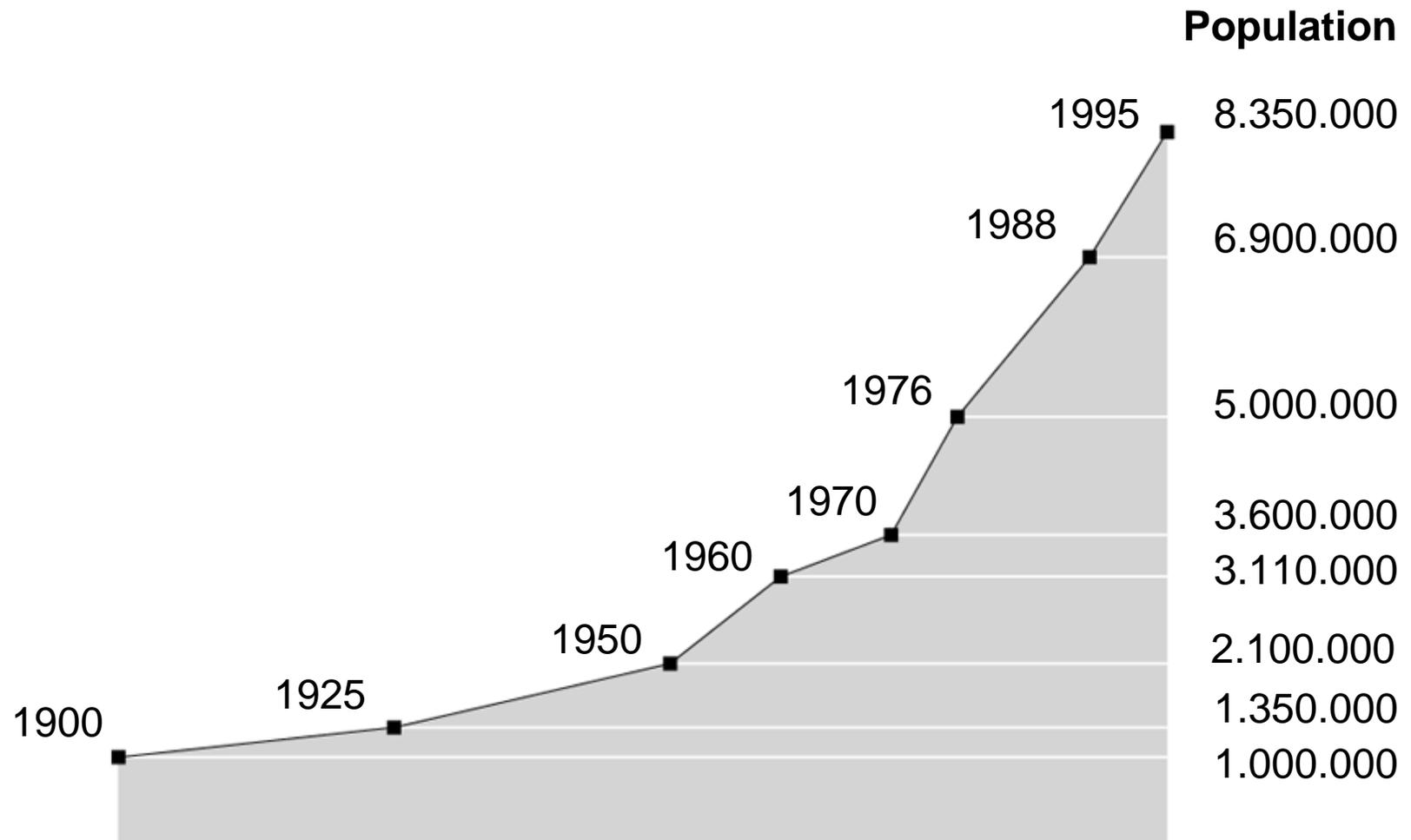
DIRECTION DE  
L'AMENAGEMENT  
DU TERRITOIRE



Agency for  
International  
Development

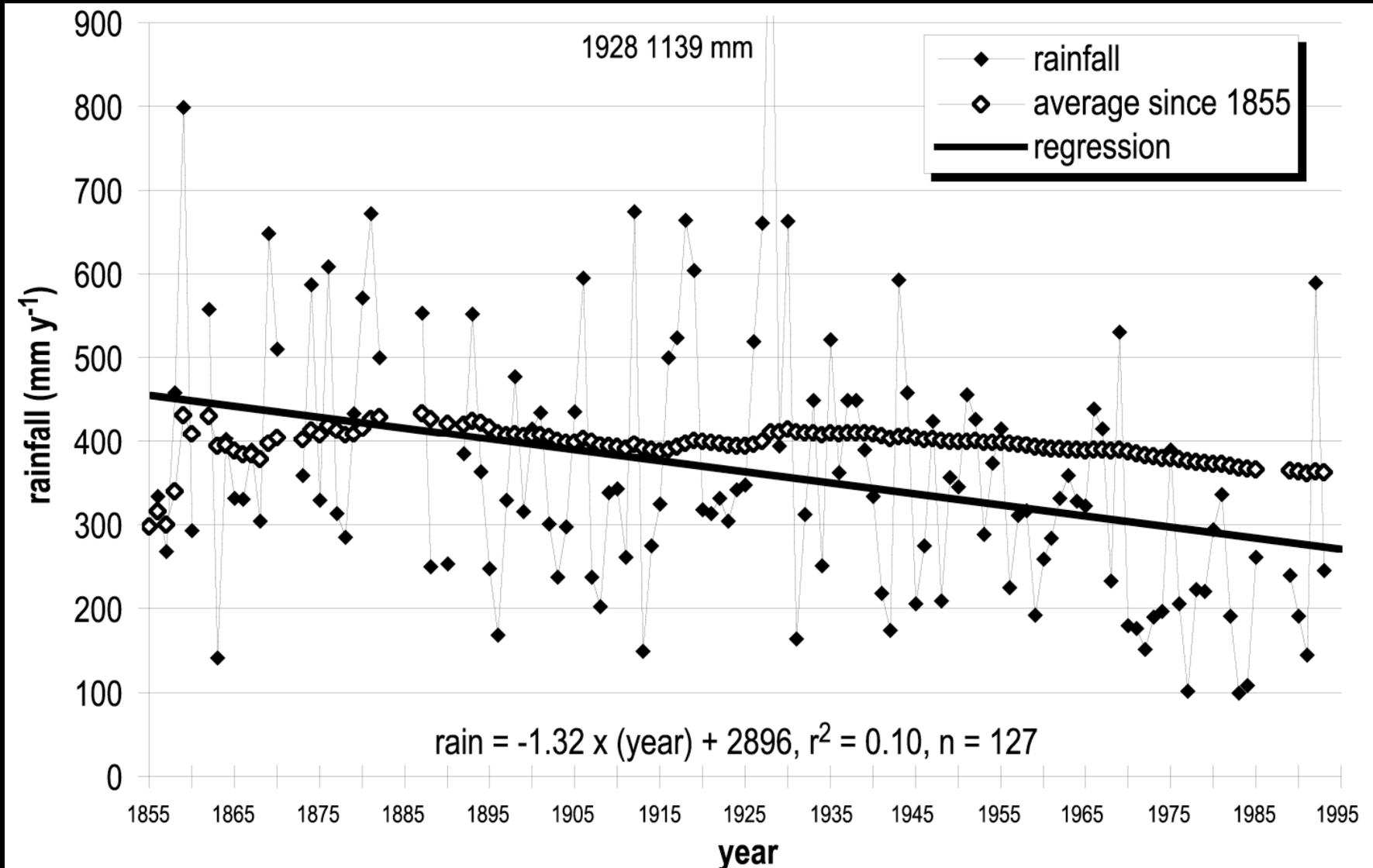
**RSI** REMOTE SENSING INSTITUTE

# Population Growth of Senegal: 1900-1995



# Rainfall at St. Louis, Sénégal 1855-1993

Sources: Aubréville (1938); Direction de la Météorologie Nationale, Dakar, Sénégal



# Changes in Land Use / Land Cover

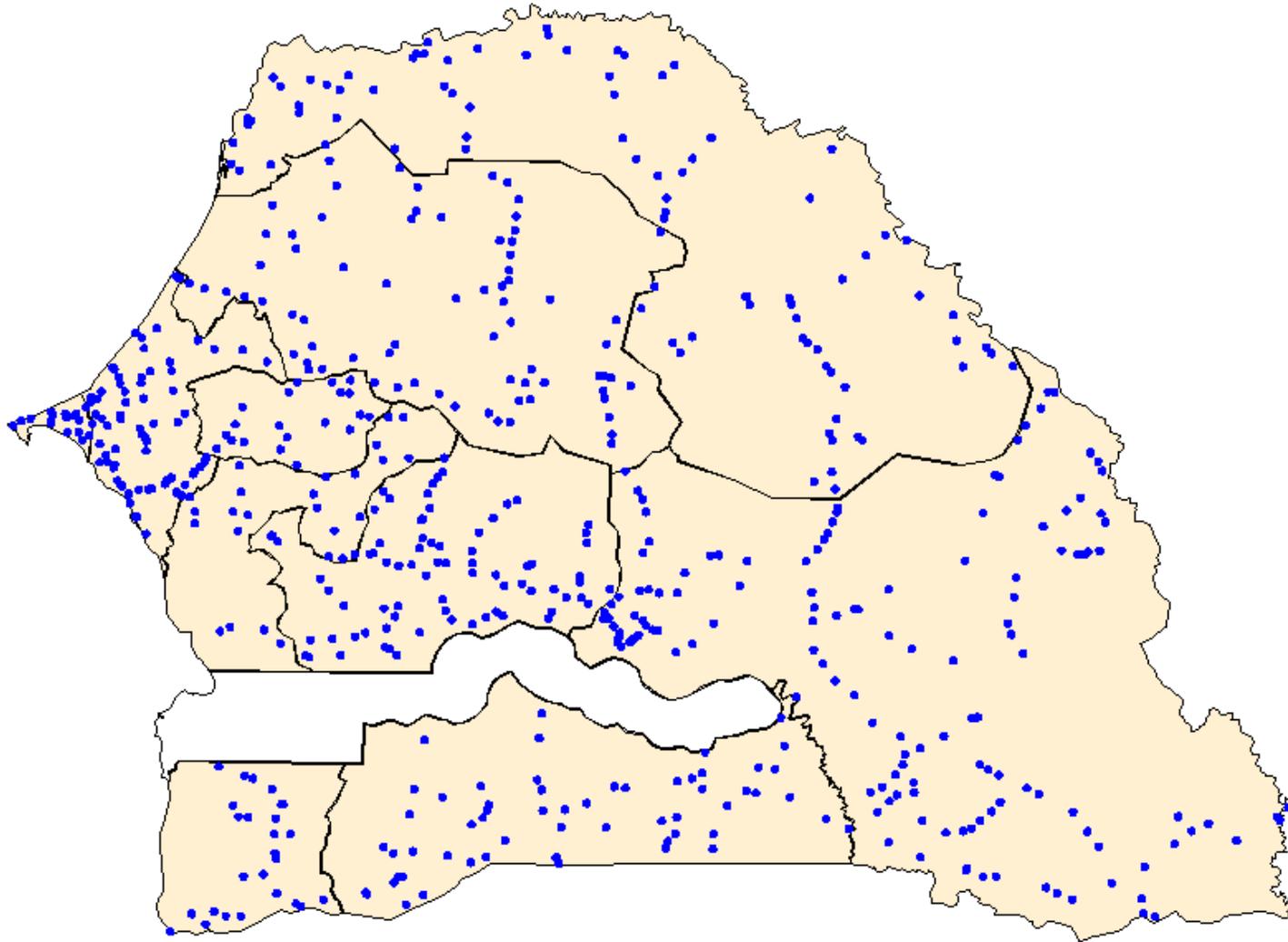
- **How are the natural and human landscapes changing?**
- **What are the rates and magnitudes of change?**
- **What are the causes and mechanisms of change?**
- **What impacts are the changes having?**

# Mapping Land Use and Land Cover in Senegal

- Project timeframe: 1982 - 1985
- Funding: USAID / Senegal
- Implementation: SDSU and GOS
- Natural Resource Inventory of Senegal
- National Plan for Land Use and Development
- Multi-thematic maps; single point in time
- One of the early Landsat projects in Africa

# Revisit Sites 10 to 15 Years Later

## Field Data Collection Sites

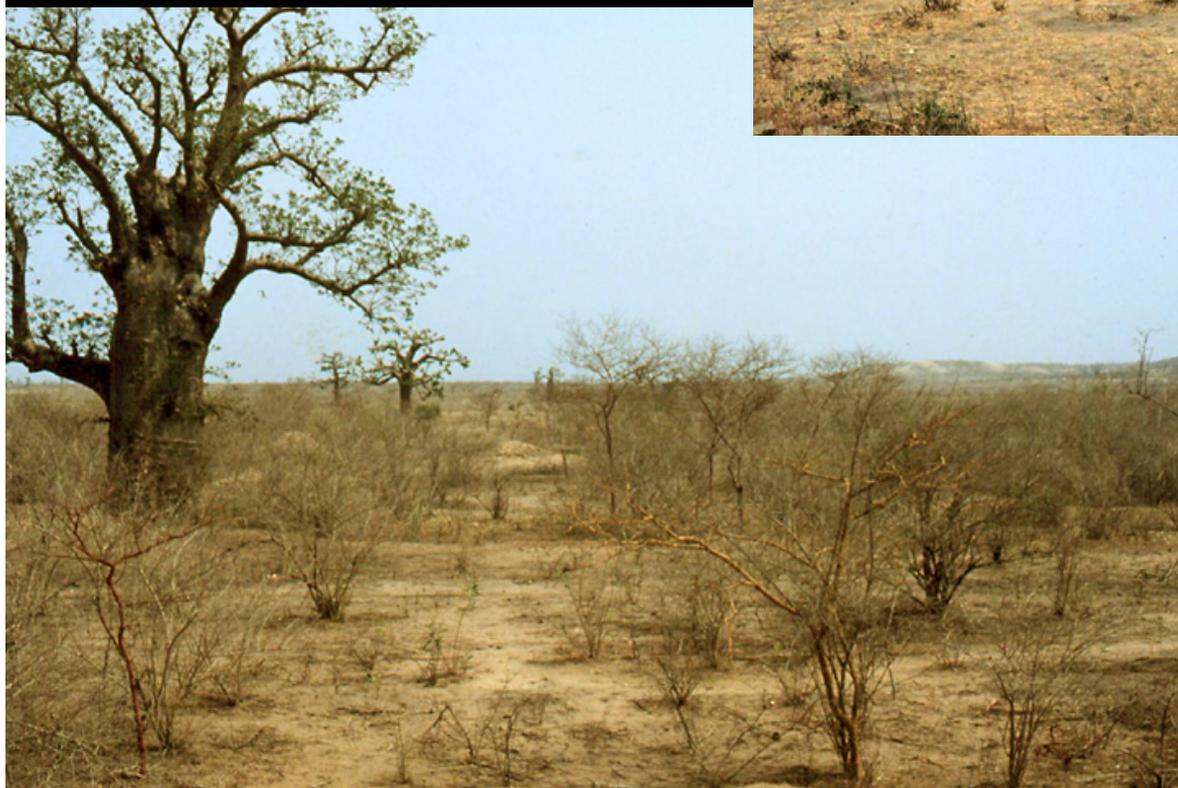


# Field Data Collection



# Revisit Ground Sites to Study Changes in Natural Resources

1983



1996

Landscape Dynamics:  
Human and livestock  
pressure (site 314)

