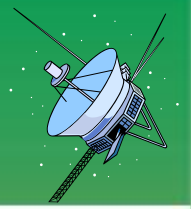
Centre de Suivi Ecologique

Pour la gestion des ressources naturelles



Geospatial Based Approaches for Monitoring and Assessing Natural Resources in Senegal

Abdoul Aziz Diouf, PhD

Centre de Suivi Ecologique
Research-Development program

aziz.diouf@cse.sn

31st March 2022

Rue Léon Gontran Damas, Fann Résidence, Dakar - BP : 15 532 Dakar Fann (Sénégal) - Fax : +221 33 825 81 68
Tel. : +221 33 825 80 66 / +221 33 825 80 67 - Courriel : contact@cse.sn - Site web : www.cse.sn

ISO 9001 BUREAU VERITAS Certification

Centre de Suivi Ecologique

The *Centre de Suivi Ecologique*

1986

Project of Sahelian Pastoral Ecosystems Monitoring

- Create new skills
- Put in place monitoring procedures and processes
- Develop quality HR
- Access to cut-off equipment
- Limited interventions in the Ferlo

1993

Creation of *Centre de Suivi Ecologique*

- Consolidation of knowledge
- Institutionalization
- Involvement in national strategies
- Contribution to national capacity building in geomatics
- Interventions across Senegal

2022

Centre de Suivi Ecologique

- 1997: Agreement with the State, recognition of public utility
- 2010: First National Entity to implement the CC Adaptation Fund
- 2015 : First National Implementing Entity of the Green Climate Fund
- 2016: ISO 9001 certification
- Interventions in several African countries

1997: Agreement with the State, recognition of Public Utility

Centre de Suivi Ecologique

Pastoralism and Drylands Pole (PPZS)

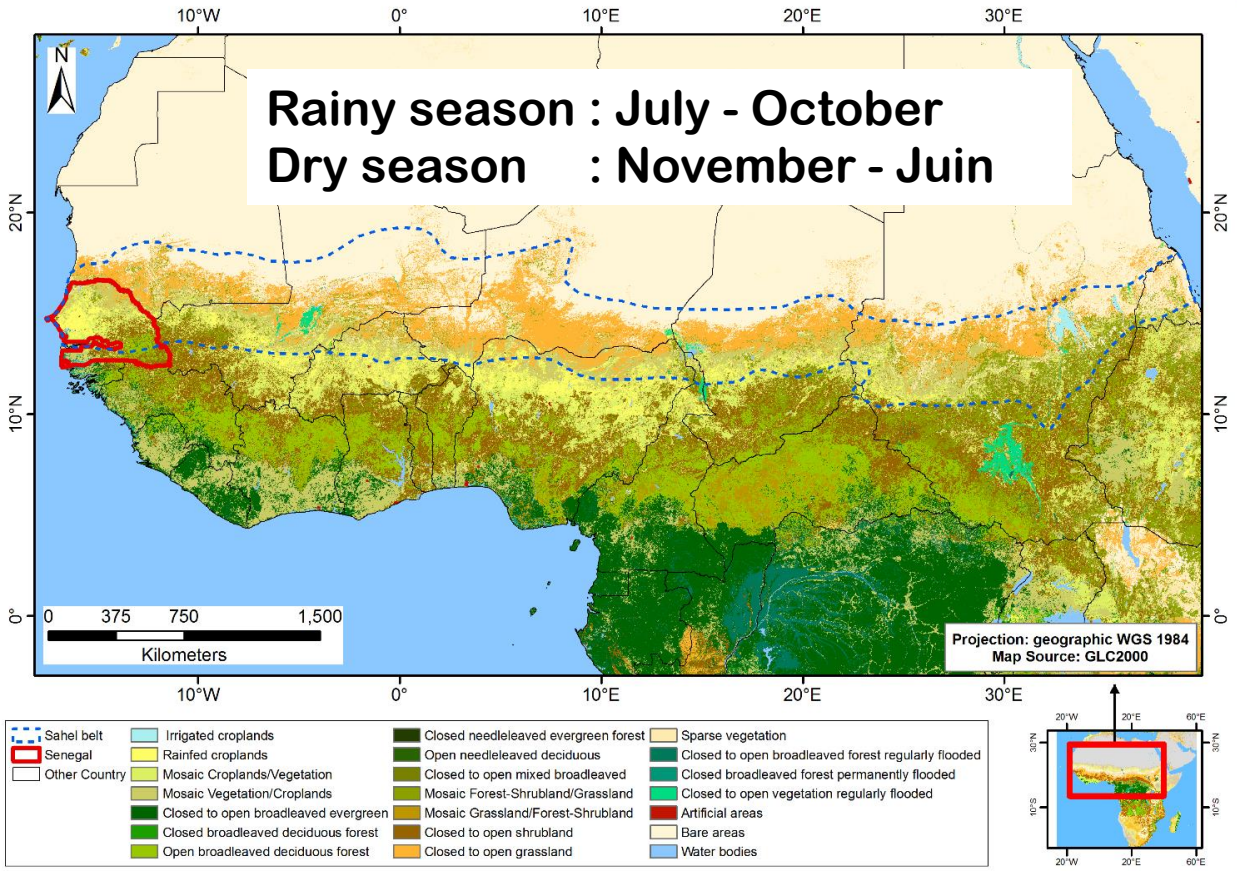
www.ppzs.org

- Broad group of researchers and teachers
- Confront the scientific knowledges and develop skills to support innovation
- Multidisciplinary expertise of national and international institutions to tackle major issues raised by future contributions of livestock to the agricultural sector, environment, livelihoods and food security of the populations in the Sahel

www.ppzs.org

Centre de Suivi Ecologique

Location of Senegal



Population 2022(P): 17 738 795

Population women: 8 913 568

Population men: 8 825 227

Area (km²): 196 712

Density (Pers/km²): 90

Capitale: Dakar

Three climatic zones:

- humid to subhumid (south)
- subhumid to semi-arid (centre)
- semi-aride to arid (north)

Rainfall:

- from 1200 mm in the South to 300 mm in the North

Agriculture:

60% of households (in 2013)

Rue Léon Gontran Damas, Fann Résidence, Dakar - BP : 15 532 Dakar Fann (Sénégal) - Fax : +221 33 825 81 68
Tel. : +221 33 825 80 66 / +221 33 825 80 67 - Courriel : contact@cse.sn - Site web : www.cse.sn

www.ansd.sn/

ISO 9001 BUREAU VERITAS Certification

Centre de Suivi Ecologique

Outline

1. Current applications
    - 1.1. Monitoring of vegetation growth
    - 1.2. Assessment of the forage biomass production
    - 1.3. Monitoring ephemeral waterbodies
    - 1.4. Assessment of the woody canopy cover
    - 1.5. Targets and end-users

2. Some ongoing research activities
    - 2.1. Monitoring of dry season forage biomass
    - 2.2. Assessment of herbaceous mass using UAV and photogrammetry

Centre de Suivi Ecologique

Current applications

Centre de Suivi Ecologique

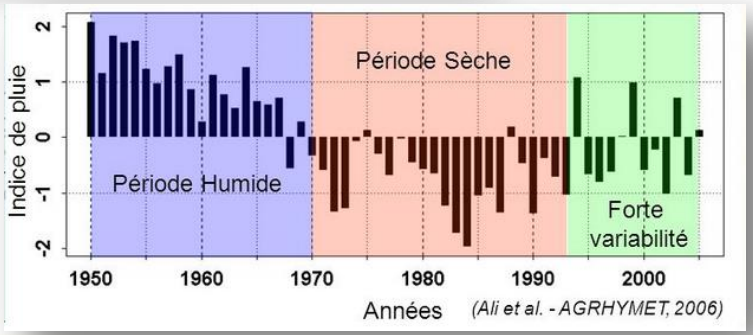
Why forage biomass monitoring?

~ 60% of the population <-- livestock

~ 17 million heads (in 2015)