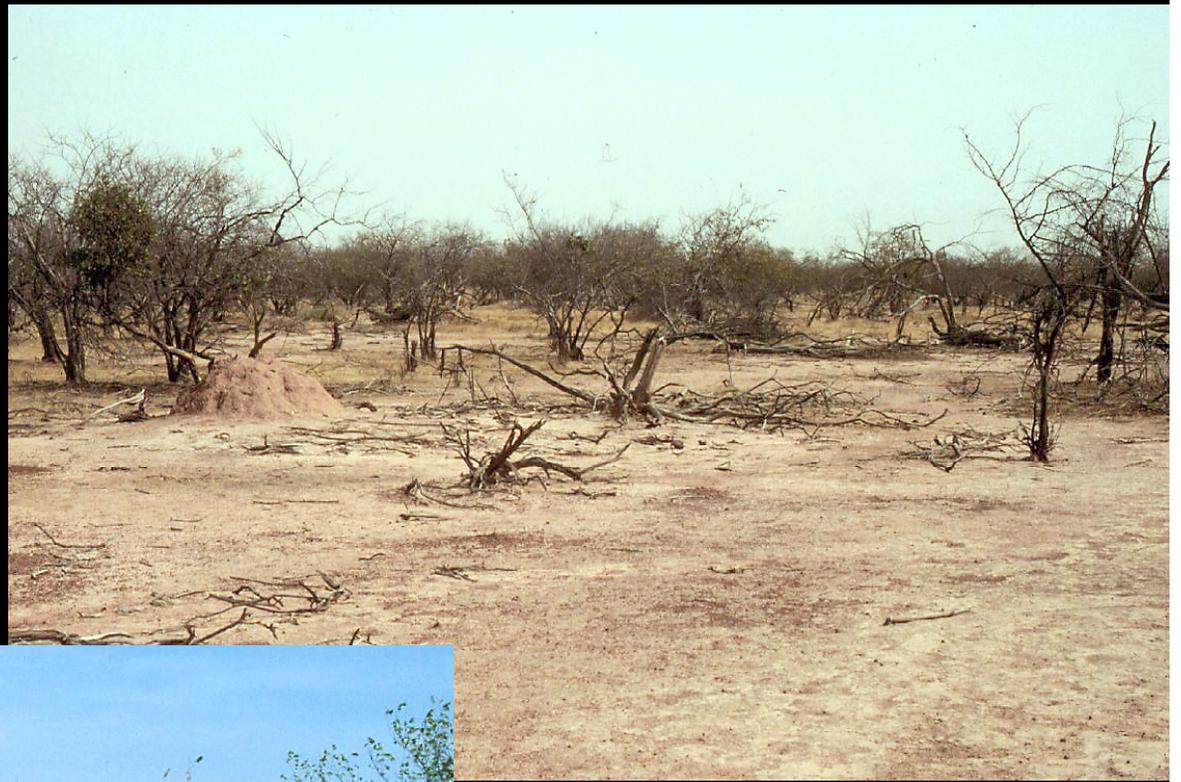
1983



1994

Landscape Dynamics:  
Impact of Declining  
Rainfall and Drought  
(Site 355)

1983



1996

# Landscape Dynamics: Decline in Biodiversity (Site 403)

## Woody Species at Site 403 – Mar. 1984

*Combretum micranthum*  
*Combretum nigricans*  
*Combretum glutinosum*  
*Bombax costatum*  
*Adansonia digitata*  
*Acacia macrostachya*  
*Acacia polyacantha*  
*Gardenia ternifolia*  
*Grewia bicolor*  
*Lannea acida*  
*Lonchocarpus laxiflorus*  
*Sclerocarya birrea*  
*Sterculia setigera*  
*Strychnos spinosa*  
*Feretia apodanthera*  
*Boscia angustifolia*  
*Guiera senegalensis*  
*Pterocarpus lucens*

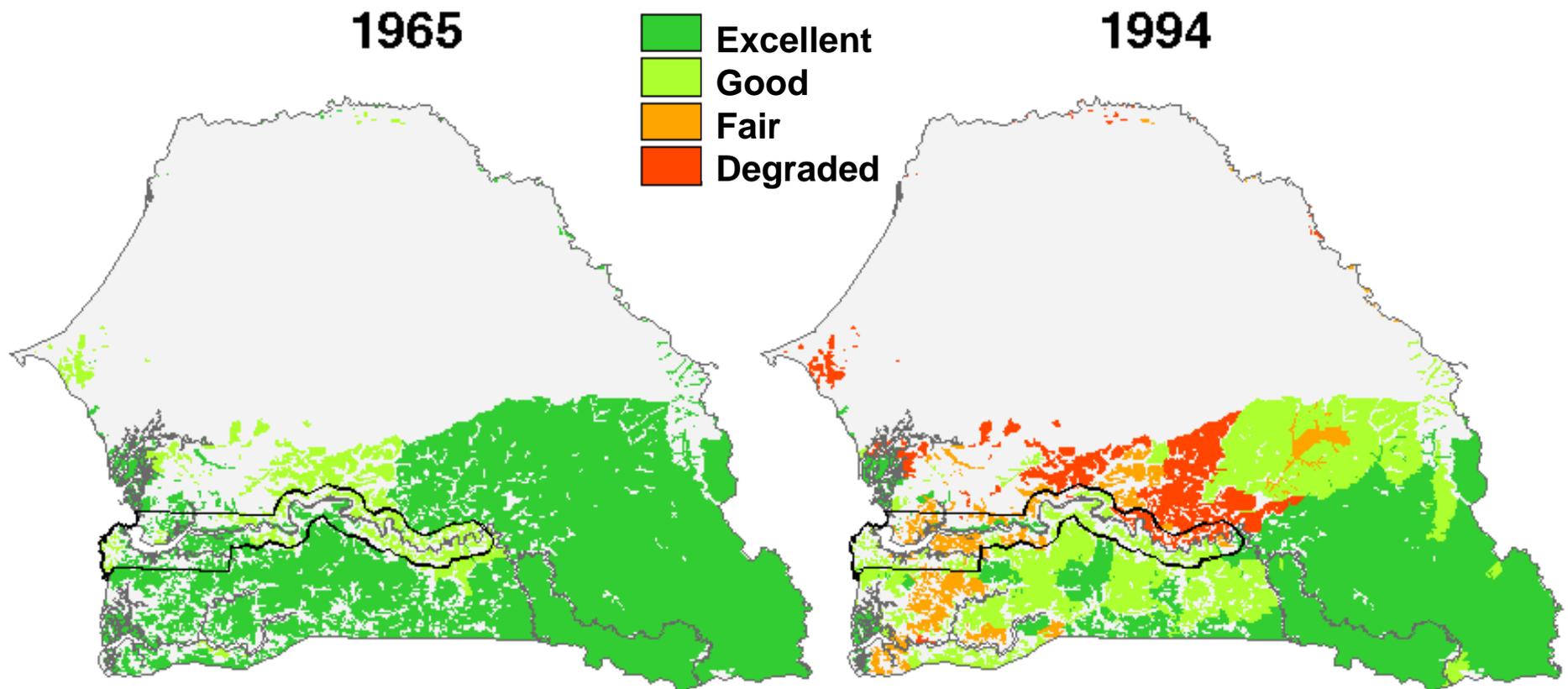


## Woody Species at Site 403 – Feb. 1994

*Combretum micranthum*  
*Combretum nigricans*  
*Combretum glutinosum*  
*Bombax costatum*  
*Acacia macrostachya*  
*Adansonia digitata*  
*Grewia bicolor*  
*Sterculia setigera*  
*Boscia angustifolia*  
*Guiera senegalensis*  
*Pterocarpus lucens*

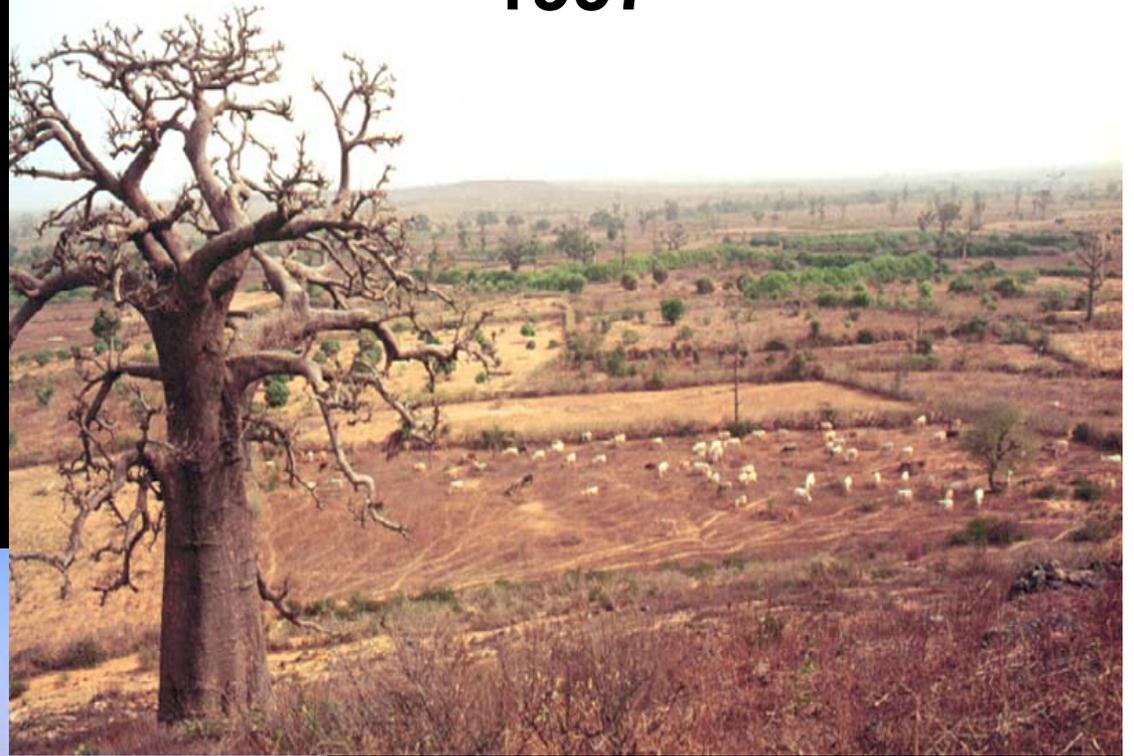


# Condition of Wooded Lands in Senegal



Landscape Dynamics:  
Diversification of  
Production  
(Site 586)

1997



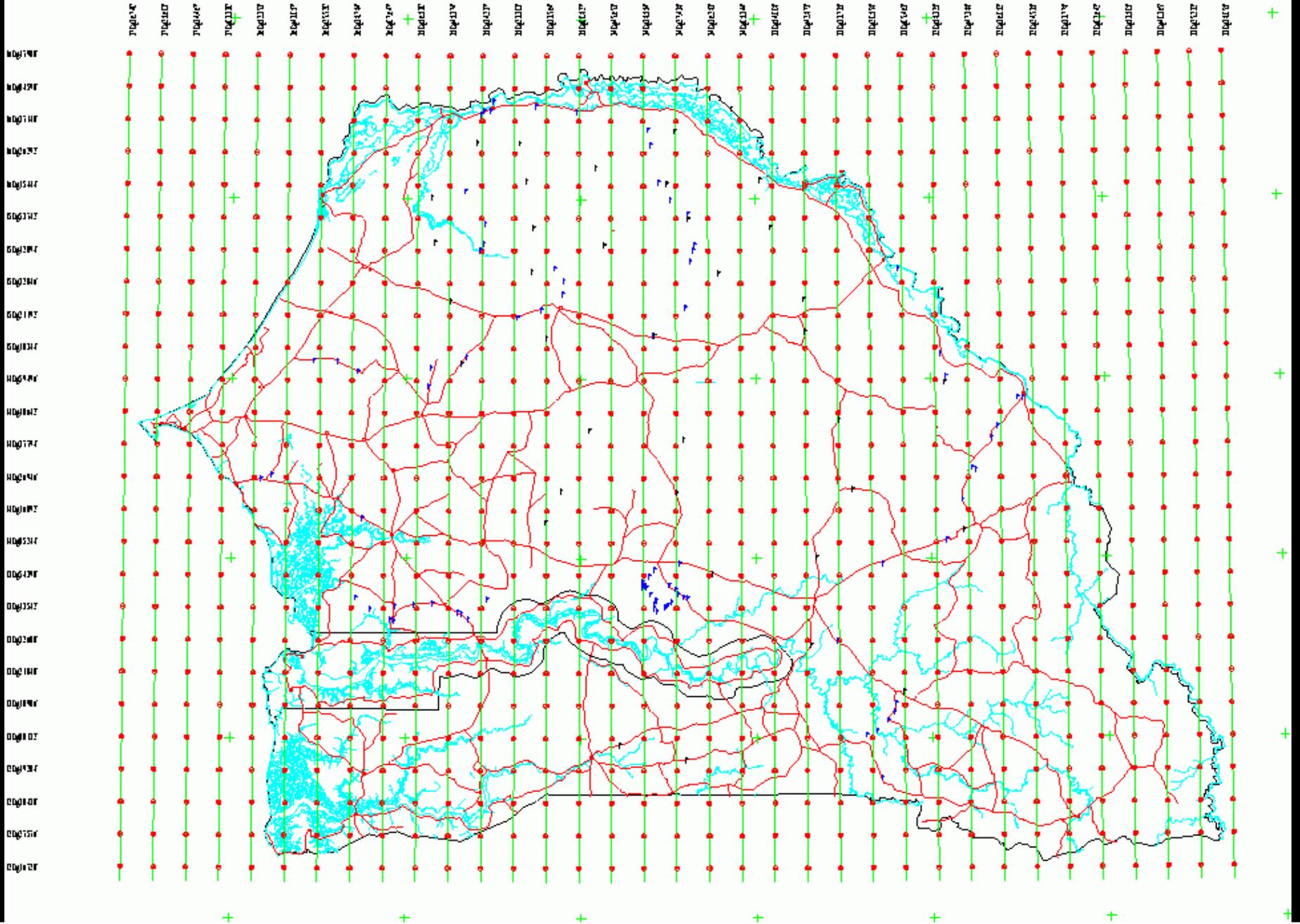
1984



**Basic Hardware:**  
**8 mm Camcorder: vertical view**  
**Hi8 mm Camcorder: oblique view**  
**GPS**  
**Computer**  
**Cessna 206**



# October 1994 Mission: Aerial Flightlines



# October 1994 Aerial Videography Mission Overview

- establish baseline for monitoring
- 16 days of flight
- 13,000 km of imagery acquired
- 25 transects (national distribution)
- 200 meter swath (vertical)
- \$24,000 cost



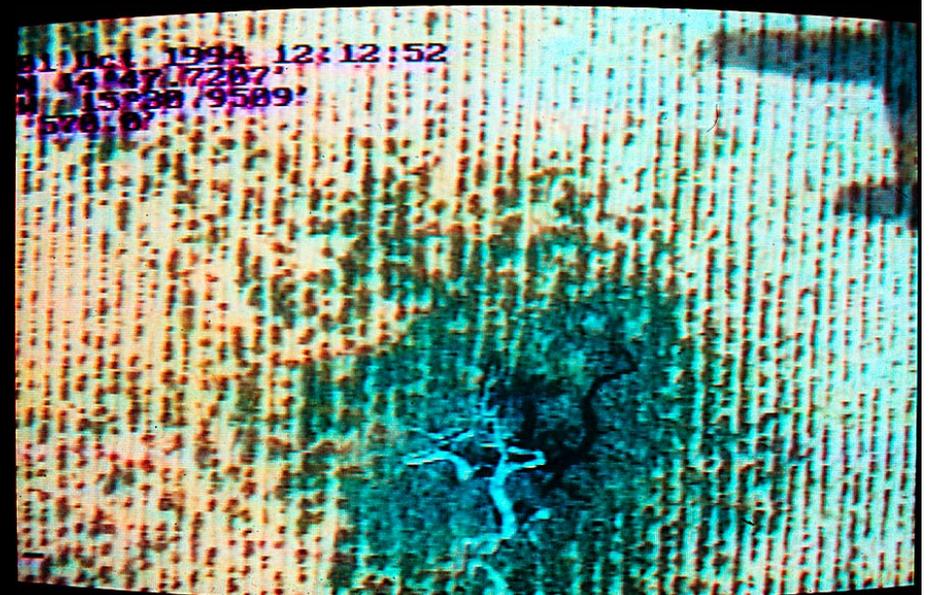
# October 1994 Aerial Videography: Examples

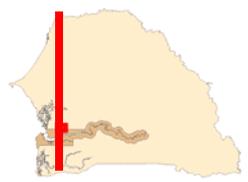


## Natural and Human Related Landscape Features Identified or Inventoried using Aerial Videography

NATURAL FEATURES	HUMAN RELATED FEATURES	
Percent tree cover	Village structure/ethnic affiliation	Stone lines/ridge contours (NRM)
Shrub cover	Percent cultivated area	Crop residues (NRM)
Land cover type	Land use type	Grass strips (NRM)
Presence of dead trees (mortality)	Number/diversity of crops (NRM)	Wells and gardens (NRM)
Forest/woodland fragmentation	Crop productivity (qualitative)	Alley cropping (NRM)
Percent bare or eroded soil	Grassy Fallow (NRM)	Orchards (NRM)
Water course	Bush/Wooded Fallow (NRM)	Industrial Plantations (NRM)
Temporary ponds	Roads	Acacia albida (NRM)
Mud and salt flats	Tracks	Field trees (NRM)
Termite mounds	Paths	Woodlots (NRM)
Herbaceous productivity	Cattle migration routes	Charcoal production mounds
Woodland/forest condition (qualitative)	Live hedges (NRM)	Dune stabilization (NRM)
	Scrub (dead) hedges (NRM)	Protected forests (NRM)
	Wind breaks (NRM)	Fire breaks (NRM)
	Rock bunds (NRM)	Water retention dams (NRM)
	Exclosures (NRM)	

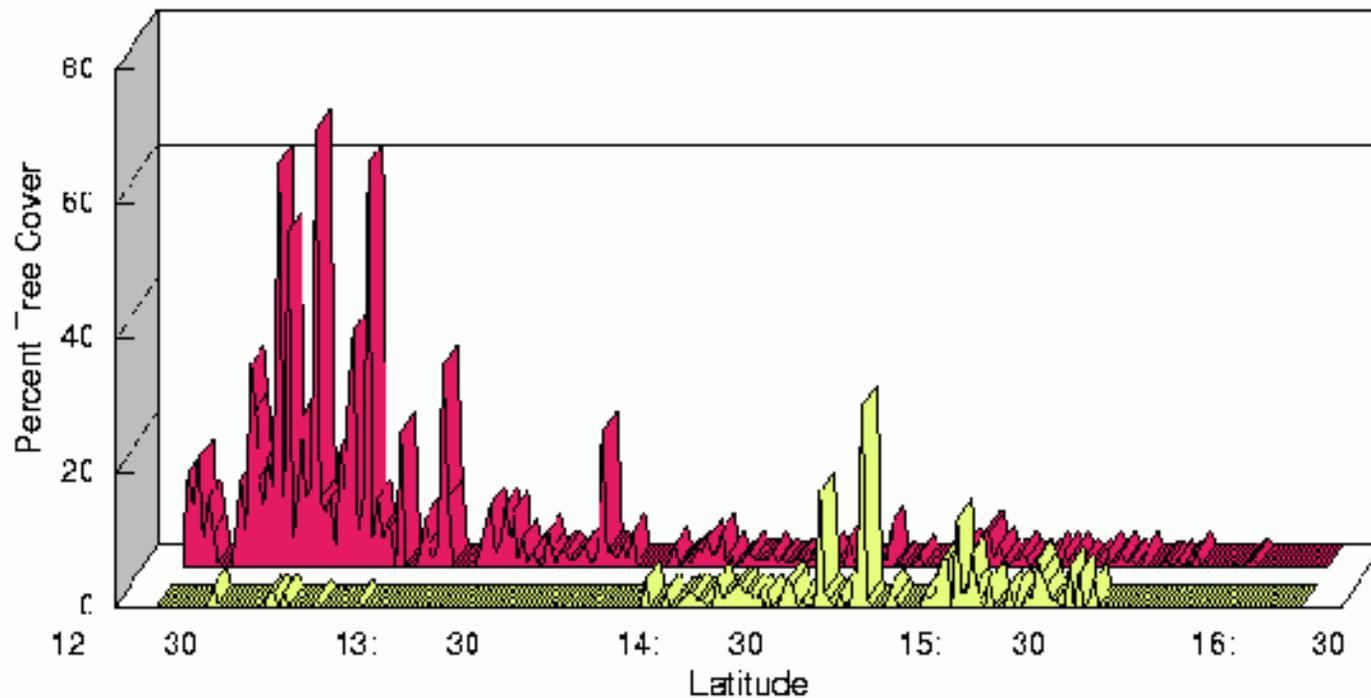
# Unique Characteristics of *Faidherbia albida*





# Longitudinal Profile of Vegetation Cover

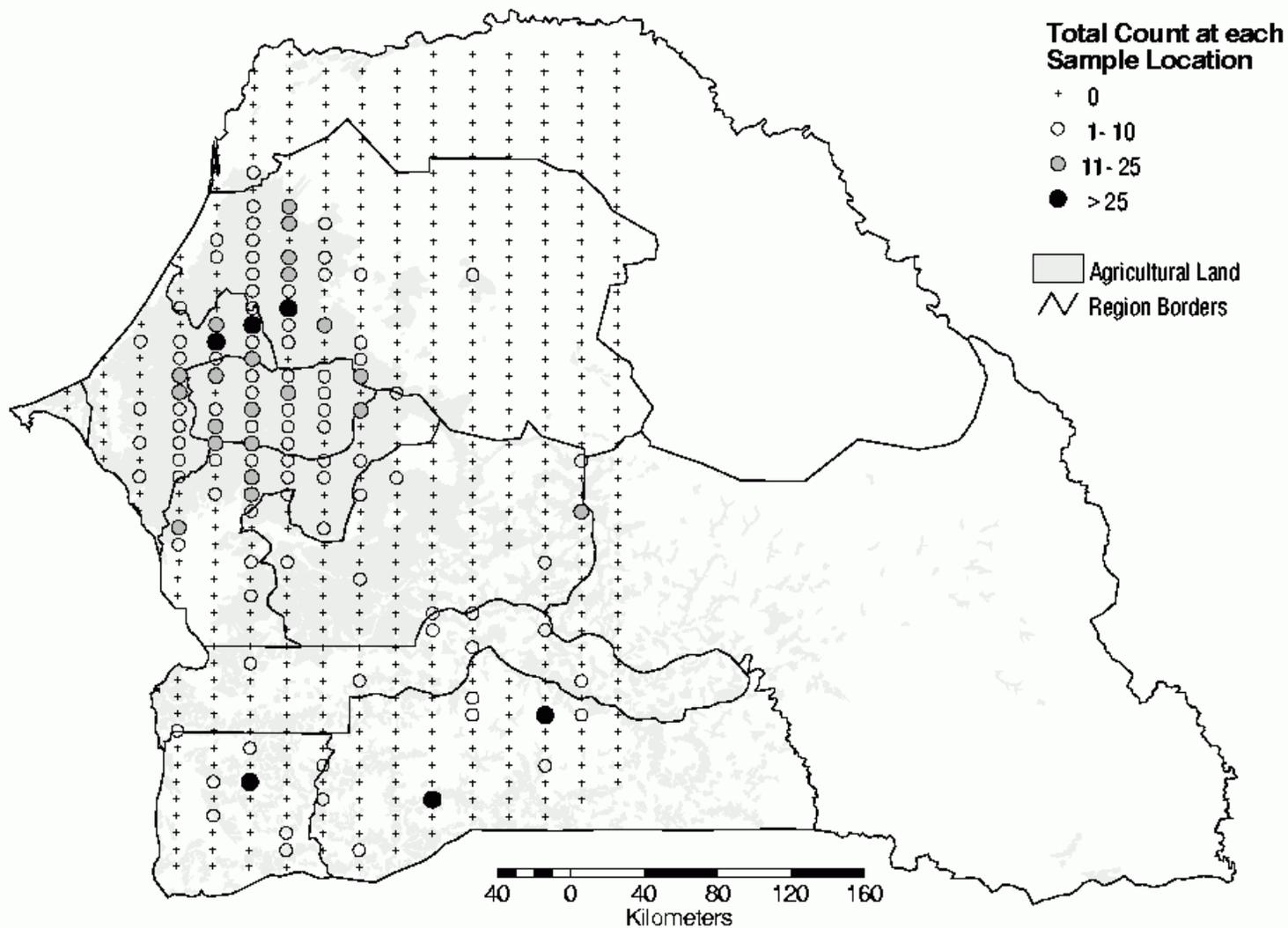
Total Tree Cover Compared to Acacia Albida  
Longitudinal Transect 16 d 07.64 m



Acacia Albida (Kad) Tree Cover %

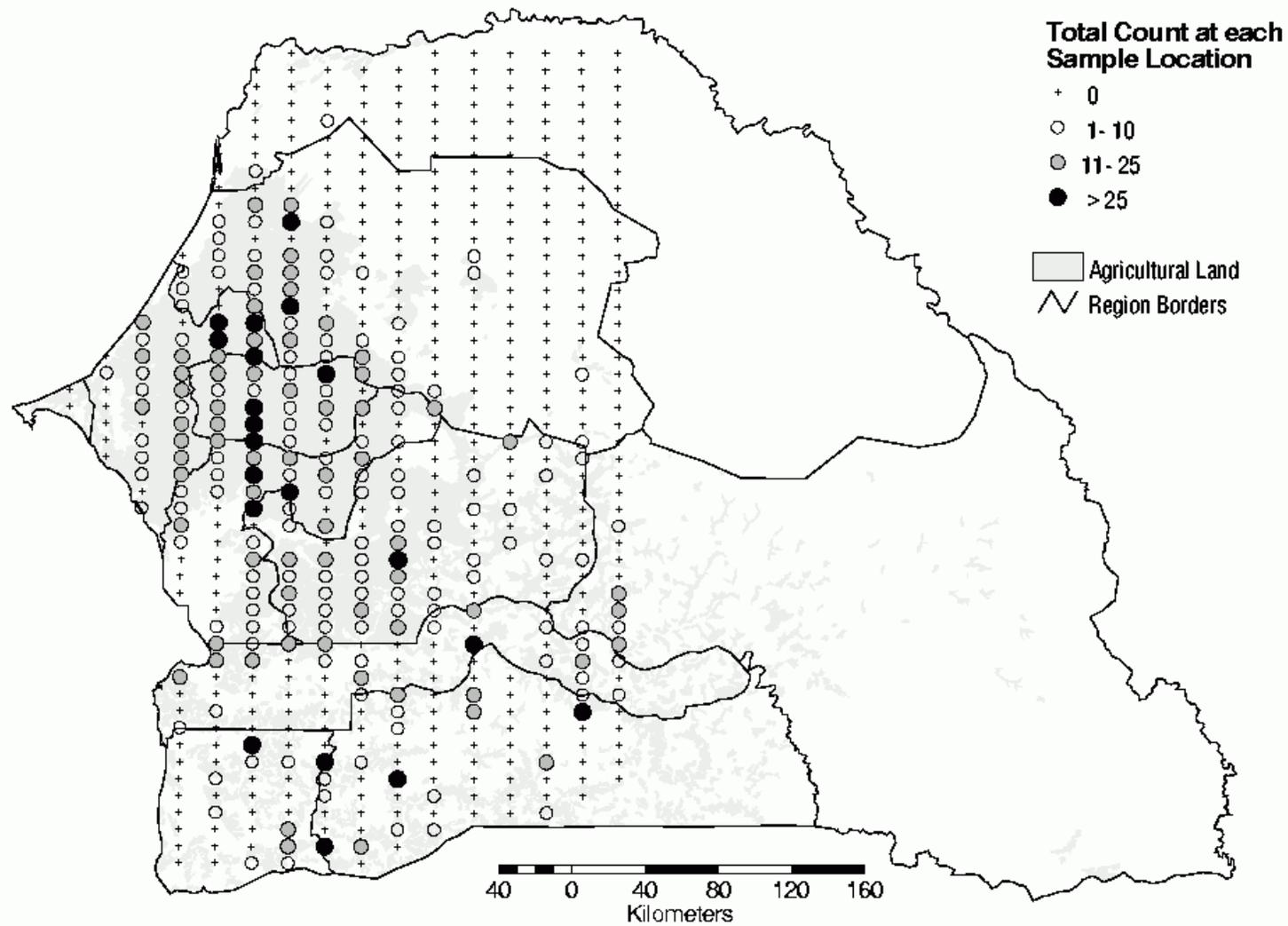
# National Level Natural Resource Inventories

## Distribution of *Acacia Albida* In Senegal In 1994



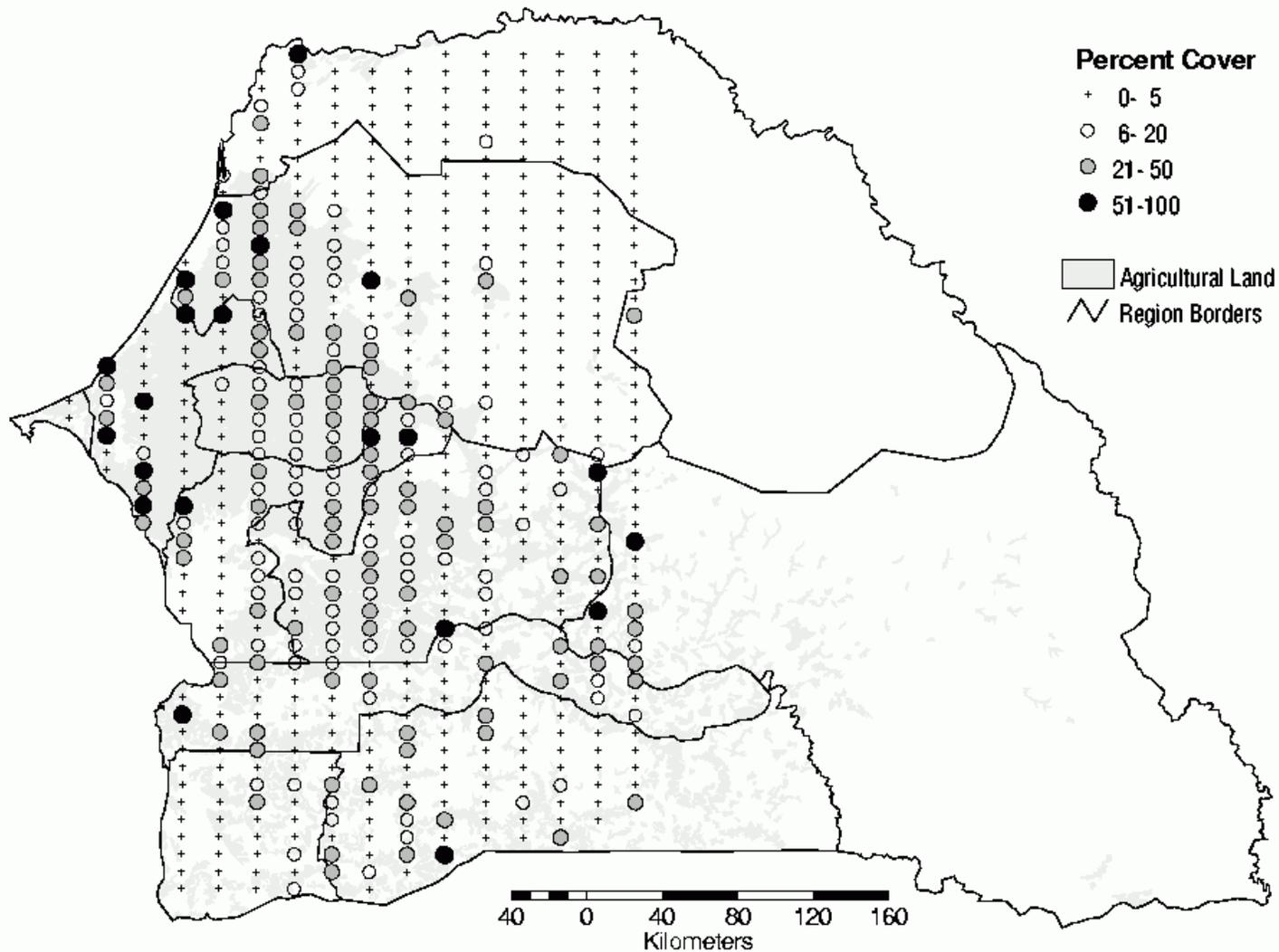
# National Level Natural Resource Inventories

## Distribution of *Field Trees* In Senegal In 1994



# National Level Natural Resource Inventories

## Distribution of *Fallow* In Senegal In 1994



**Wide-angle video:  
Single frame and  
mosaic**



## Video Image Mosaic: *Terroir de Soukouto*



# Land Use Map from Video Mosaic

## TRANSECT DE L'OCCUPATION DU SOL A TRAVERS LE TERROIR DE SOUKOUTO, SENEGAL LAND USE/LAND COVER TRANSECT THROUGH THE SOUKOUTO VILLAGE TERRITORY, SENEGAL

Basé sur des images aériennes vidéo acquises le 10 octobre, 1984, et sur une mission de contrôle de terrain, complétée le 28 janvier, 1985.

Based on aerial videography flown on October 10, 1984, and ground truth collected January 28, 1985.