Source of income

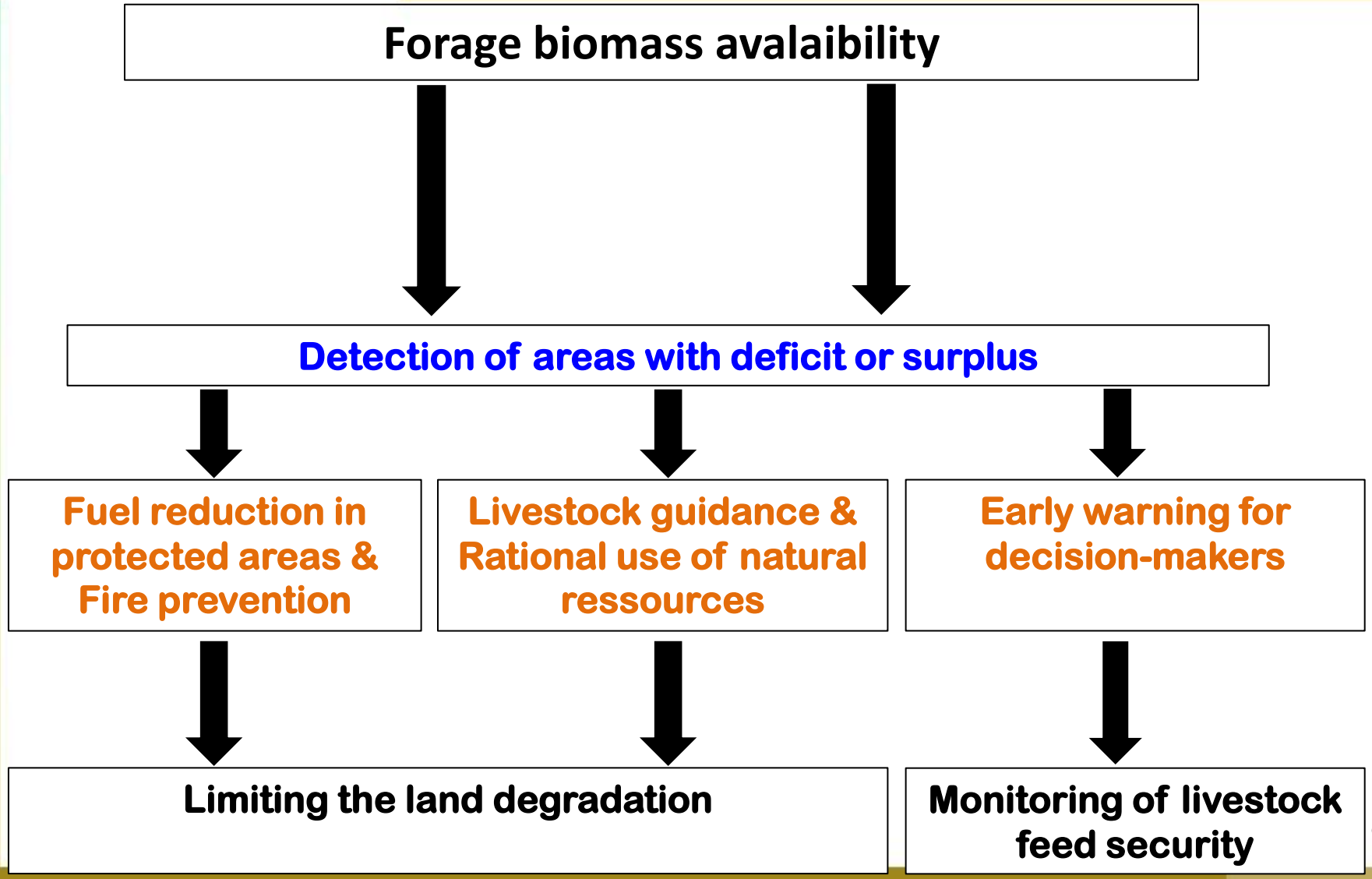
~30% of the population



>>> **High variability in production and quality of forage biomass**

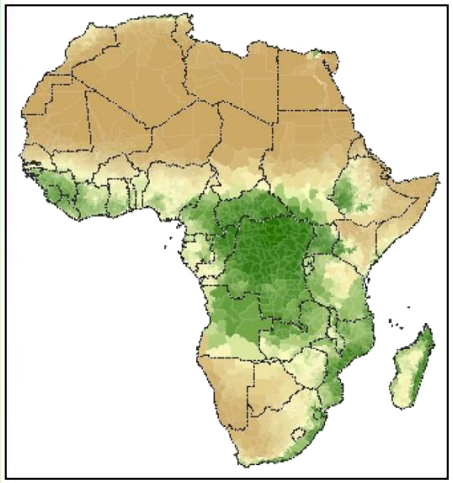
Centre de Suivi Ecologique

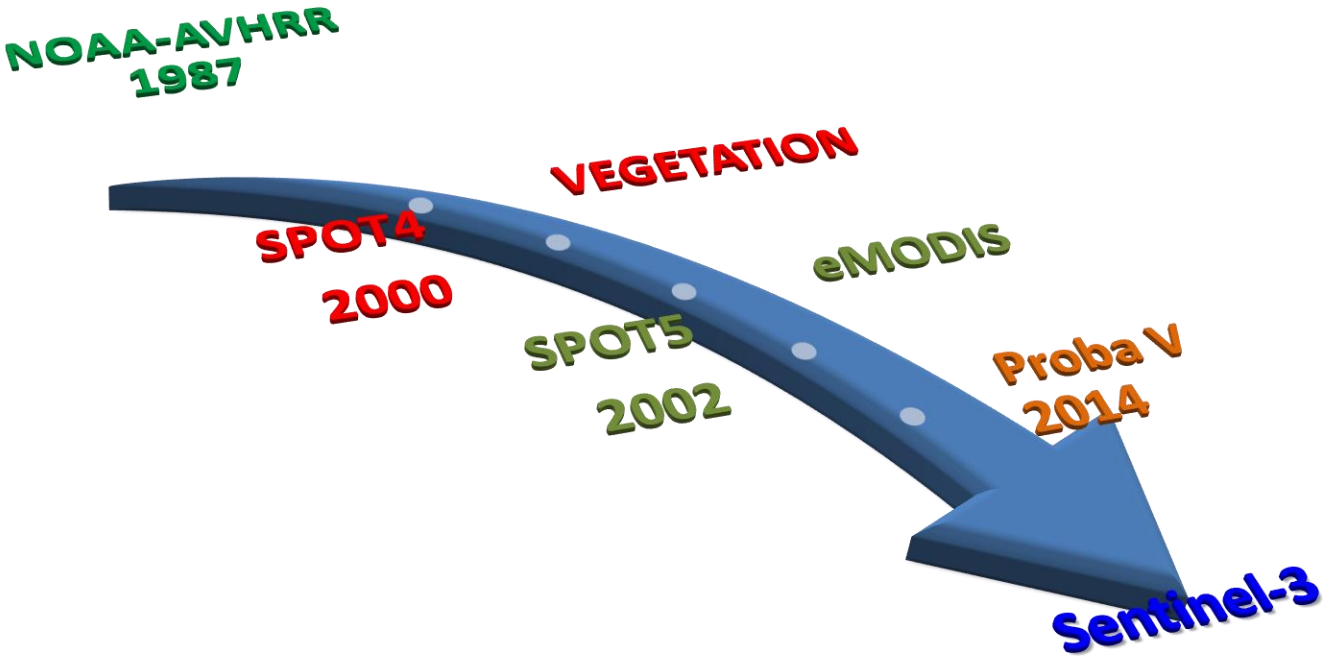
Why forage biomass monitoring?



Centre de Suivi Ecologique

Satellite data acquisition





NDVI: Normalized Difference Vegetation Index

FAPAR: Fraction of Absorbed Photosynthetically Active Radiation

LAI: Leaf Area Index

Rue Léon Gontran Damas, Fann Résidence, Dakar - BP : 15 532 Dakar Fann (Sénégal) - Fax : +221 33 825 81 68
Tel. : +221 33 825 80 66 / +221 33 825 80 67 - Courriel : contact@cse.sn - Site web : www.cse.sn

ISO 9001 BUREAU VERITAS Certification

Centre de Suivi Ecologique

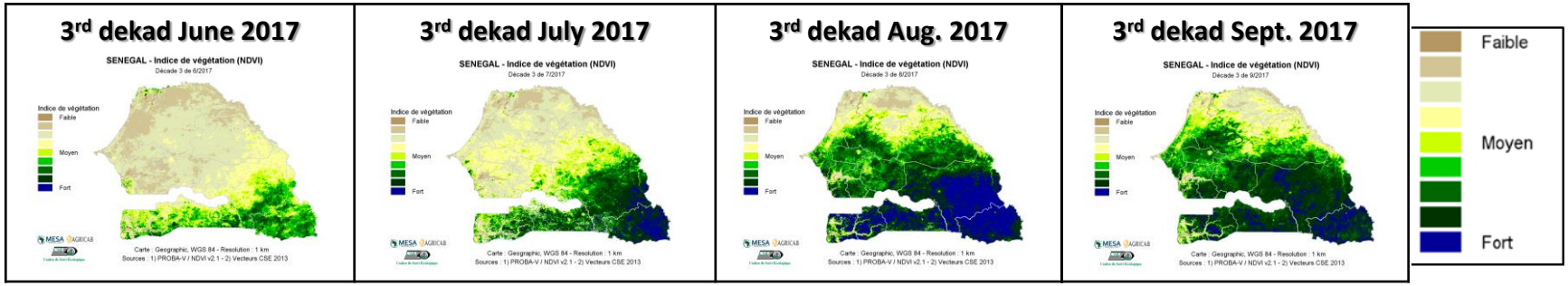
Monitoring of vegetation growth

Normalized Difference Vegetation Index (NDVI)

Expresses the chlorophyll activity of plants and is thus a metrics of the vegetation presence on the ground in a given area

NDVI = (NIR – R) / (NIR + R)

Where **NIR** = % of reflectance in the Near Infra Red
R = % of reflectance in the Red



Used to detect areas with chlorophyll activity

Rue Léon Gontran Damas, Fann Résidence, Dakar - BP : 15 532 Dakar Fann (Sénégal) - Fax : +221 33 825 81 68
Tel. : +221 33 825 80 66 / +221 33 825 80 67 - Courriel : contact@cse.sn - Site web : www.cse.sn

ISO 9001 BUREAU VERITAS Certification

Centre de Suivi Ecologique

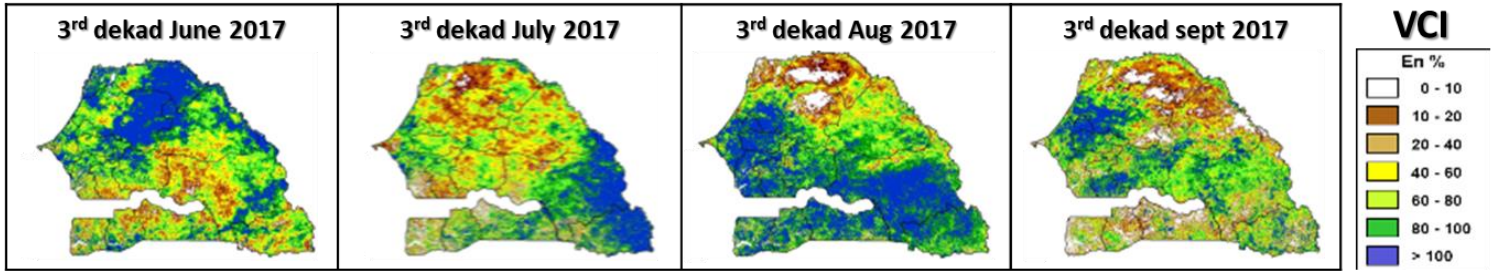
Monitoring of vegetation growth

Vegetation Condition Index (VCI)

VCI is used to rank, from 0 to 100, the level of vegetation growth in relation to the maximum value recorded for the same decade since 1999.

VCI = [(NDVIdek – NDVImindek) / (NDVImaxdec - NDVImindek)] * 100

Where **NDVIdek** is the NDVI value of the study period ; **NDVImindek** and **NDVImaxdek** correspond to the minimum and maximum NDVI values of the same dekad, calculated on the historical series of SPOT-Vegetation /PROBA-V /Sentinel-3.

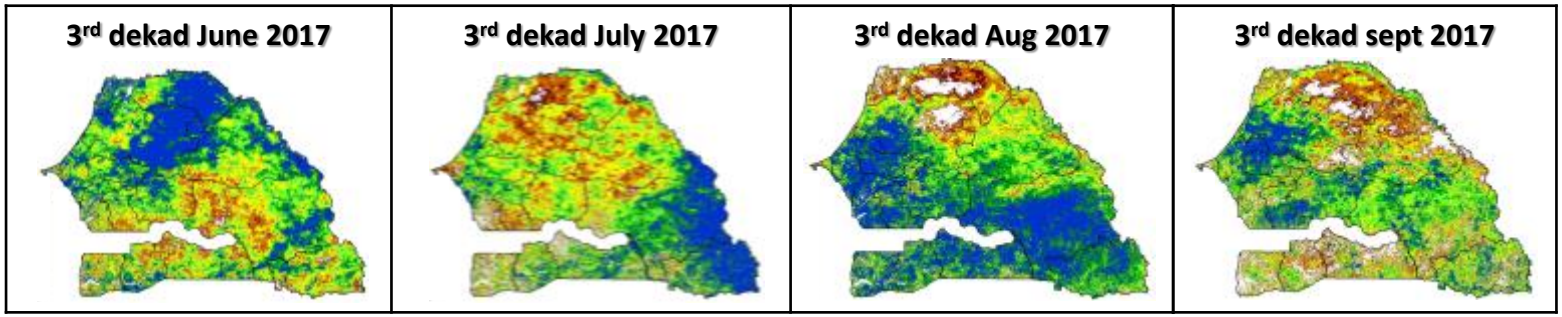


Used to detect areas with plant growth anomalies (for Early Warning)

Centre de Suivi Ecologique

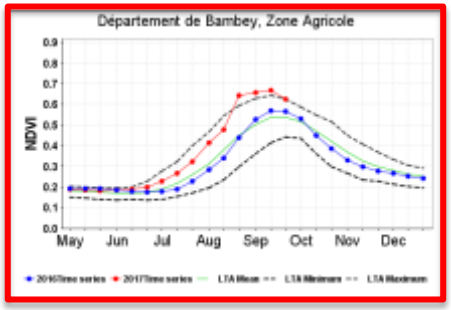
Monitoring of vegetation growth

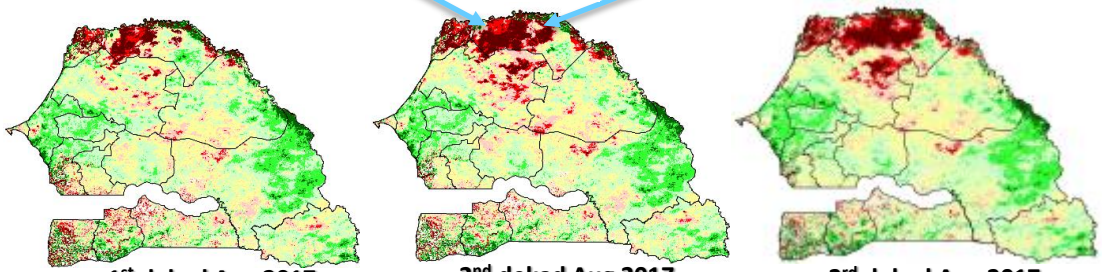
Vegetation growth anomalies (NDVI, VCI and SOS: start of season)



LULC mask

Croplands Rangelands





1st dekad Aug 2017 2nd dekad Aug 2017 3rd dekad Aug 2017

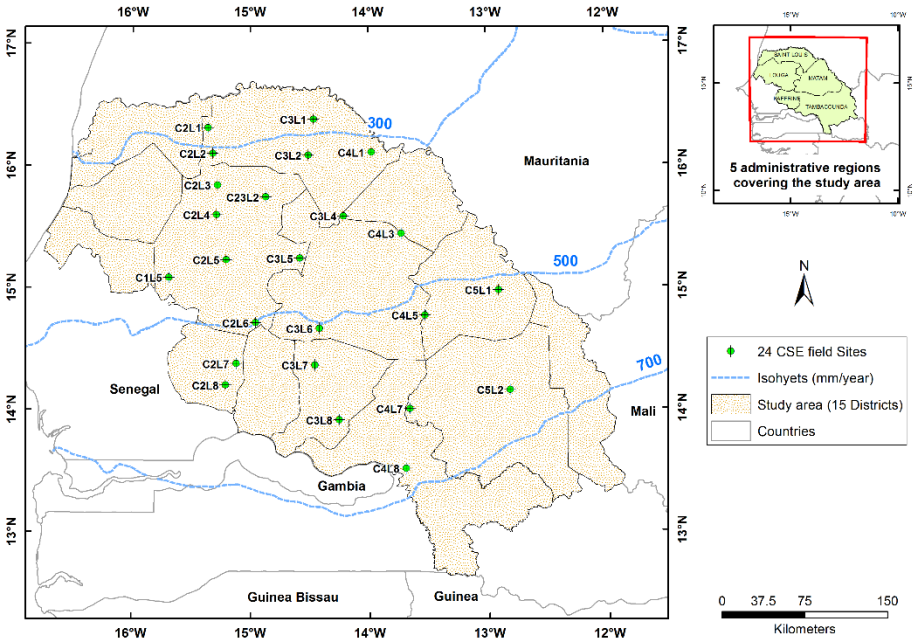
SOS => detect areas with growing delay or advance (in dekads)

Rue Léon Gontran Damas, Fann Résidence, Dakar - BP : 15 532 Dakar Fann (Sénégal) - Fax : +221 33 825 81 68
Tel. : +221 33 825 80 66 / +221 33 825 80 67 - Courriel : contact@cse.sn - Site web : www.cse.sn

Centre de Suivi Ecologique

Assessment of the forage biomass production

Monitoring sites and field data collection



- 24 sites
- 3km*3km ~ 9 pixels SPOT-VGT
- Accessibility ;
- Homogeneity of ecological conditions ;
- Good representation of the landscape

- Sampling (mesures) -> end of the growing season (Octobre)
  - Herbaceous layer
  - Woody stratum

Centre de Suivi Ecologique

Assessment of the forage biomass production

Stratified sampling of the herbaceous layer

Transect length = 1000 meters

- Noting of frequency of four approximate production classes(or levels)
  - Class 1 (0 = bare soil)
  - Class 2 (1 = low production)
  - Class 3 (2 = fair production)
  - Class 4 (3 = high production)

- Collection and weighing of fresh biomass of 35 to 100 plot (1 meter square)
- Resampling of the four classes
- **3 samples of about 200 g taken for each class to the lab (Oven)**

Centre de Suivi Ecologique

Assessment of the forage biomass production

Systematic sampling of woody stratum

Along the 1000m transect

- Four circular plots sampled at the distance 200, 400, 600 et 800 m (every 2 years)
- Complete inventory (every 2 years)
- Cut leaves from ten twigs of each of the most representative especies (annually)
- **Weighing of fresh foliar mass of each especies**

Centre de Suivi Ecologique

Assessment of the forage biomass production

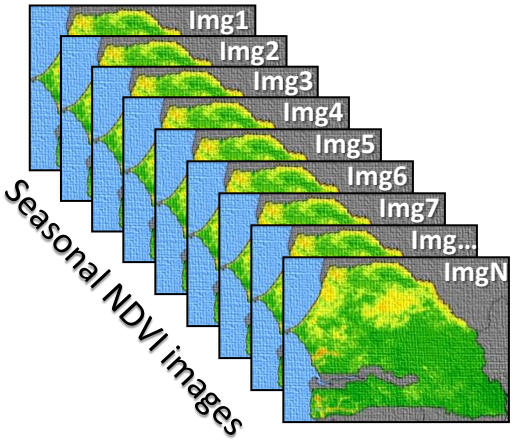
Linear regression model (traditional)