Légende / Legend

**AGRICULTURE**

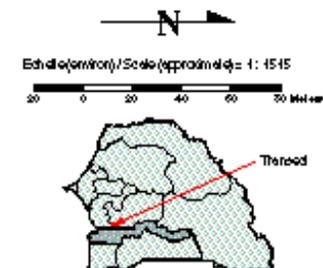
[Brown]	AGRICULTURE
[Yellow]	AGRICULTURE
[Orange]	AGRICULTURE
[Light Green]	AGRICULTURE
[Dark Green]	AGRICULTURE
[Light Blue]	AGRICULTURE
[Dark Blue]	AGRICULTURE
[Light Brown]	AGRICULTURE
[Dark Brown]	AGRICULTURE
[Light Orange]	AGRICULTURE
[Dark Orange]	AGRICULTURE

**DIVERS / MISCELLANEOUS**

[Light Green]	DIVERS / MISCELLANEOUS
[Dark Green]	DIVERS / MISCELLANEOUS
[Blue]	DIVERS / MISCELLANEOUS
[Light Blue]	DIVERS / MISCELLANEOUS
[Dark Blue]	DIVERS / MISCELLANEOUS
[Light Brown]	DIVERS / MISCELLANEOUS
[Dark Brown]	DIVERS / MISCELLANEOUS

**ARBRES / TREES**

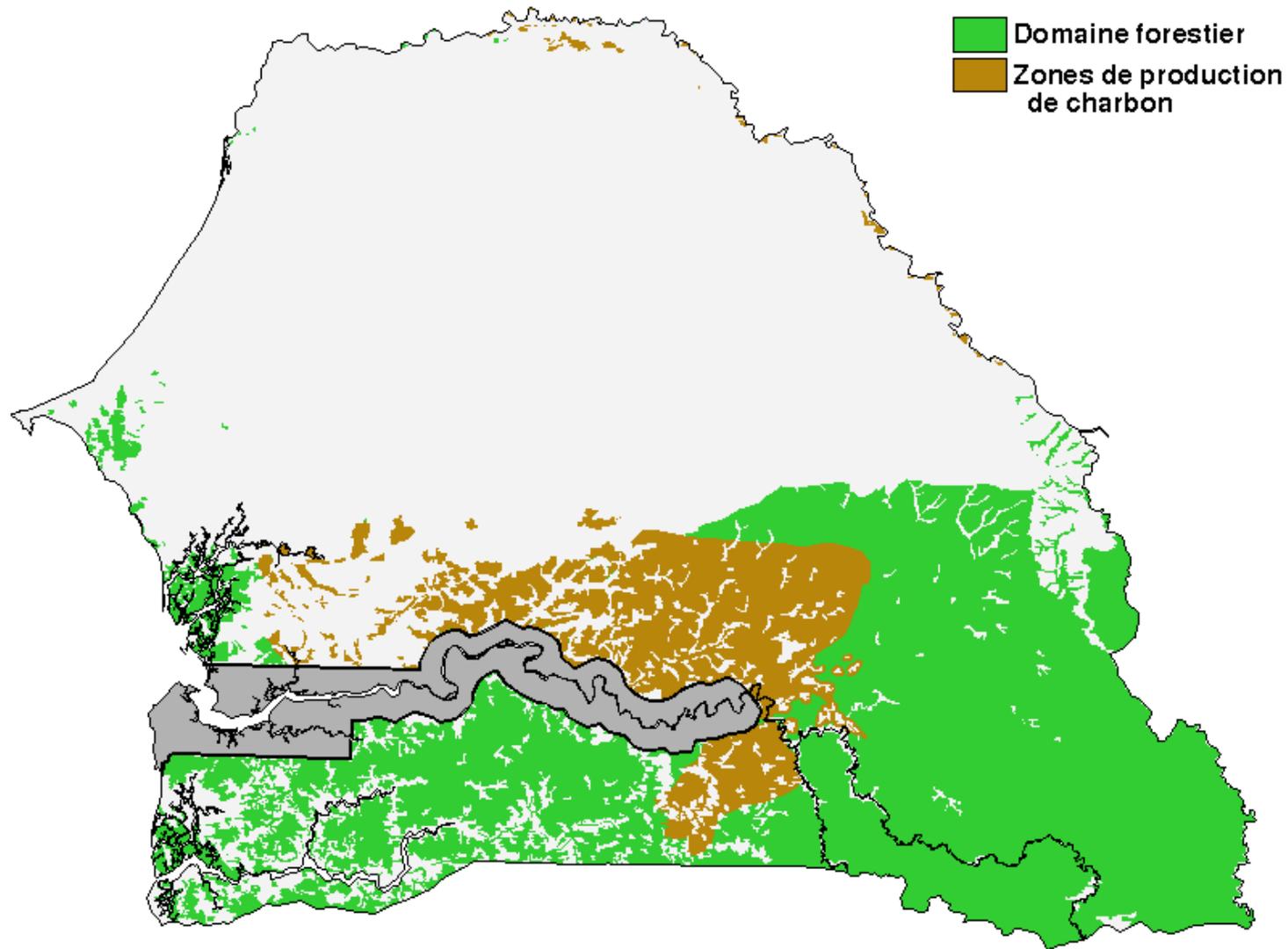
[Dark Green]	ARBRES / TREES
[Light Green]	ARBRES / TREES
[Yellow]	ARBRES / TREES
[Orange]	ARBRES / TREES
[Light Orange]	ARBRES / TREES
[Dark Orange]	ARBRES / TREES
[Light Brown]	ARBRES / TREES
[Dark Brown]	ARBRES / TREES
[Light Orange]	ARBRES / TREES
[Dark Orange]	ARBRES / TREES



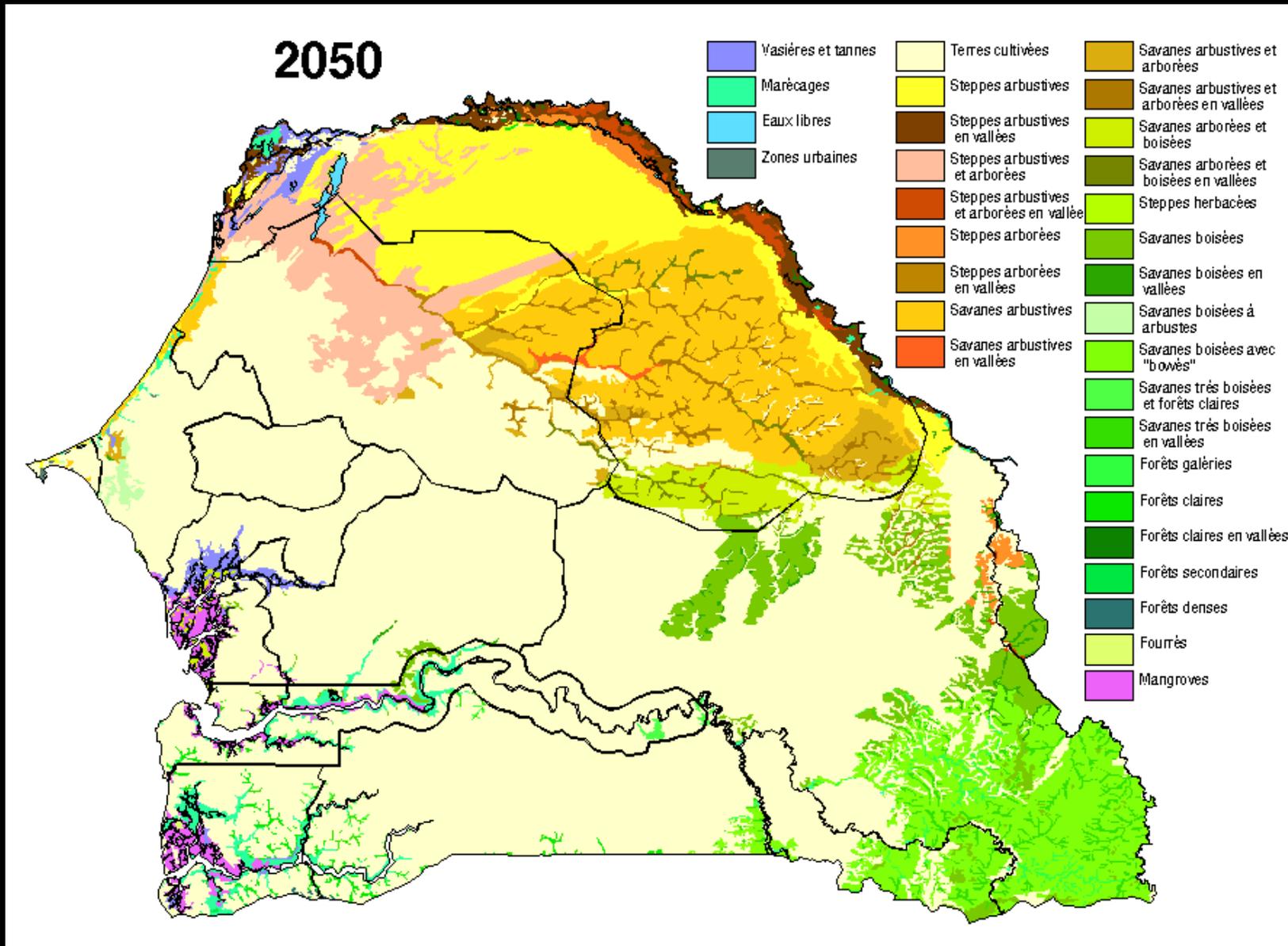
# L'exploitation charbonnière



# Les zones de production de charbon (1994)



# Predictive Models of LULC Change



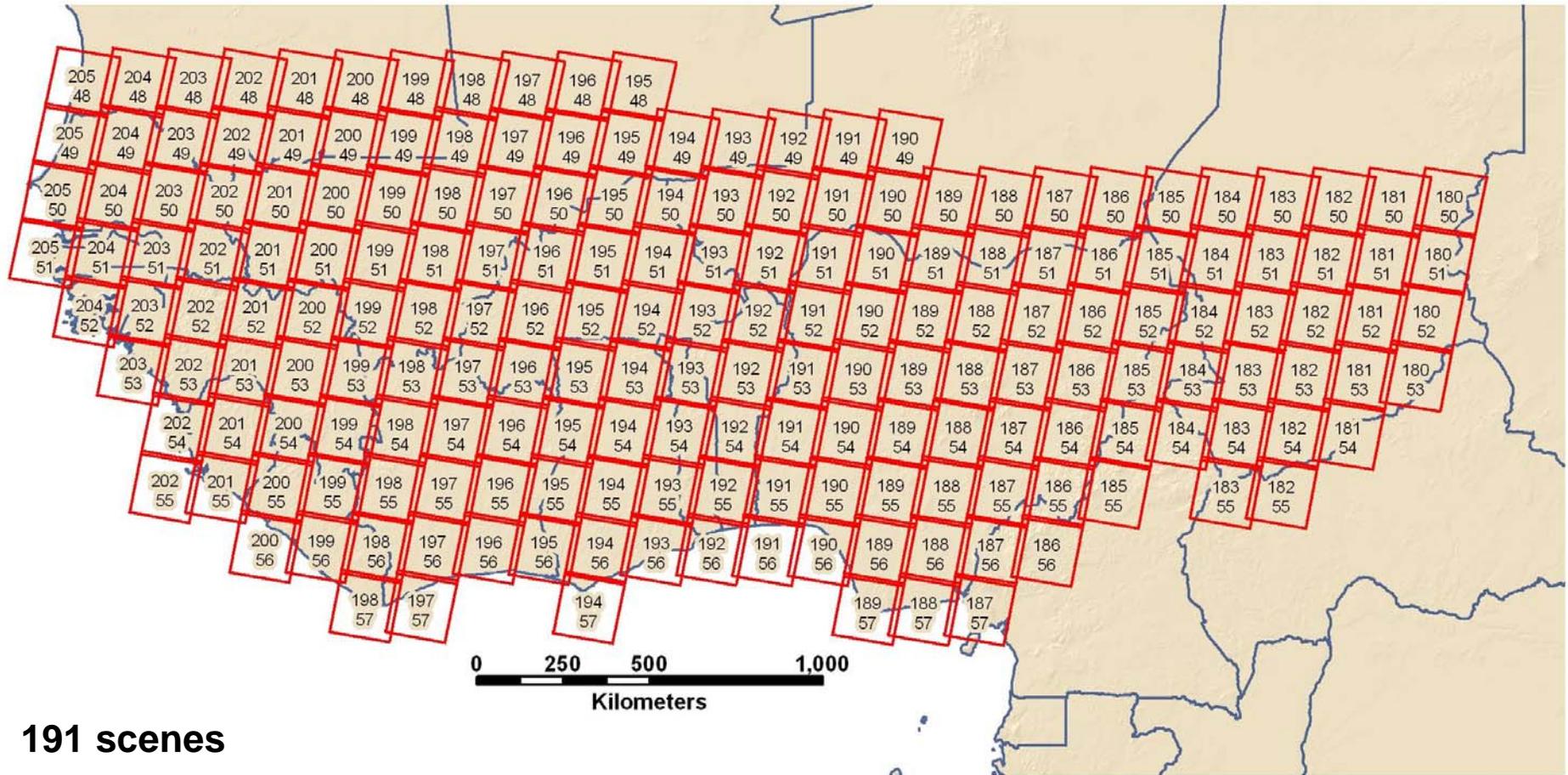
## Some Key Results

- **Developed a long-term monitoring framework with CSE**
- **Gained a better understanding of natural resource changes and relationships with human activities**
- **Promoted environmental awareness in Senegal: government, education, public**
- **Provided information to environmental policy-makers**

# Scaling Up to Regional Land Use / Land Cover Monitoring



# Geographic extent of the West Africa LULC Trends Project as depicted through Landsat scene coverage



# Sahel LU/LC Project Cooperators



Centre Régional AGRHYMET

## West Africa LULC Project Cooperators

- African Cooperators:
  - CILSS
  - Centre Régional AGRHYMET
  - Institut du Sahel
  - National Government Agencies
- US Cooperators:
  - U.S. Agency for International Development
  - U.S. Geological Survey

# West Africa LULC National Cooperators

- Burkina
  - Institut de l'Environnement et de Recherches Agricoles
  - Dir. des Etudes et de la Planification / Agriculture
- Chad
  - Dir. de la Production Agricole
- Gambia
  - Forestry Department
  - National Environment Agency
- Guinea Bissau
  - Dir. Générale de l'Environnement
- Mali
  - Institut Géographique du Mali
  - Institut d'Economie Rurale
- Mauritania
  - Direction de l'Elevage et de l'Agriculture
  - Centre National de l'Elevage et Recherche Vétérinaire
- Niger
  - Dir. de l'Environnement
  - Institut Géographique National du Niger
- Senegal
  - Centre de Suivi Ecologique

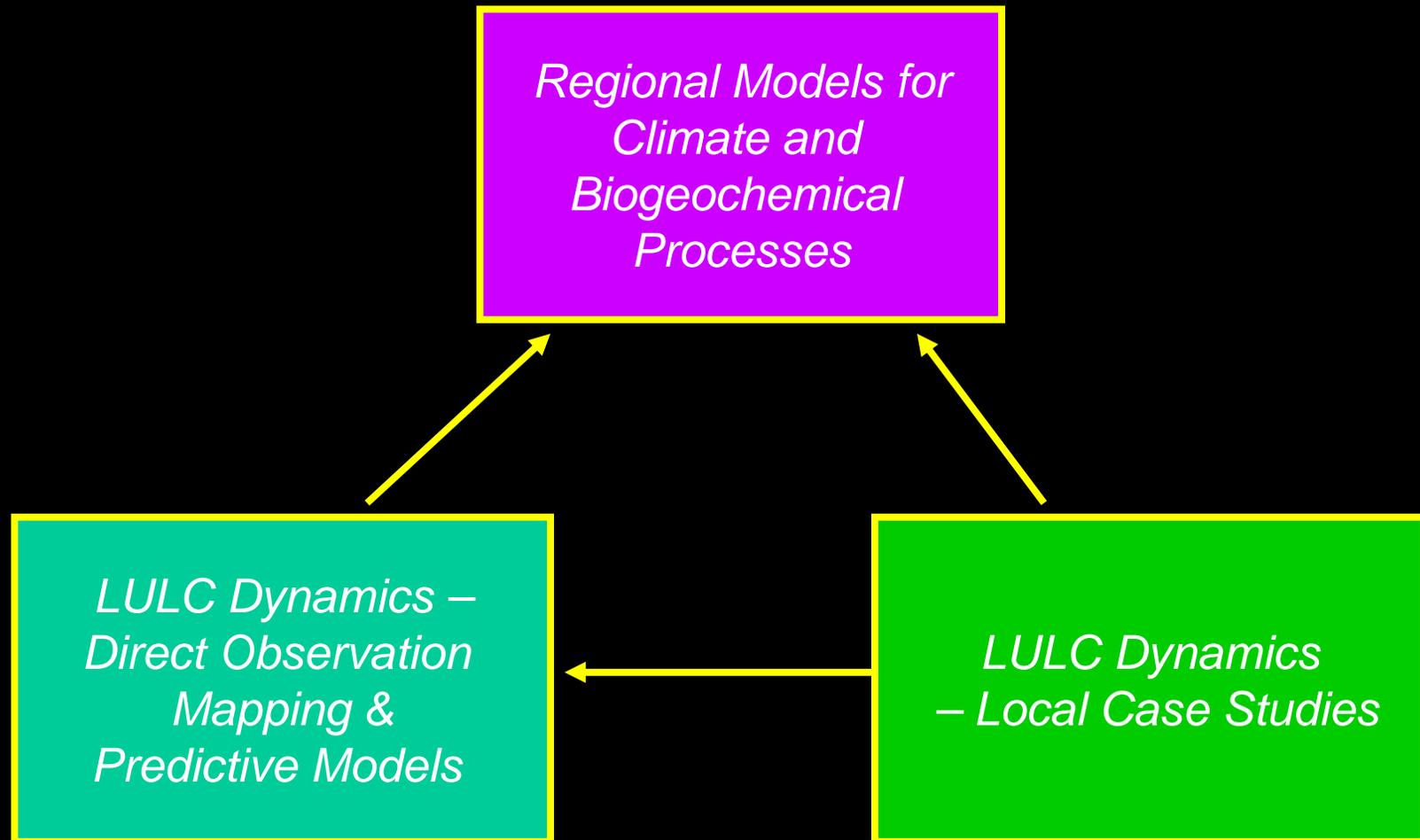
# West Africa LULC National Cooperators

- Bénin
  - Centre Nat. de Télédétection et de Surveillance du Couvert Forestier
- Ghana
  - Environmental Protection Agency
  - Dept. of Geography, University of Ghana
- Guinea
  - Service National des Sols, Ministère de l'Agriculture
  - Direction National de la Météorologie
- Nigeria
  - National Centre for Remote Sensing
  - Regional Centre for Training in Aerospace Surveys
- Togo
  - Direction Météorologie Nationale
  - Institut Togolais de Recherche Agronomique