Calculation of NDVI integral and extraction

1. Growing season determined by visual analysis of decadal images

2. Weighed average of seasonal images

NDVI_integrated = $(\sum^{t}_{i=1} NDVI * Xi)/P$



Where **NDVI** = dekadal NDVI image,
Xi = covered period by image = 10,
P = number of day of considered period

Centre de Suivi Ecologique

Assessment of the forage biomass production

Linear regression model (traditional)

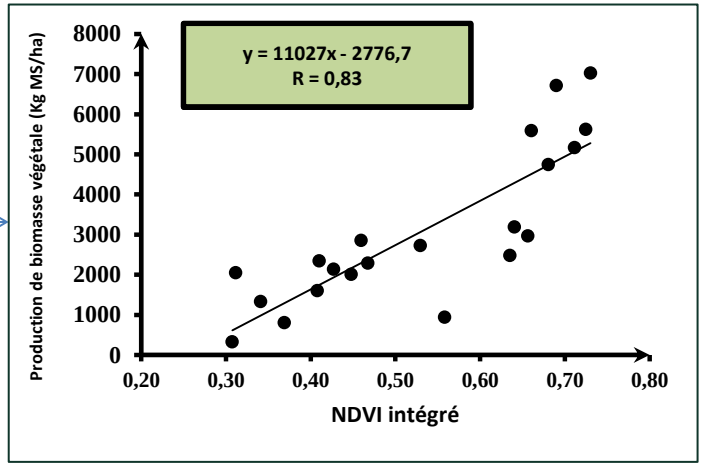
Model calibration

Data table

J	K	L
SCS	NDVIi	Biotot
C1L5	0,4260	1230
C2L1	0,3030	940
C2L2	0,3811	1508
C2L3	0,4340	1829
C2L4	0,4100	1378
C2L5	0,5255	2287
C2L6	0,5949	2368

Linear regression

CSE result in 2013



P= a * NDVI + b

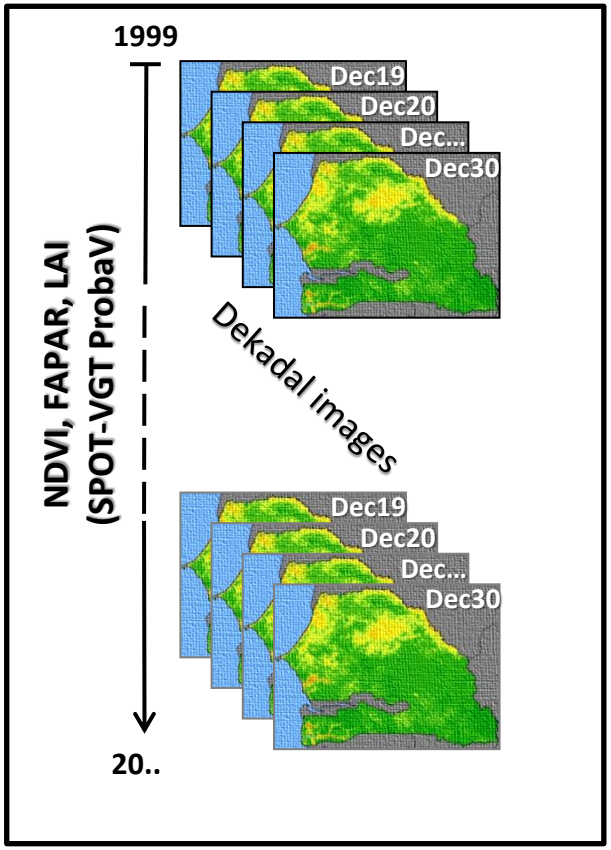
Performance measure = R^2 (good if near to 1)

Centre de Suivi Ecologique

Assessment of the forage biomass production

Intra-seasonal approach with non-linear models

Satellite data processing

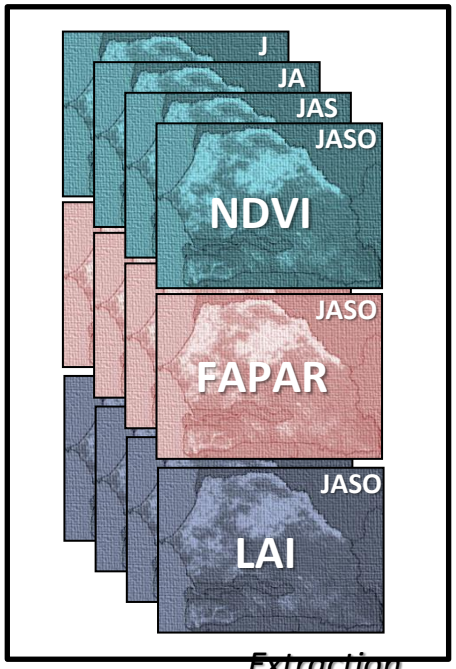


http://land.copernicus.eu/

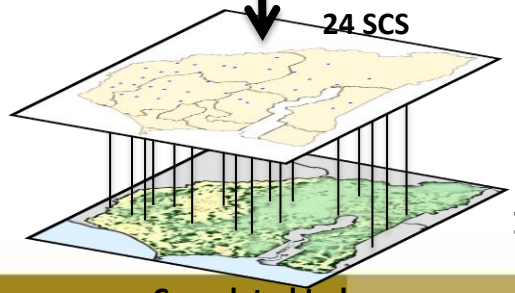
J =	Cumul of July
JA =	Cumul of July and August
JAS =	Cumul from July to September
JASO =	Cumul from July to October

Temporal smoothing

Cumulation



Extraction



Cumulated Index

Data table (for Modeling)

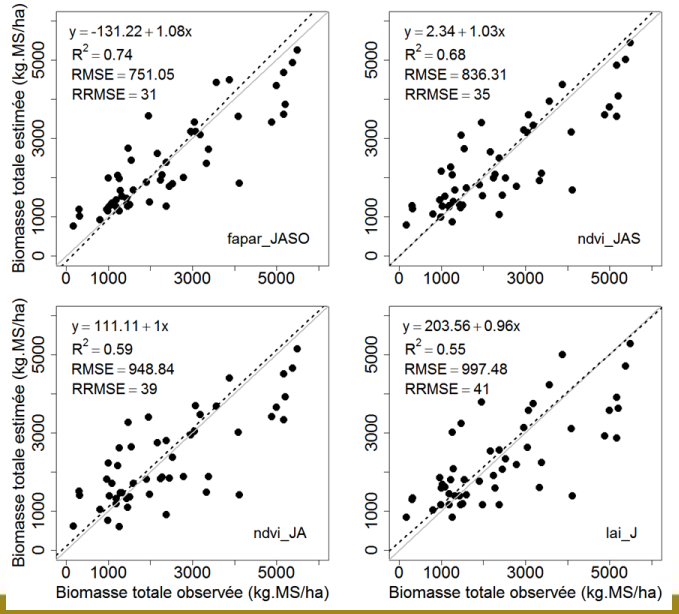
Centre de Suivi Ecologique

Assessment of the forage biomass production

Intra-seasonal approach with non-linear models

Equation et statistical performance of selected models

Variable	Equation	R^2	RMSE (kg.MS/ ha)
fapar_JASO	Y = 669.1 * exp(X * 0.22)	0,66	769,25
ndvi_JAS	Y = 403.2 * exp(X * 0.41)	0,62	806,31
ndvi_JA	Y = 750.8 * (X^1.37)	0,56	866,40
lai_J	Y = 2420.8 * (X^0.46)	0,58	851,22



- LAI (**lai_J**) most suited for biomass forecasting at the begining of the season
- NDVI (**ndvi_JA** et **ndvi_JAS**) most suited for the mid season
- FAPAR (**fapar_JASO**) works better at the end of the season
- Increasing performance of models along the season

Centre de Suivi Ecologique

Assessment of the forage biomass production

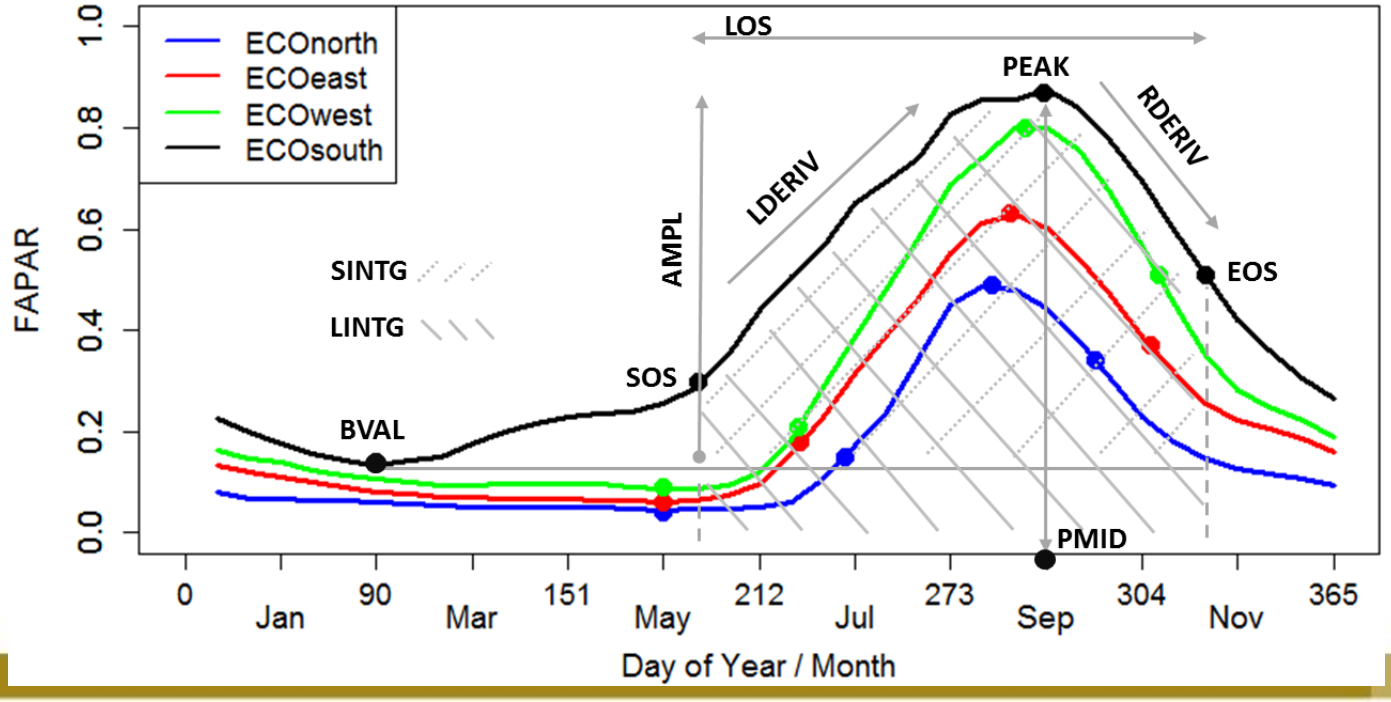
Approach with multi-linear regression models

Phenological variables from FAPAR Time Series

TIMESAT

Start of season = 20%
End of season = 50 %
Numb. of iterations = 2
Adaptation strength = 2
Windows size = 4 decades

11 phenological metrics



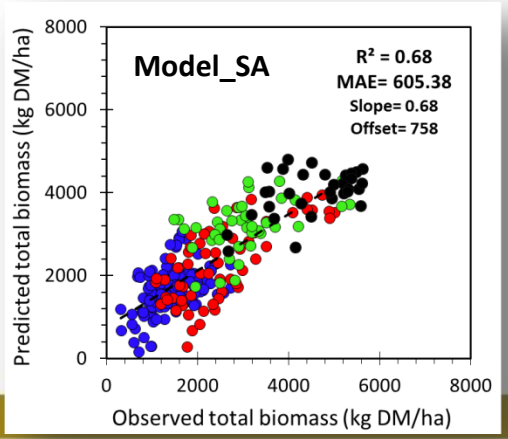
Centre de Suivi Ecologique

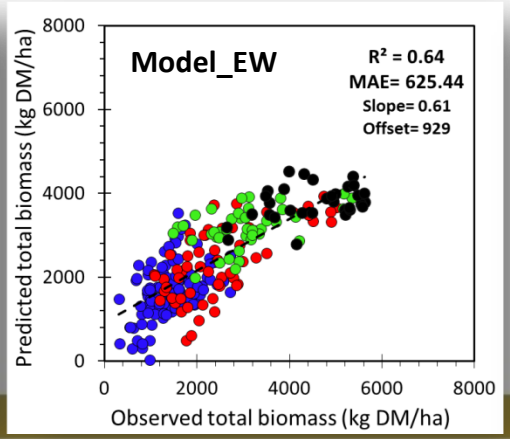
Assessment of the forage biomass production

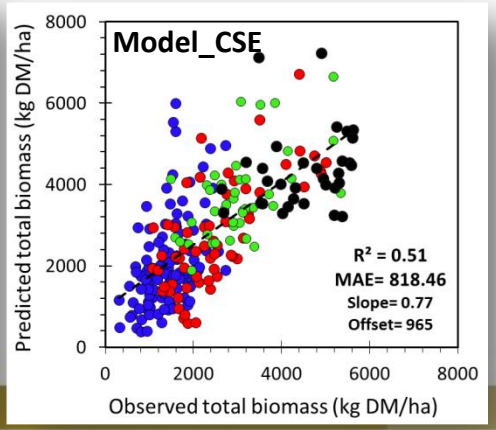
Approach with multi-linear regression models

Equation and statistical performance of models

Region	Estimation Model of Total Biomass (B)		Adj. R^2	MAE (kg·DM/ha)	NMAE (%)	n/n_test
Study area	Model_SA	$B = 424.13 \times LINTG - 100.91 \times LOS + 39.80 \times RDERIV + 293.71$	0.67	608	26.0	263/39600
	Model_EW	$B = 4594.18 \times PEAK - 129.09 \times SOS + 1866.17$	0.62	641	27.3	263/39600