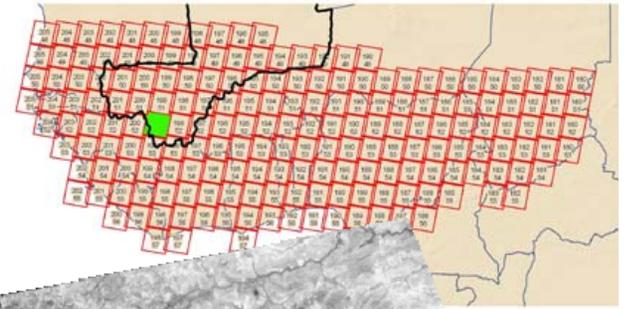
## West Africa LULC Trends: Goals

- Develop and Implement a West African regional LULC monitoring framework in partnership with AGRHYMET, INSAH, and national institutions
- Construct and provide a complete satellite image archive of West Africa for four periods: years 1965, 1972, 1985, and 2000
- Stratify West African landscapes by ecological regions
- Characterize and quantify LULC trends by ecoregion
- Produce LULC maps of West Africa for the periods of 1972, 1985, and 2000
- Provide information to CILSS and ECOWAS food security and natural resource management programs
- Engage decision-makers in the results of LULC trends, and involve them in running future scenarios of LULC using geographic models

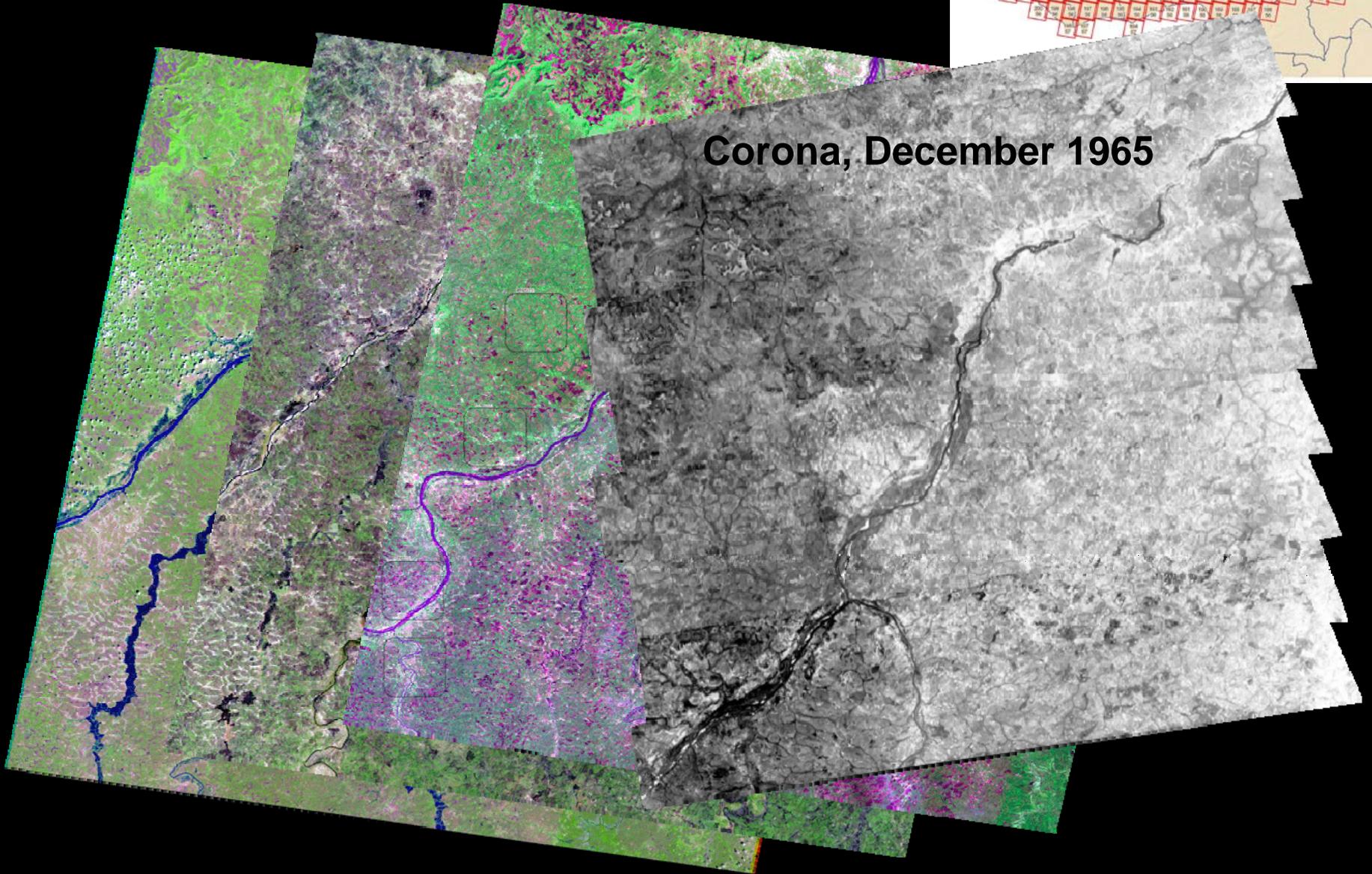
# Pillars of the West Africa LULC Trends Project



# Four Periods of Image Coverage



Corona, December 1965



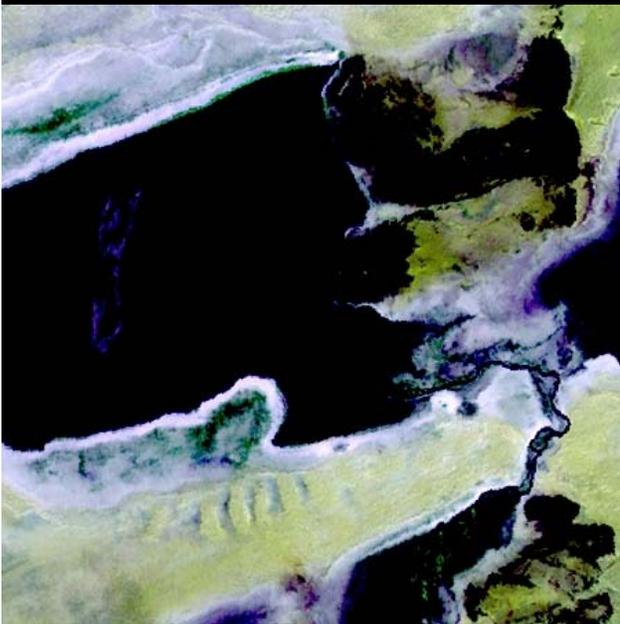
# Major Environmental Concerns in West Africa

- Rainfall has declined (Sahel)
- Natural resources degrading under increasing human pressure (agricultural expansion, wood cutting, etc.)
- Land Use and Land Cover changes occurring at unprecedented rates
- Forest cover diminishing
- Biodiversity is declining (flora and fauna)