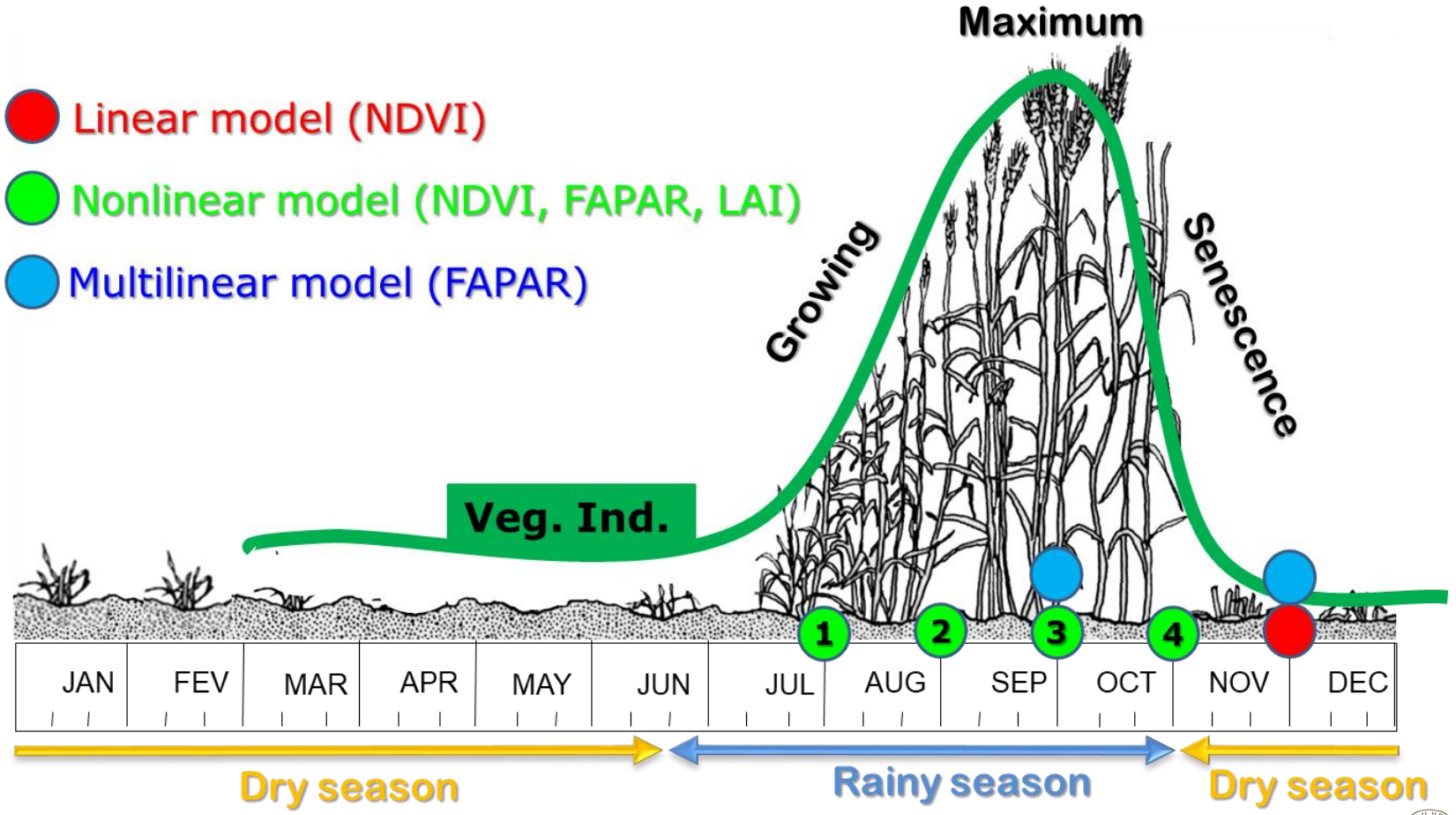




Centre de Suivi Ecologique

Assessment of the forage biomass production

Operational system for forage assessment



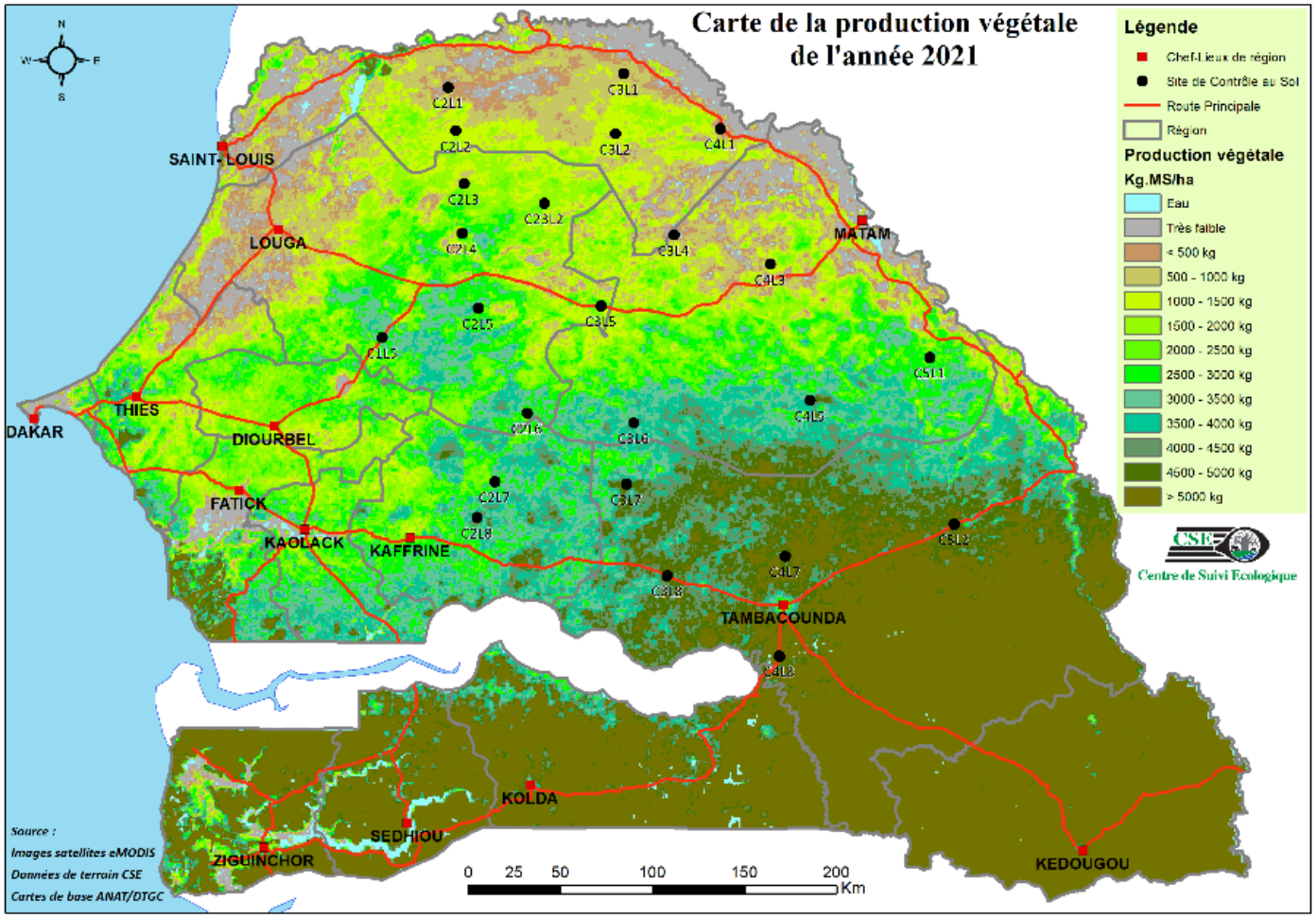
Rue Léon Gontran Damas, Fann Résidence, Dakar - BP : 15 532 Dakar Fann (Sénégal) - Fax : +221 33 825 81 68
Tel. : +221 33 825 80 66 / +221 33 825 80 67 - Courriel : contact@cse.sn - Site web : www.cse.sn

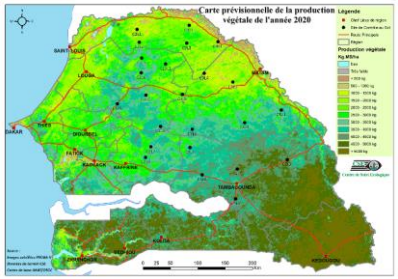
ISO 9001 BUREAU VERITAS Certification

Centre de Suivi Ecologique

Assessment of the forage biomass production

Operational system for forage assessment



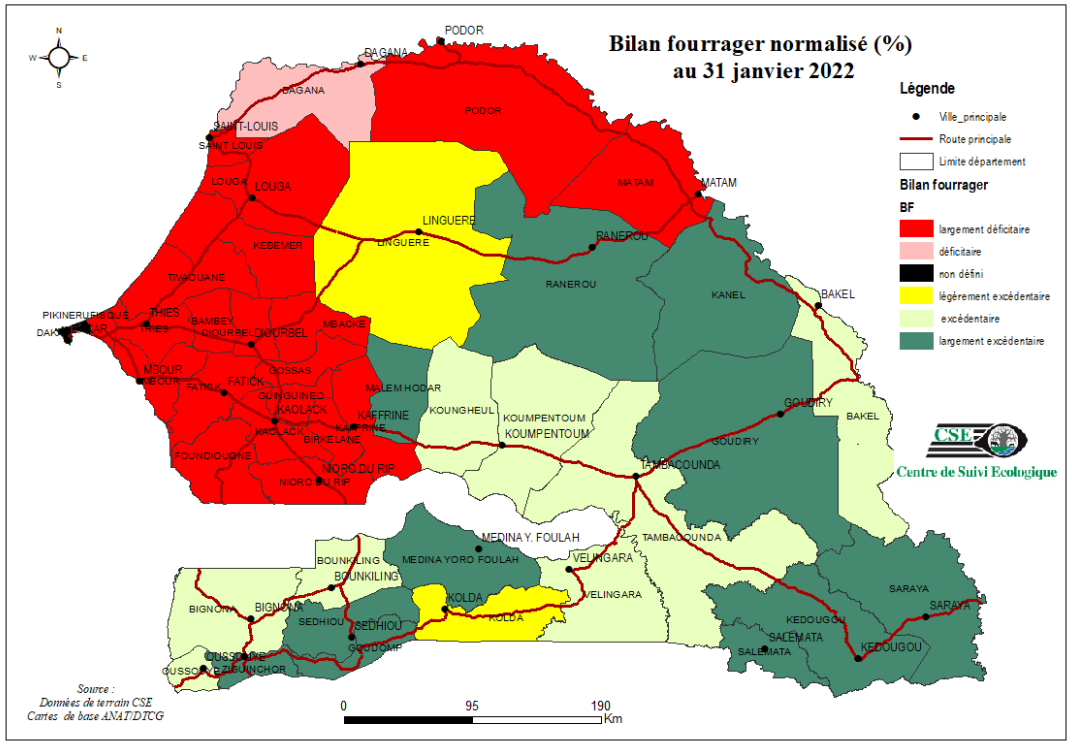


Examples of map shared with end-users (i.e. Natural resource managers, livestock and rangeland managers)

Centre de Suivi Ecologique

Assessment of the forage biomass production

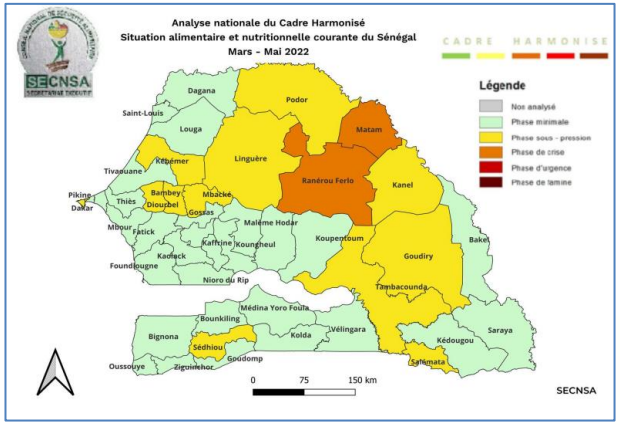
Forage stock and feed balance



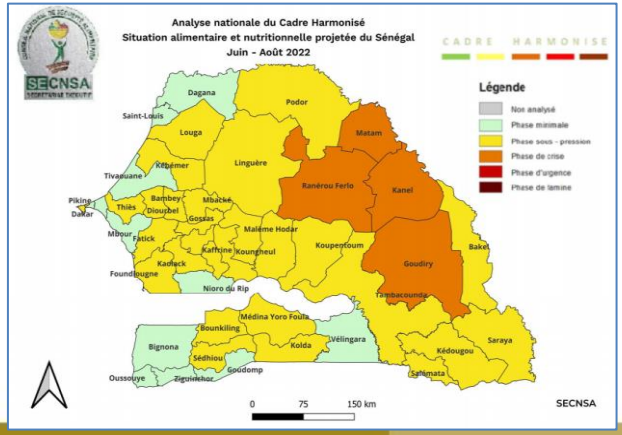
Feed balance is monthly updated along the dry season

Monitor feed balance status in administrative unit (i.e. level-3)

Current situation (March 2022)



Projected situation (JJA 2022)