# Lake Faguibine, Mali: A view through time



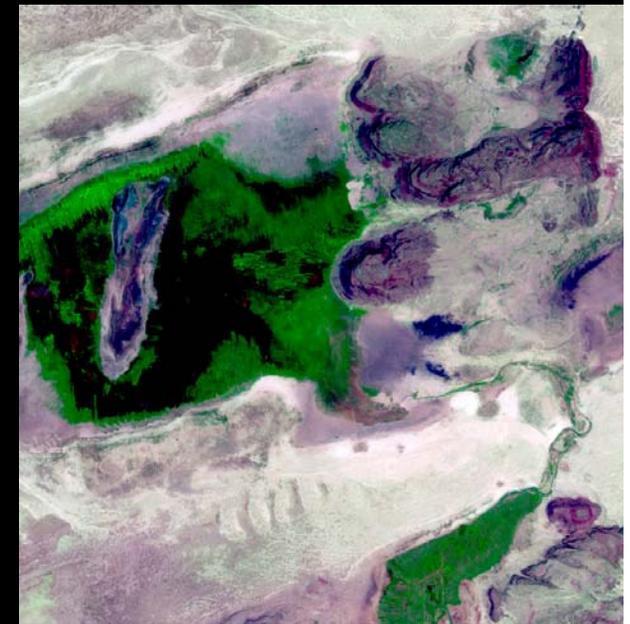
**1972**



**1985**



**2000**



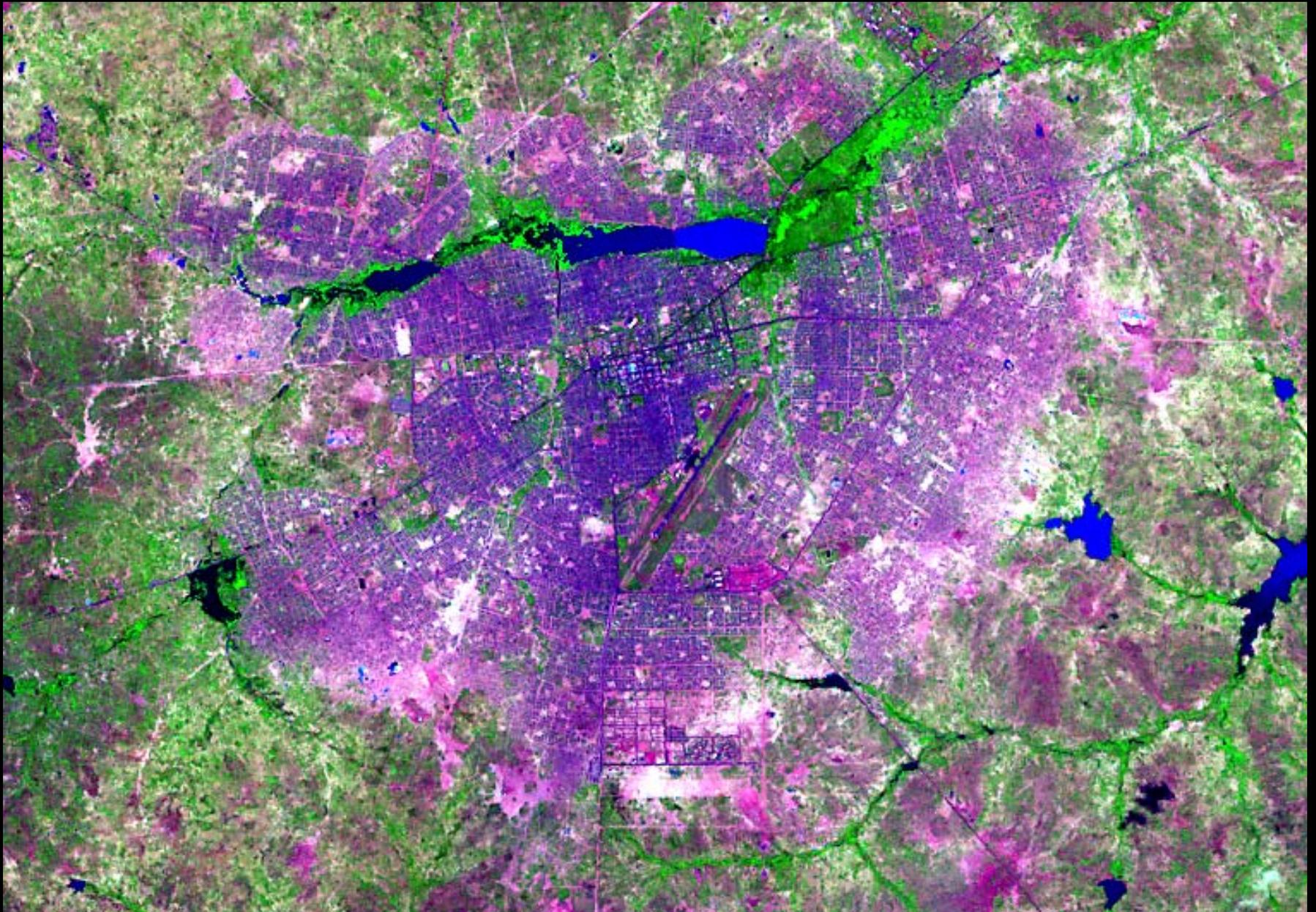
**26 km**



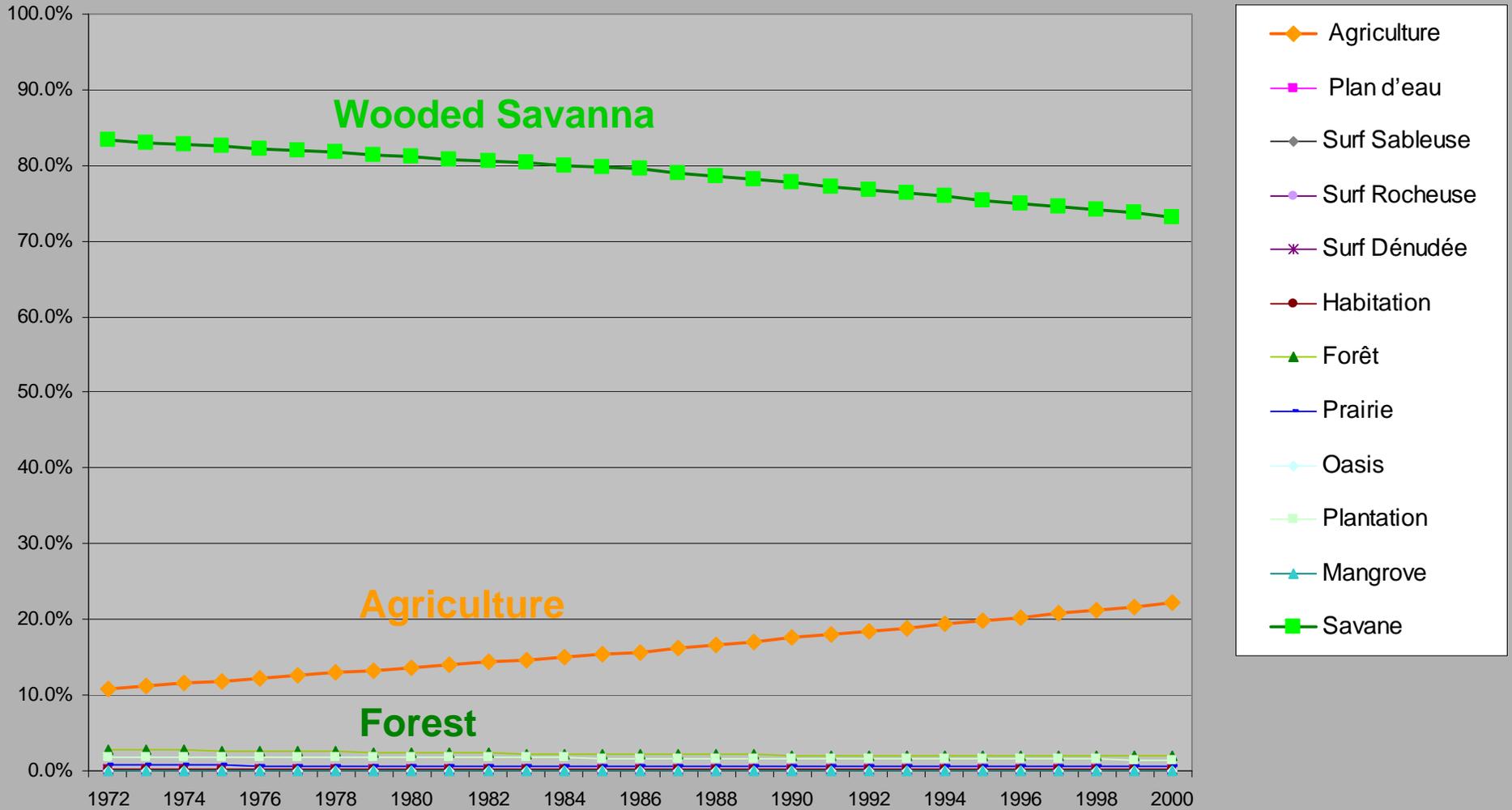
# Ouagadougou January 1968 - Corona



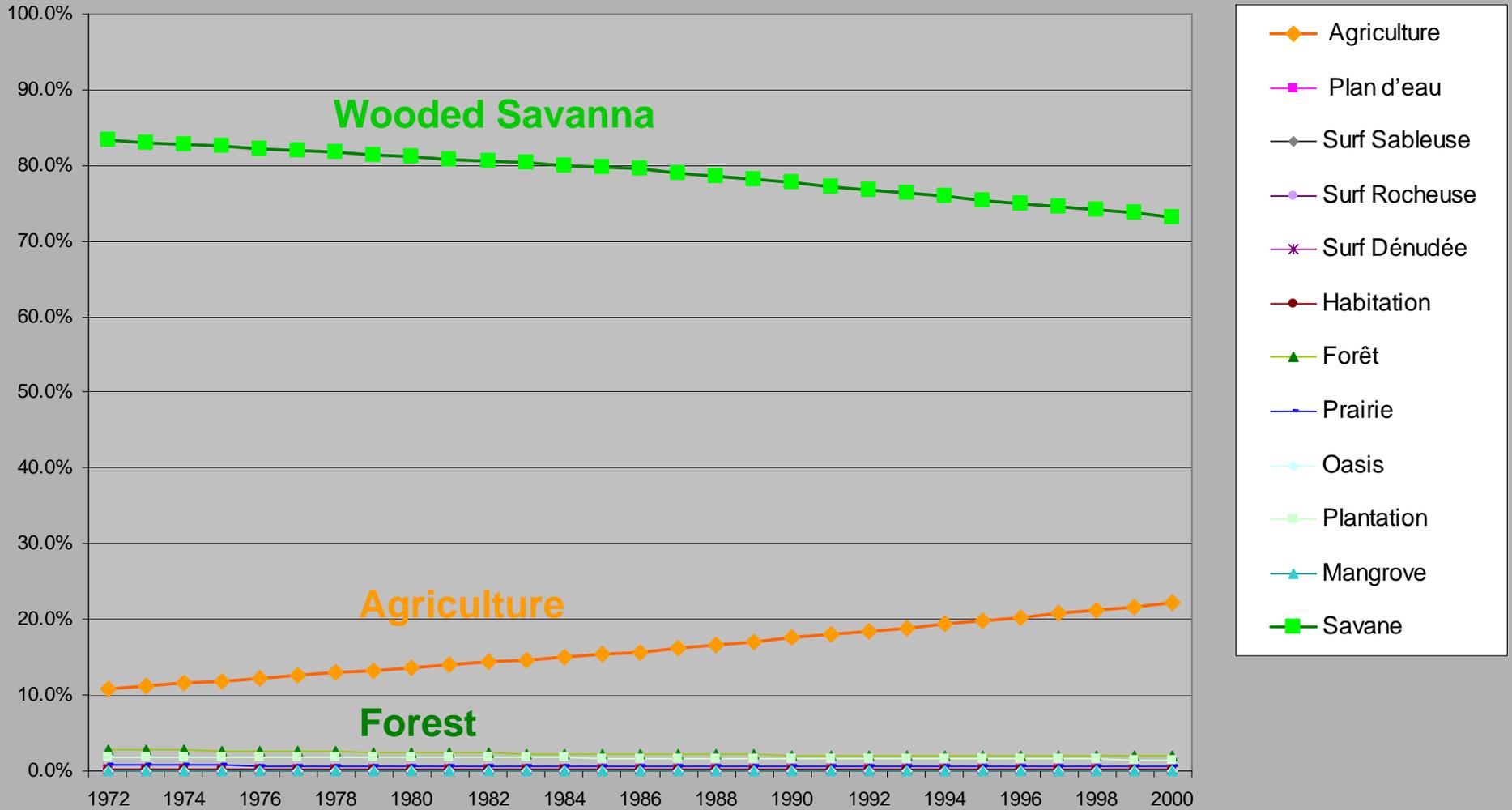
# Ouagadougou October 2000 – Landsat ETM+



## National Trends for Benin



## National Trends for Benin



# Major Environmental Concerns in West Africa

- Rainfall has declined (Sahel)
- Natural resources degrading under increasing human pressure (agricultural expansion, wood cutting, etc.)
- Land Use and Land Cover changes occurring at unprecedented rates
- Forest cover diminishing by 2.9 million ha per year (Sub-Saharan Africa)
- Biodiversity has declined (flora and fauna)

# Expected Benefits

- Improved understanding of the biophysical aspects of lu / lc change over the past 50 years
- Improved understanding of desertification, including:
  - Changes in land performance
  - Changes in ecosystem type
  - Impact on ecosystem services
- Identification of environmental success including positive NRM impact
- Improved understanding of the socioeconomic driving factors of change
- Increased public awareness of environmental issues and land resource changes
- Work with CILSS regional and national environmental policy-makers to provide a better understanding of the changing natural resource base, implications for social and economic well-being, and implications for the future
- Improved understanding of future options based on geographic models that project and predict lu / lc trends to 2050 under various 'what if' scenarios of population growth, economic activity, climatic conditions, and social factors
- Provide linkages between lu/lc trends and biogeochemical cycling, with special emphasis on carbon system dynamics in soils and vegetation

# Special Publication in Journal of Arid Environments

**Land Cover, Biomass, and Soil Carbon Trends in Senegal: Management Options and Climate Sensitivity**

**Guest Editors:** Larry L. Tieszen, USGS/EROS Data Center and G. Gray Tappan, SAIC at USGS/EROS Data Center

**Sequestration of Carbon in Soil Organic Matter in Senegal: An Overview**

Larry L Tieszen, Gray Tappan, and Assize Touré

**JAE 03/327: Ecoregions and Land Cover Trends in Senegal**

G G Tappan, M Sall, E C Wood, M Cushing

**JAE 04/042: Evaluation of Land Performance in Senegal using Multi-Temporal NDVI and Rainfall Series**

J Li, J Lewis, J Rowland, G Tappan, L L Tieszen

**JAE 03/331: Assessing Land Cover Performance in Senegal, West Africa Using 1-km Integrated NDVI, Local Variance Analysis, and High Resolution Satellite Imagery**

M E Budde, G Tappan, J Rowland, J Lewis, L L Tieszen

**JAE 03/326: Carbon Stocks in Senegal's Sahel Transition Zone**

P L Woomeer, A Touré, M Sall

**JAE 03/330: Biophysical Potential for Soil Carbon Sequestration in Agricultural Systems of the Old Peanut Basin of Senegal**

P Tschakert, M Khouma, M Sène

**JAE 03/332: The Social Context of Carbon Sequestration: Considerations from a Multi-Scale Environmental History of the Old Peanut Basin of Senegal**

P Tschakert, G Tappan

**JAE 03/324: Understanding the Drivers of Agricultural Land Use Change in South-Central Senegal**

E C Wood, G G Tappan, A Hadj

**JAE 03/328: Impacts of Land Use and Climate Change on Carbon Dynamics in South-Central Senegal**

S Liu, M Kaire, E Wood, O Diallo, L L Tieszen

**JAE 03/329: Ecological Impact of Historical and Future Land Use Patterns in Senegal**

W Parton, G Tappan, D Ojima, P Tschakert

**JAE 03/325: Land Use Change and Terrestrial Carbon Stocks in Senegal**

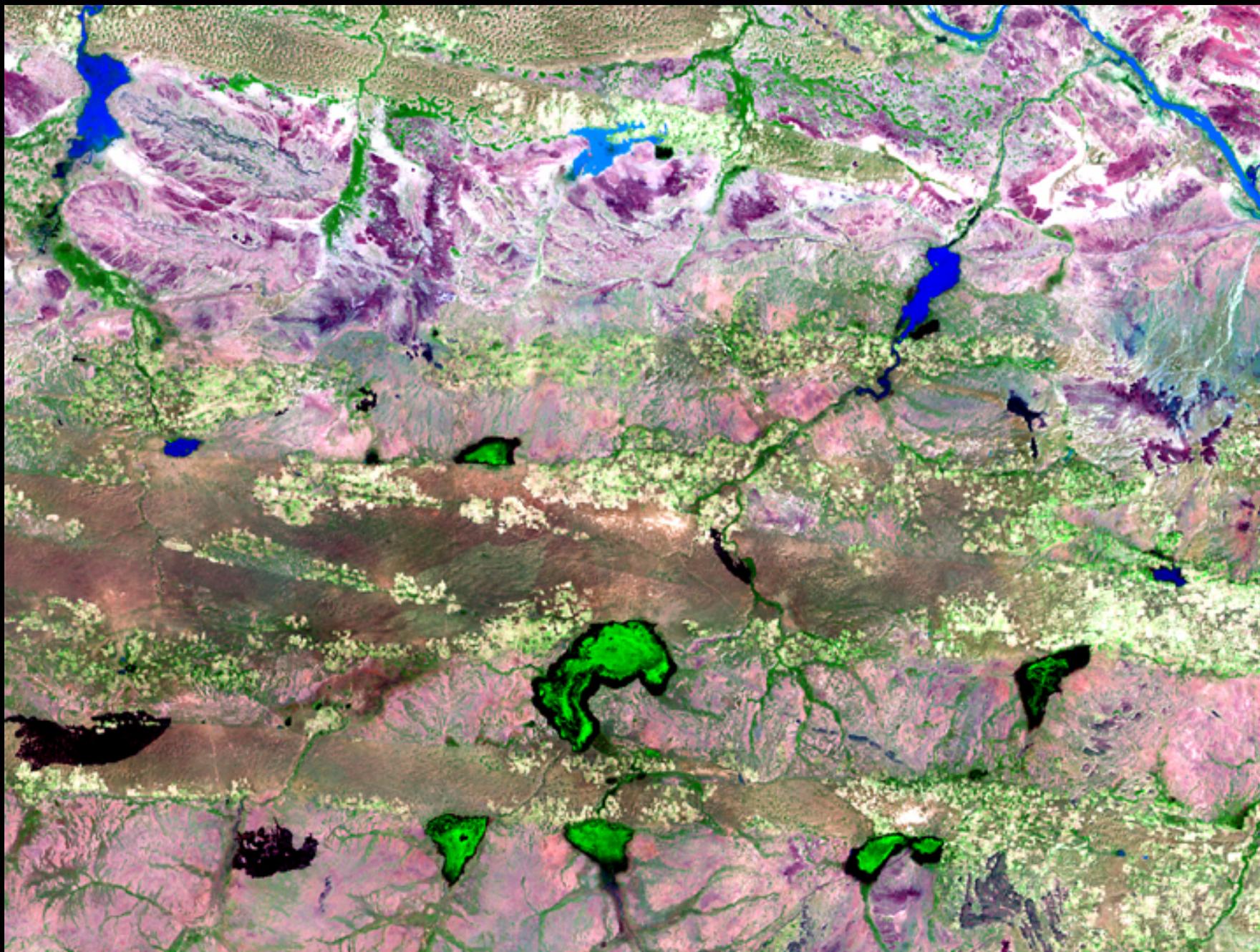
P L Woomeer, L L Tieszen, G Tappan, A Touré, M Sall

**Soil Carbon Sequestration and Its Role in Economic Development: A Donor Perspective**

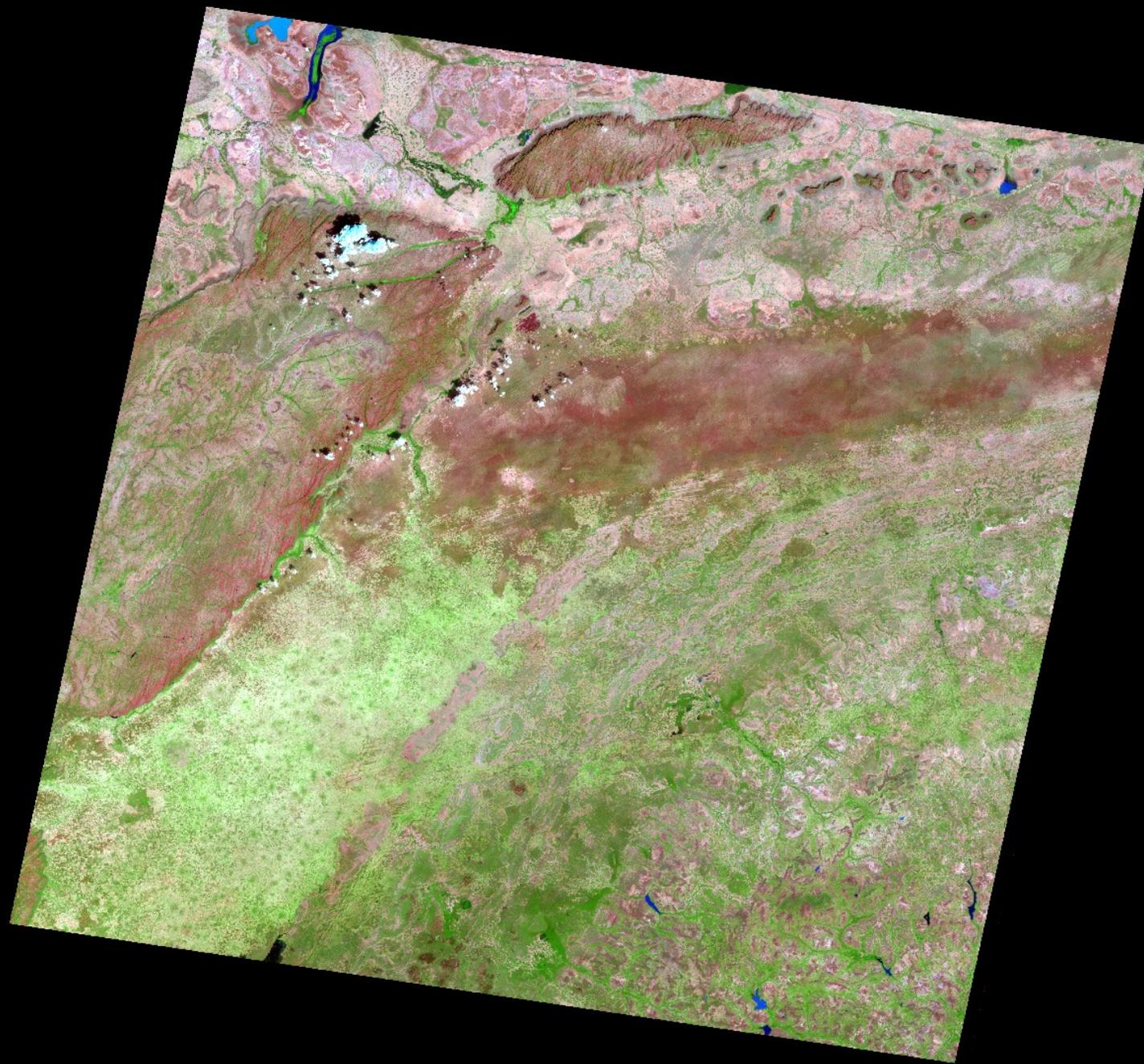
(Concluding Comments)

P Bartel, USAID

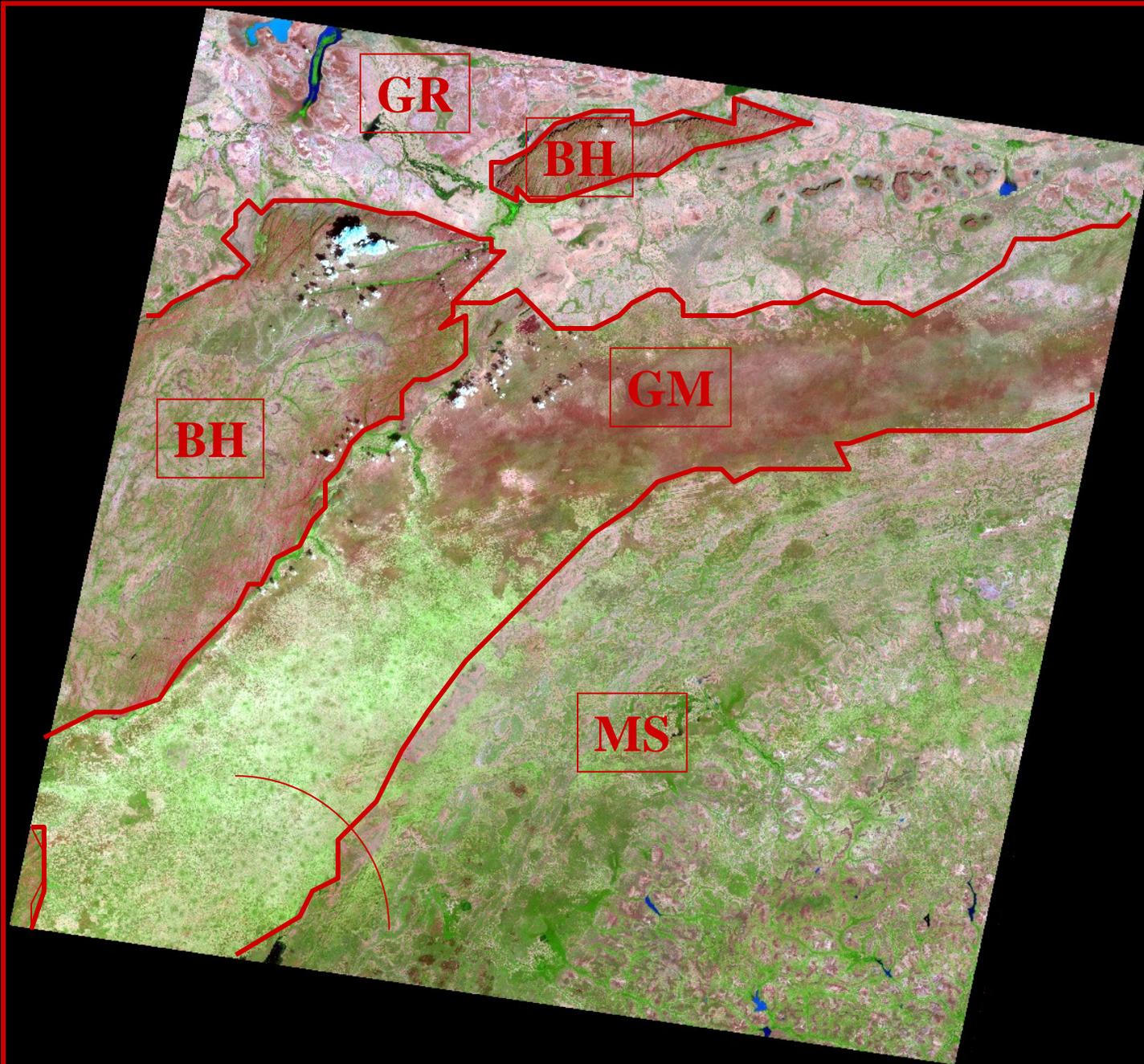
## Image Landsat: vue du Niger occidental



## Exemple d'image Landsat ETM+ du novembre 2000

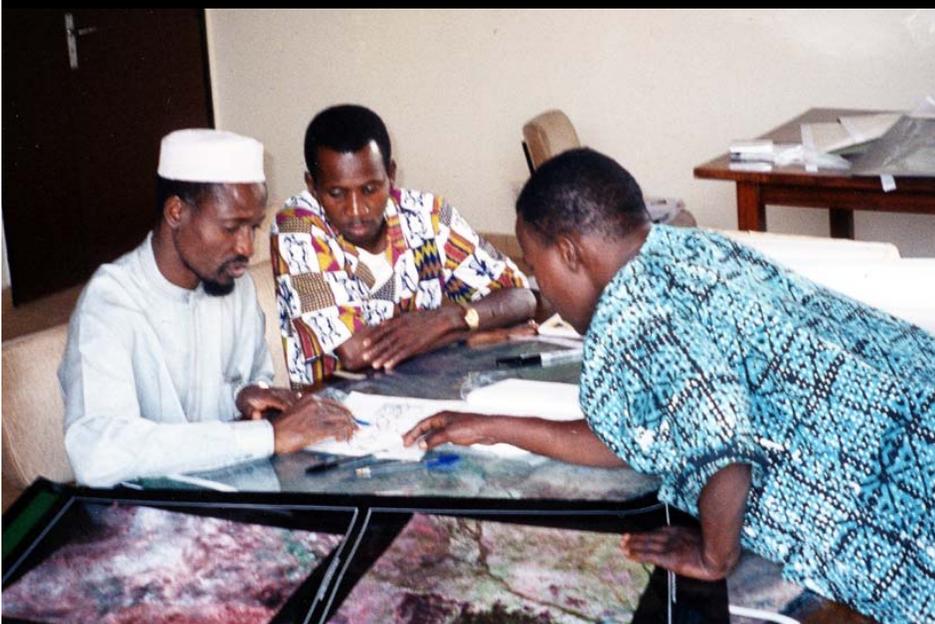


## Exemple de la stratification en régions écologiques, Mali-Burkina

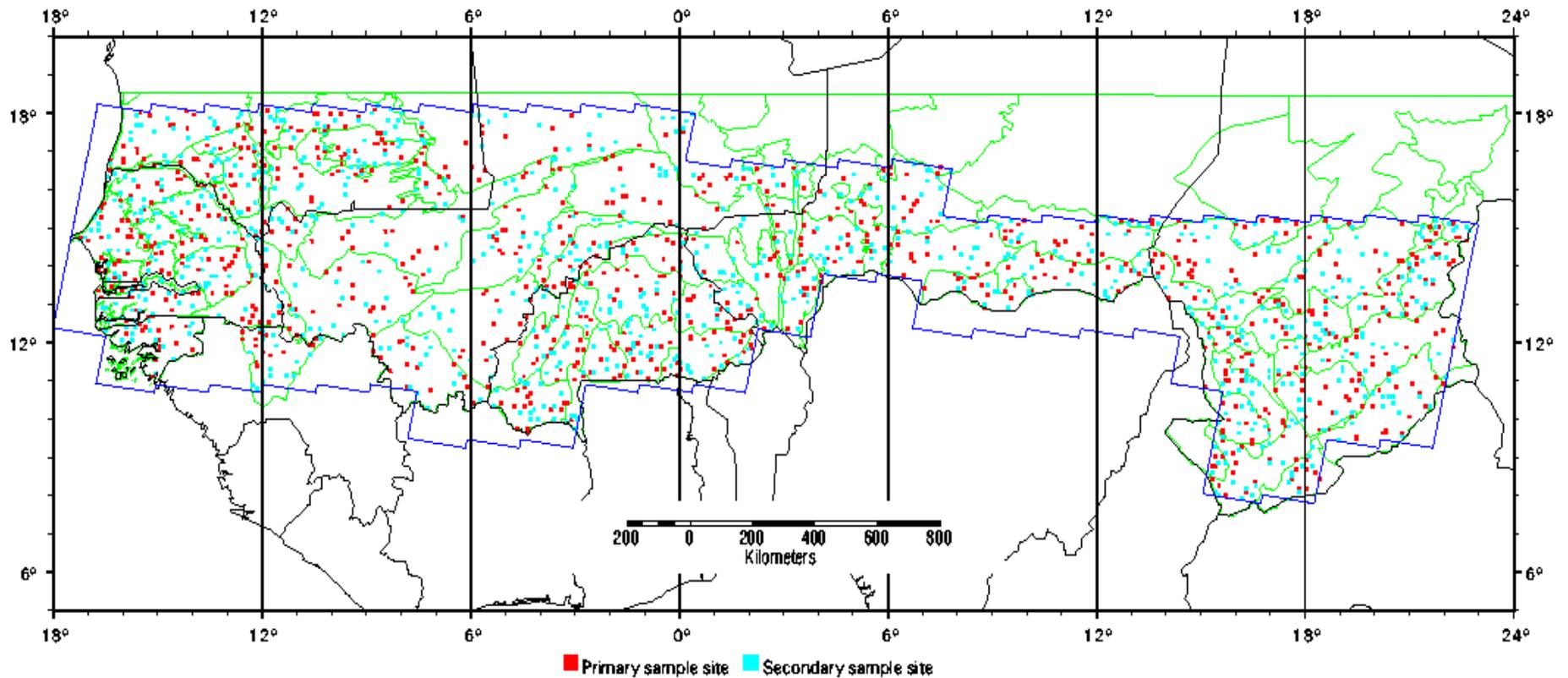


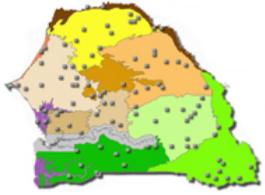


# Atelier sur la stratification des régions écologiques AGRHYMET / Niamey



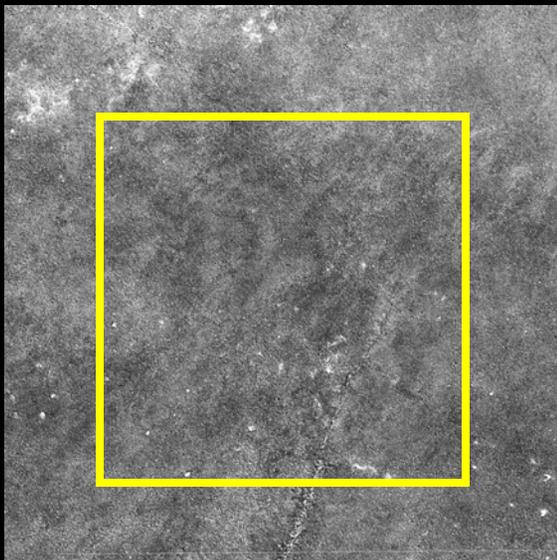
# Echantillons et Régions Ecologiques





## Exemple d'un échantillon en Casamance (Sénégal)

**Corona 1965**



**10 X 10 km**

**Landsat TM 1985**



**10 X 10 km**

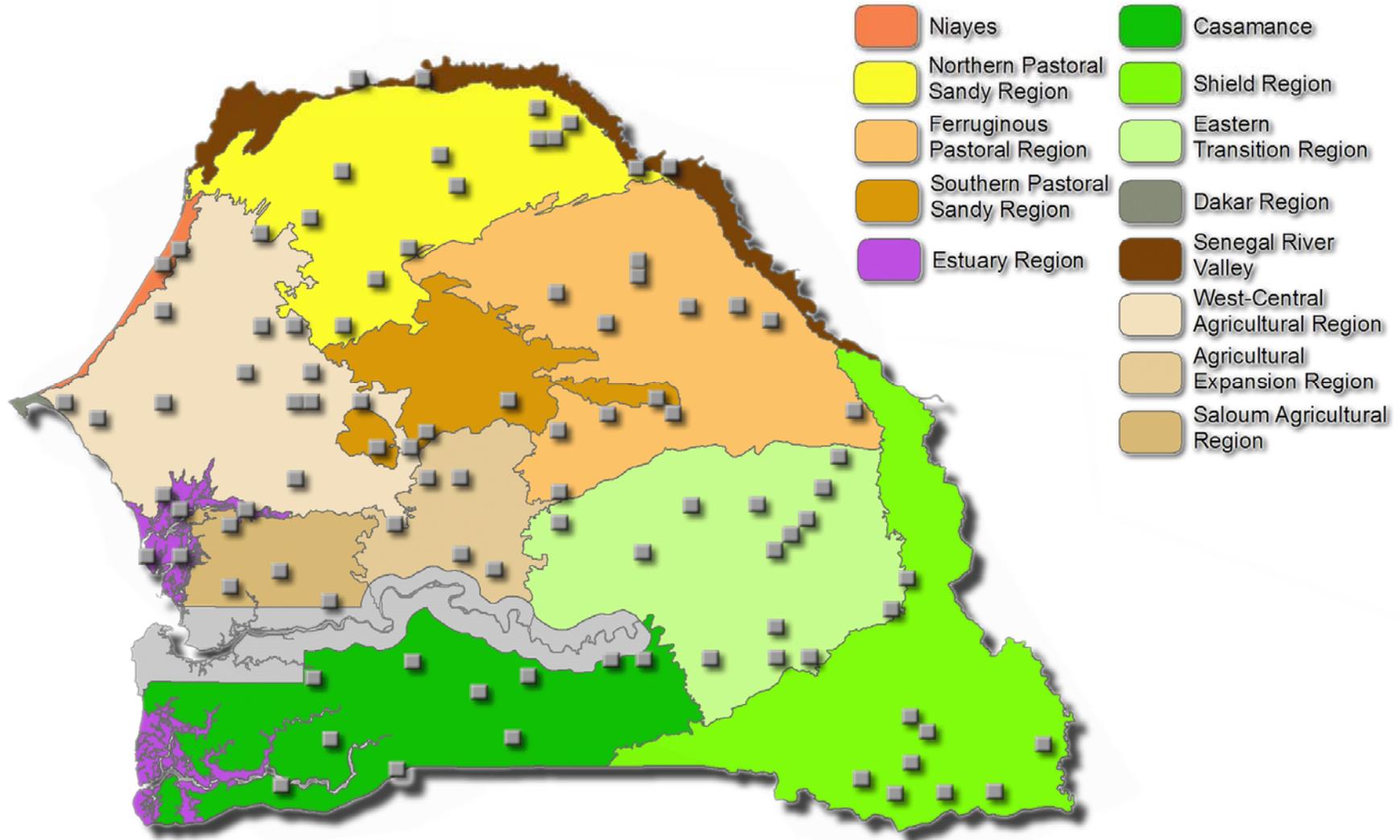
**Landsat ETM 2000**



**10 X 10 km**

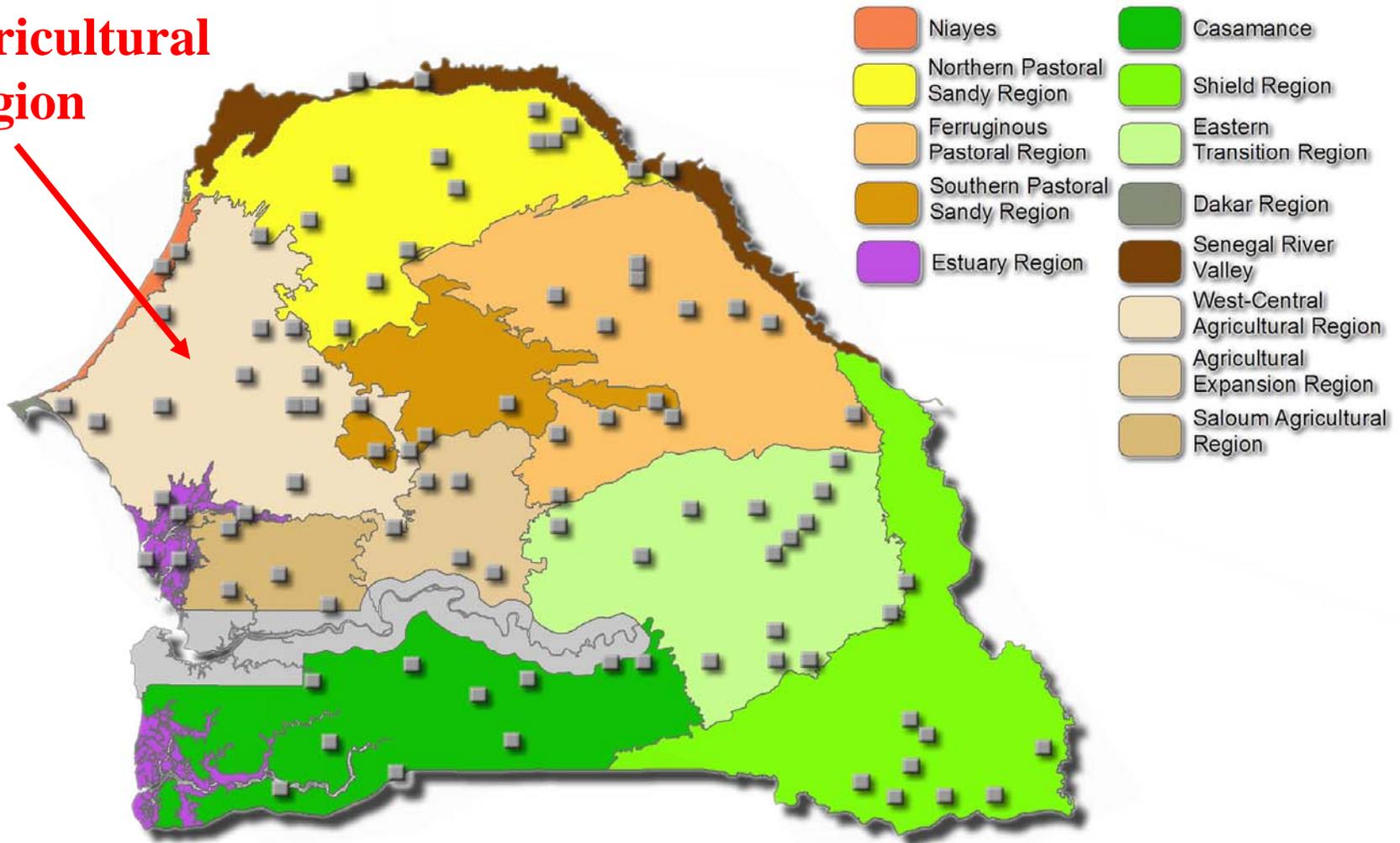
# The Ecoregions of Senegal

showing the 10x10 km Sampling Frames



**West-Central  
Agricultural  
Region**

**The Ecoregions of Senegal**  
showing the 10x10 km Sampling Frames



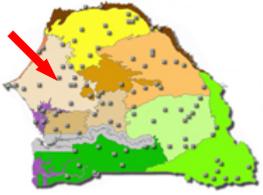
**Landscape Dynamics:  
“Peanut Basin” Land-Cover  
In the 1930’s and 1940’s**