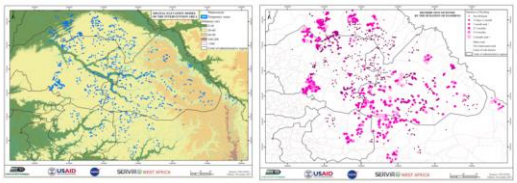


Centre de Suivi Ecologique

Monitoring ephemeral waterbodies

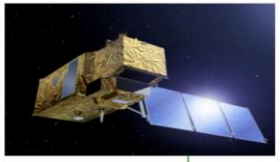
System development and calibration

Field data



Pond of Loumboul Amar (Sarr, 2017)

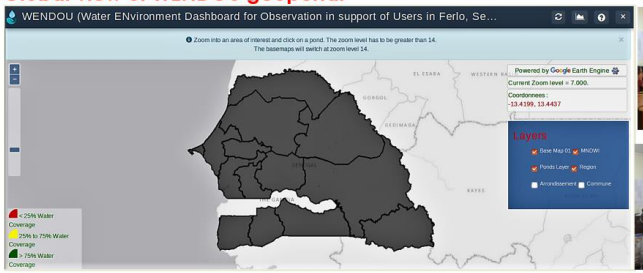
Landsat-8 and Sentinel-2



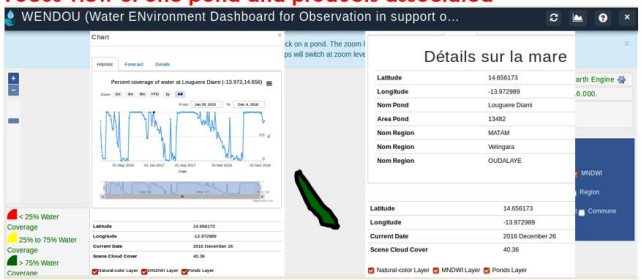
Modified Normalized Difference Water Index (MNDWI)

Tethys Platform

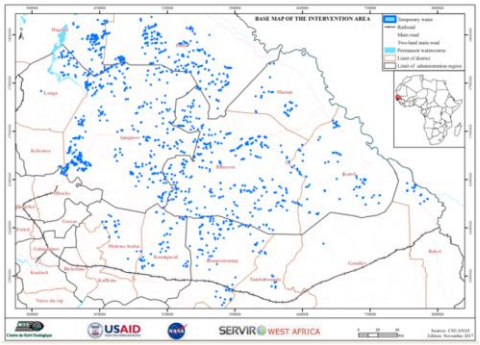
Global view of WENDOU geoportal



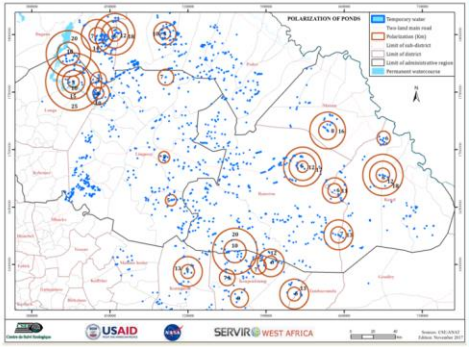
Focus view of one pond and products associated



Ponds location



Polarization area of ponds



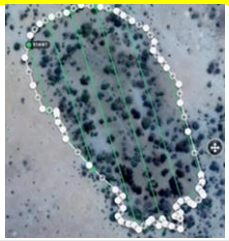
Rue Léon Gontran Damas, Fann Résidence, Dakar - BP : 15 532 Dakar Fann (Sénégal) - Fax : +221 33 825 81 68
Tel. : +221 33 825 80 66 / +221 33 825 80 67 - Courriel : contact@cse.sn - Site web : www.cse.sn

ISO 9001 BUREAU VERITAS Certification

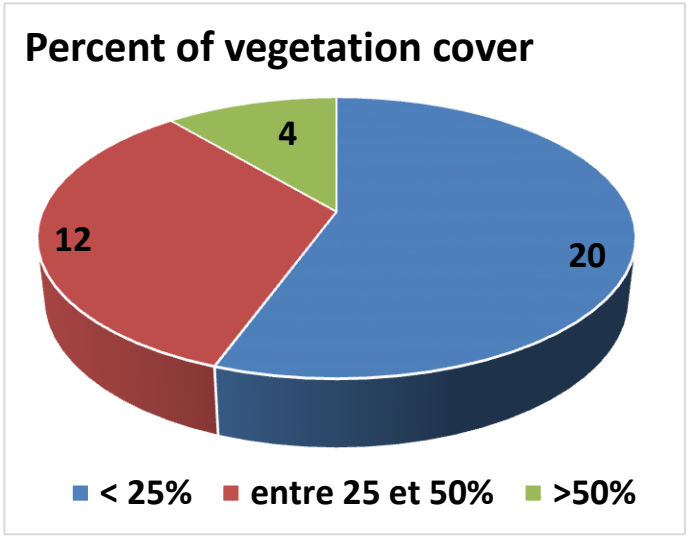
Centre de Suivi Ecologique

Monitoring ephemeral waterbodies

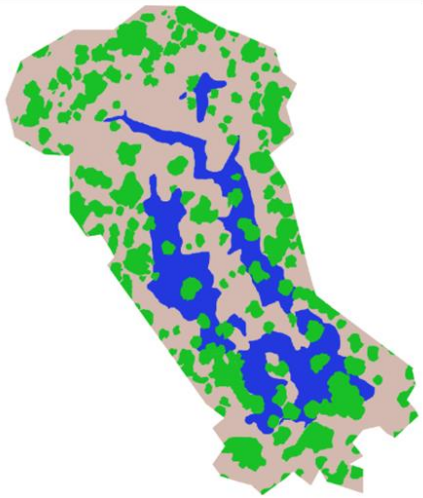
Validation process



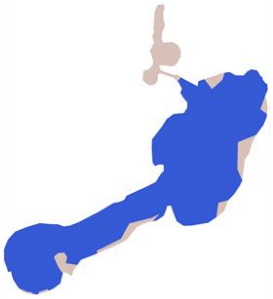
% of vegetation cover	True detection	False detection	Total
< 25%	15	5	20
25 and 75%	10	5	15
> 75%	1	0	1
Total	26	10	36



Sadock Thily



Diatme Ndouboulene



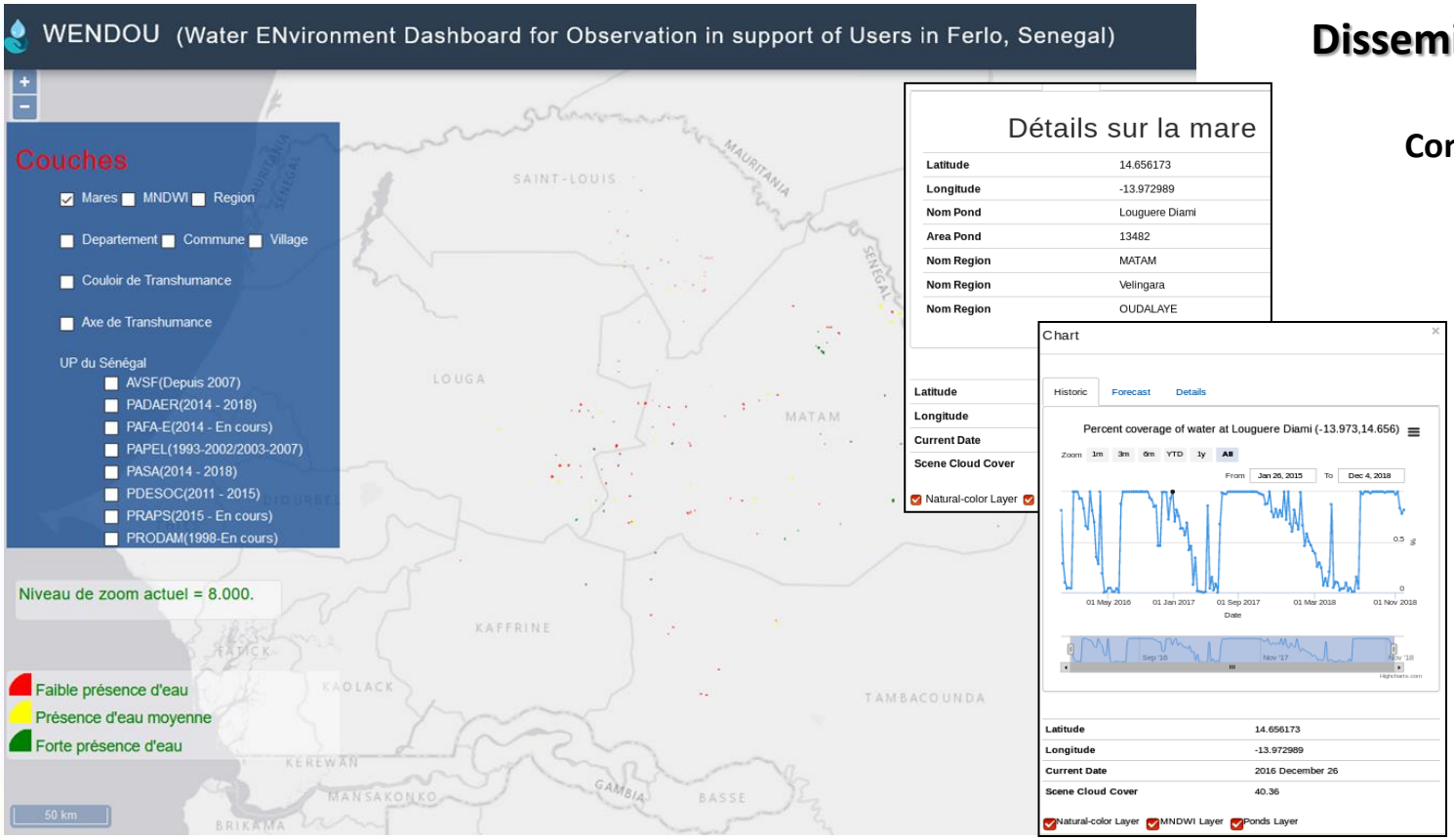
Calculated Chi-2 (2.78) is lower than the theoretical one (7.82)

>>> Independence between detection and vegetation cover rate with only 5% chance of error

Centre de Suivi Ecologique

Monitoring ephemeral waterbodies

Online platform based on python algorithms (Proc.) and Tethys (visual.)