**North of Bambey, 26 Nov. 1943**



**East of Mbour, 1930’s**



## Stability in Old Agricultural Fields (Site 1)

1982



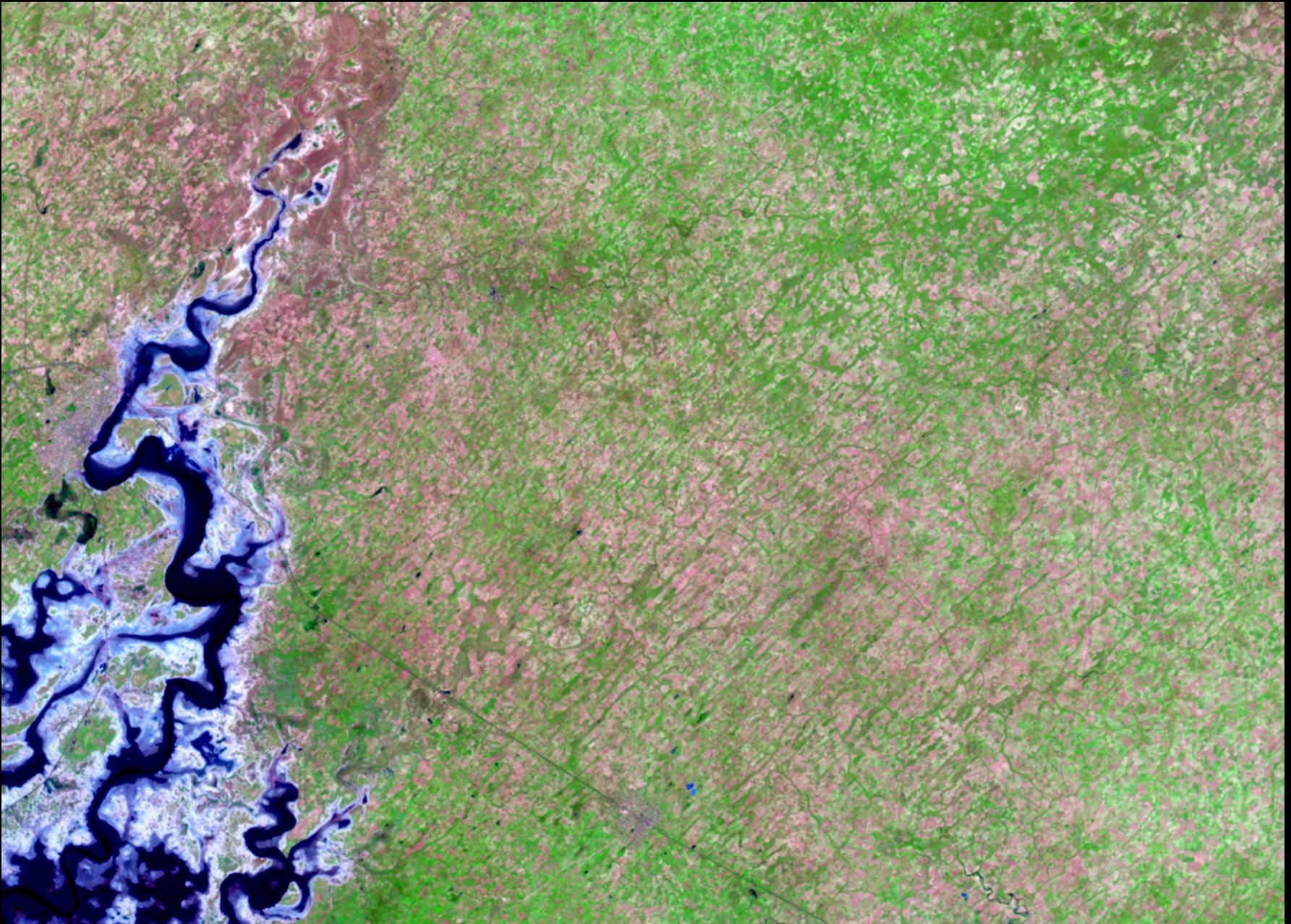
2003

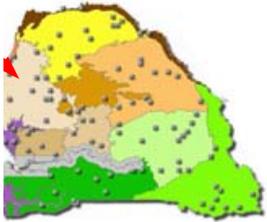
### Percent Woody Cover

1942, 1965: 5 - 10 %

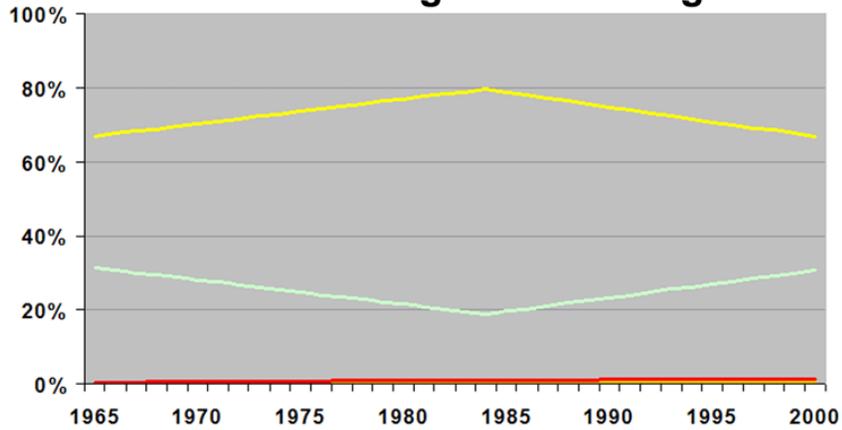
1994: 1 - 2 %

# Senegal Peanut Basin





**West-Central Agricultural Region**



**LU/LC Graph Legend**

- Agriculture / Zones de Culture
- Bare Soils / Sols Dénudés
- Forests / Forêt
- Mangroves / Mangroves
- Savannas / Savanes
- Settlements / Habitations
- Steppes / Steppes
- Water Bodies / Plans d'eau
- Wetland - Floodplain / Prairie marécageuse - Vallée inondée





## Increase in Fallow Area in the “Peanut Basin”

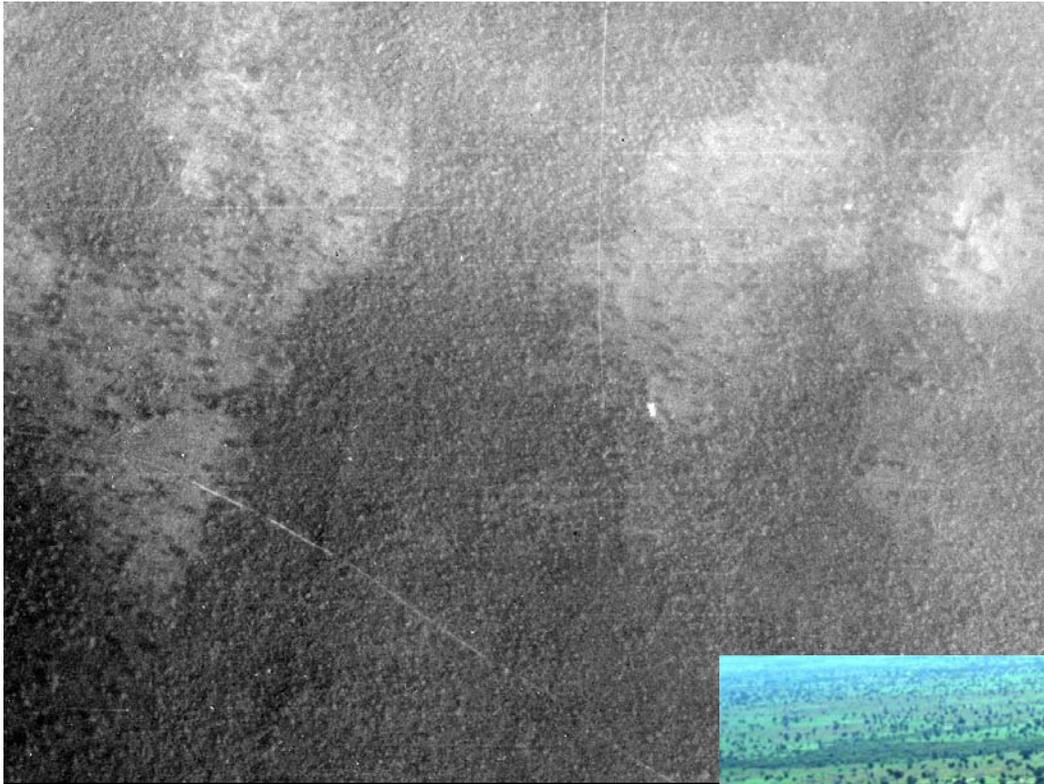


1983



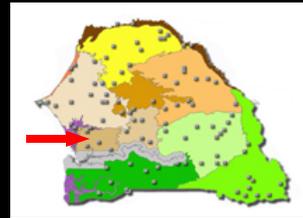
1996





Niombatu, 25 October 1943

## Saloum Agricultural Region



### Percent Woody Cover

1943:	40 – 70 %
1994 (woodlands)	10 - 20 %
1994 (cultivated)	1 – 2 %

October 1994

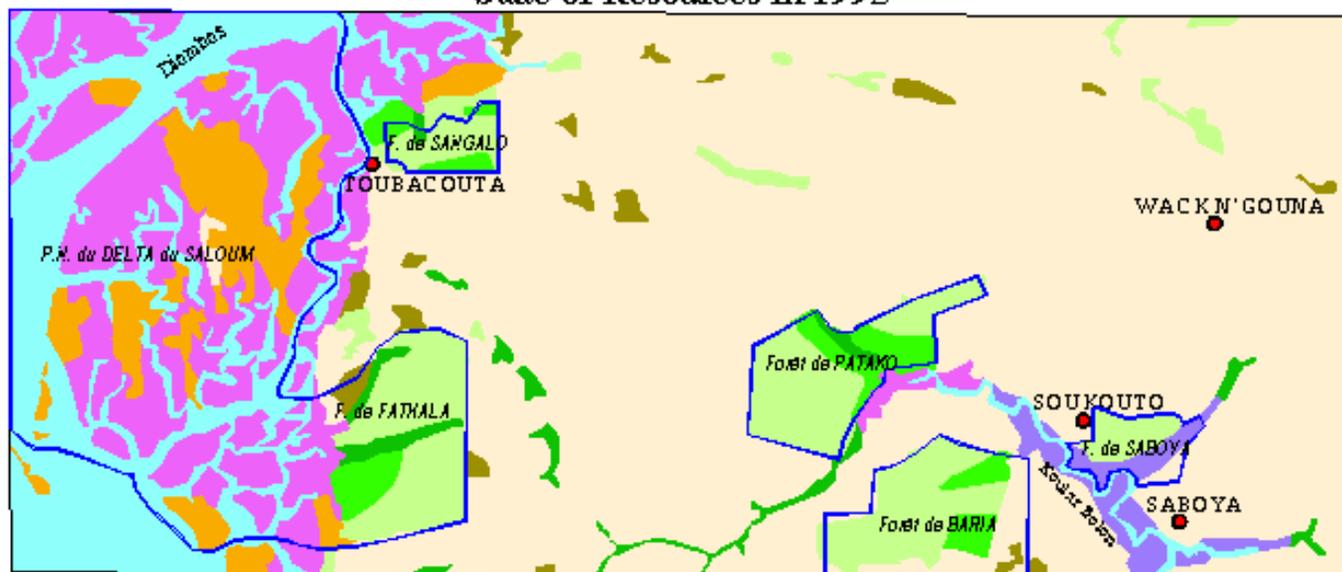


# Land Use / Land Cover Southern Peanut Basin, Senegal

State of Resources in 1963



State of Resources in 1992

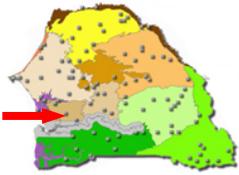


## Legend...

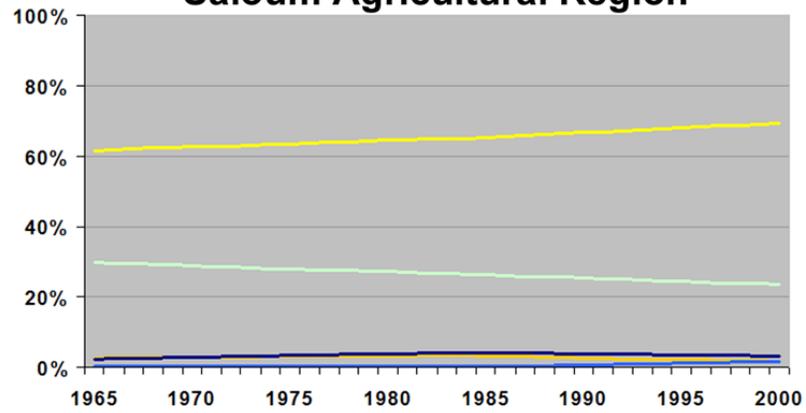
-  Intensive rainfed agriculture, limited fallow
-  Bushland, old fields
-  Savanna Woodlands
-  Woodlands
-  Woodlands in valleys, Gallery Forests
-  Tree Savannas
-  Mangroves
-  Mud Flats
-  Water
-  Major Towns
-  Protected Areas



Prepared by the U.S. Geological Survey, EROS Data Center, with funding from USAID/Senegal and the U.S. Geological Survey

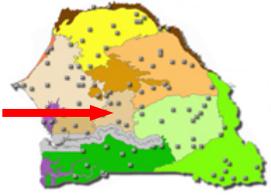


**Saloum Agricultural Region**



**LU/LC Graph Legend**





# Agricultural Expansion Region

Reduction in use of  
bush fallow (Site 581)

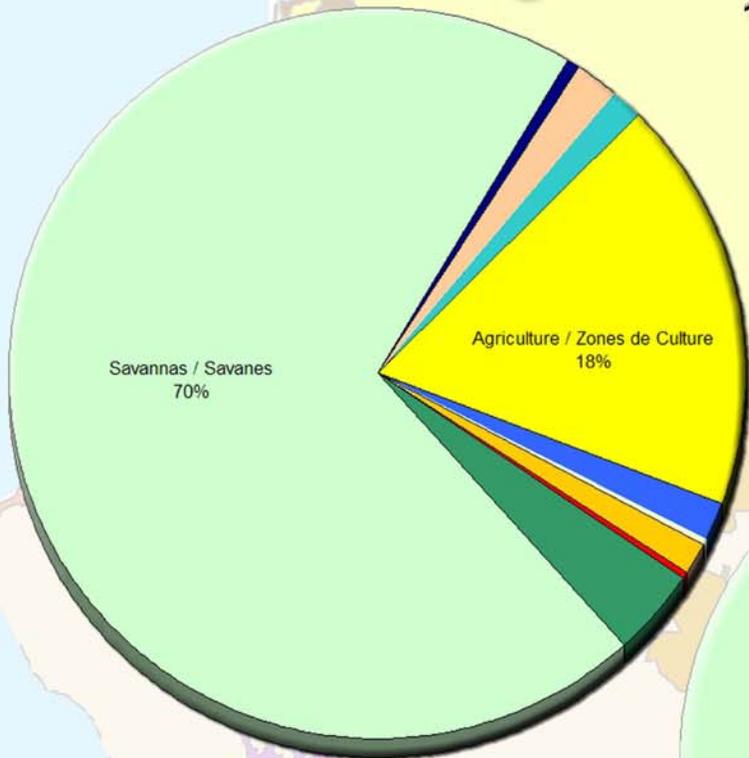
1983



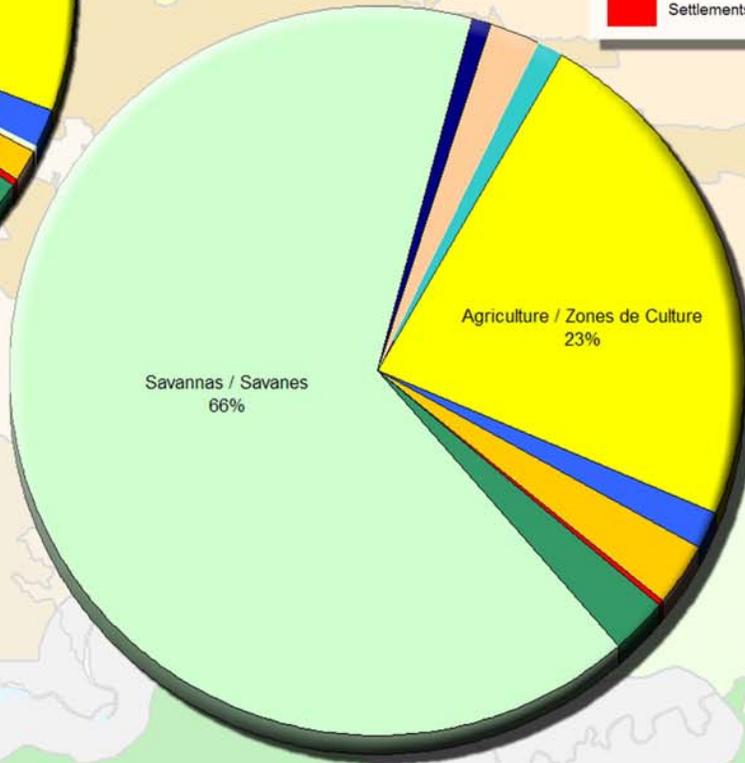
1994



# Senegal Land Use / Land Cover Change. 1965 to 2000



**1965**



**2000**

	1965	2000
Forests / Forêt	3.9%	2.3%
Savannas / Savanes	70.1%	65.7%
Wetland - Floodplain / Prairie marécageuse - Vallée	0.6%	0.7%
Steppes / Steppes	1.8%	2.3%
Mangroves / Mangroves	1.5%	1.1%
Agriculture / Zones de Culture	18.3%	23.0%
Water Bodies / Plans d'eau	1.7%	1.8%
Sandy Areas / Surfaces Sableuses	0.1%	0.1%
Bare Soils / Sols Dénudés	1.7%	2.7%
Settlements / Habitations	0.2%	0.3%

## **Basic Conclusions on Senegal Land Cover Trends**

- **Good news: rates of agricultural expansion into Senegals woodlands and savannas is slower than what most official figures have claimed**
- **Rates of agricultural expansion have slowed Since the mid 1980s**
- **Bad news: Senegal's vegetation cover has significantly declined since the 1960s, both in terms of its density, and in terms of its biodiversity**