Dissemination:

Community of Practice

Pastoralists

NGOs

AVSF AGRONOMES & VÉTÉRINAIRES SANS FRONTIÈRES
VSF INTERNATIONAL NETWORK

Monitor the water availability for ~ 300 ponds across the Ferlo area

Shared information with pastoralists via local radio and/or SMS

Centre de Suivi Ecologique

Monitoring ephemeral waterbodies

SERVIR WEST AFRICA

GC51L-0944: Real-time monitoring of ephemeral water bodies using earth observation data in Ferlo (Senegal)

Centre de Suivi Ecologique

Mamadou Adama Sarr [1], K. Markert [2,3], A. A. Diouf [1], R. Muench [2,3], E. A. Cherrington [2,3], K.Y. Sarr [1], A. M. Dieye [1]
Centre de Suivi Ecologique [1], University of Alabama in Huntsville [2], SERVIR Science Coordination Office [3]

Abstract

The Ferlo Region is located in the sylvopastoral zone of Senegal dedicated mainly to livestock activities which depend largely on water bodies exposed to the impacts of rainfall variability and climate change. Monitoring the water availability in ponds is becoming a big issue for the end-users. The data used in this study correspond to field and earth observation data. Field information were collected over 1,800 known ponds. Landsat-8 and Sentinel-2 time series data have been added from 2015 to date. Then, the Modified Normalized Difference Water Index (MNDWI) was used to build a model for assessing water availability in ponds.

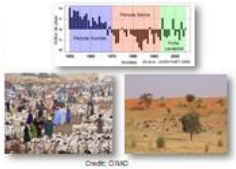
The validation process showed that the MNDWI-based model is slightly underestimating water presence but remains significantly correlated with field data about the flooding duration of the considered samples.

The obtained results highlight the possibility of monitoring the water availability for each pond according to three inclements of less than 25% filled, 25 – 75% filled, and more than 75% filled. This information, which will be regularly updated and disseminated through web platforms and other dissemination channels (community radio, messaging, local technical meetings, etc.), would be an added value for water availability and fodder biomass accessibility in the Ferlo. In perspective, further study will be done about the estimation of the water volume in ponds.

Context

Ephemeral water bodies play a very important role in livestock feeding in pastoral areas of the Sahel. However, in the current situation of climate change, ponds and fodder biomass availability are difficult to predict in relation to the high spatial and intra-annual variability of rainfall conditions.

- 60% of agricultural households (in 2013)
- 17 million heads (in 2015)
- Source of animal products for 30% of the population



Credit: CRAD

Rationale

The sylvopastoral systems of the Sahel, due to their extensive nature and their dependence on temporary water bodies, are increasingly vulnerable in the context of Climate Change. The latter creates an imbalance on the pastoral systems, hence the need to increase the accessibility of information (in connection with scientific knowledge and endogenous knowledge) about water and fodder biomass in order to increase the resilience of the Ferlo populations. The major challenges of pastoral production are related to inadequate water access and quality of pasture.

Credit: CSE

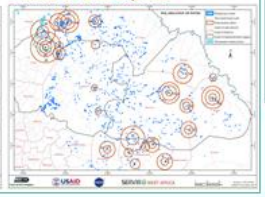
Credit: CSE

Main objective

Combine the great existing satellite datasets with the field data to characterize and enable a monitoring system of Sahelian ephemeral ponds. This will contribute to enhance the resilience of sylvopastoral systems and increase their productivity in response to climate change.

Ponds location

Polarization area of ponds



Specific objectives

- Make information on temporary ponds where water is available, accessible and usable by the populations of Ferlo
- Make information available and usable by local authorities and institutions operating in the Ferlo area.

Expected results

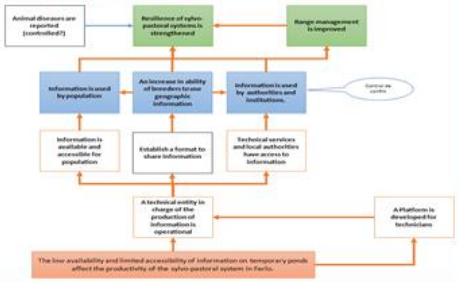
- Reliable and timely information on ponds is available and used
- Populations' capacity to use geographical information is increased

Anticipated impacts

- The resilience of pastoral systems is strengthened
- Social and Ecological Productivity is increased in the context of climate change

Credit: CSE

Theory of change

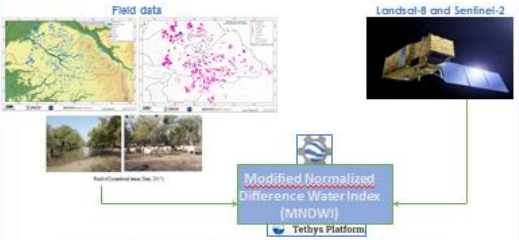


Perspective of the study

- Water volume estimate into ponds
- Assessment and integration of fodder biomass information
- Scaling-up at the regional level in partnership with the Sahel Regional Pastoral Project (PRAPS)

Methodologic Approach

- Script development with the Google earth engine platform
  - Use existing free satellite imagery datasets (Landsat-8 and Sentinel-2) and compute/select a water index
  - Integrate the ancillary data (polygons of ponds, water characteristic, etc.)
- Model development for monitoring and predicting ephemeral water bodies characteristics (DEM, hydrological model based on rainfall and soil humidity)
- Incorporation of fodder biomass mapping
- Visualization and dissemination using appropriate messages to beneficiaries (Geoportal, SMS, community radios, hard copy maps, etc..)



Results/Pre-Validation/Dissemination

Global view of WENDOU geoportal

Focus view of one pond and products associated

Dissemination strategy

USAID NASA CILSS RCMRD ICIMOD adpc SERVIR

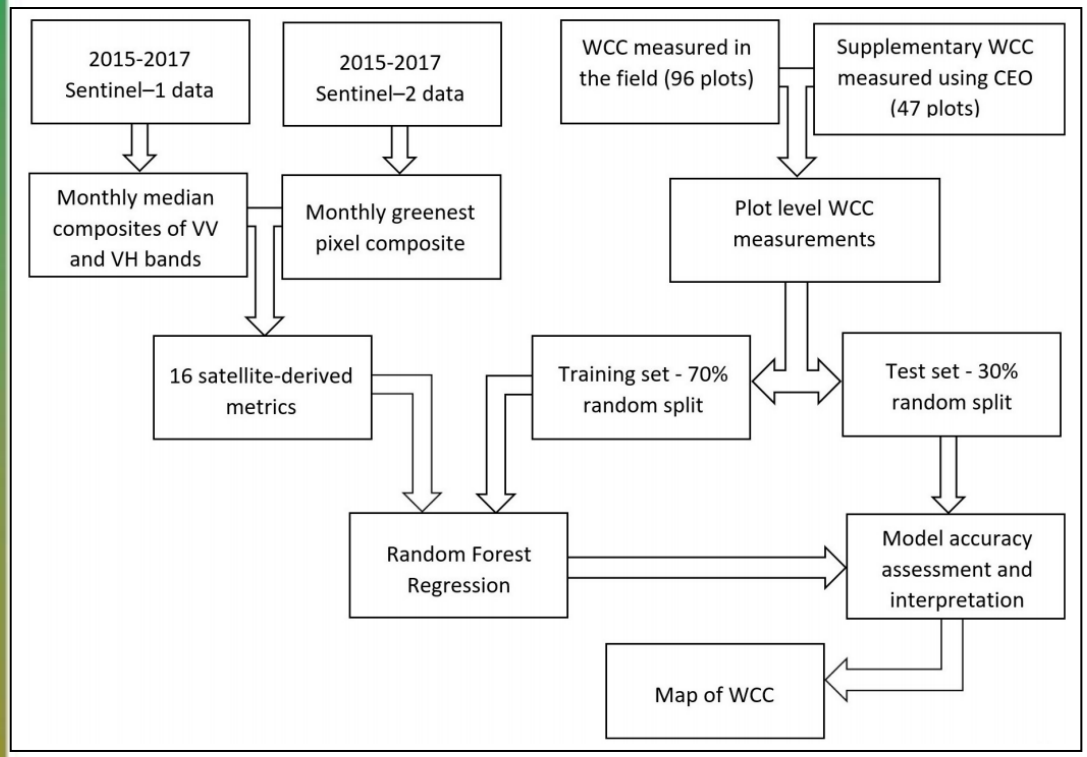
Questions?
Contact
adama.sarr@cse.sn

Centre de Suivi Ecologique

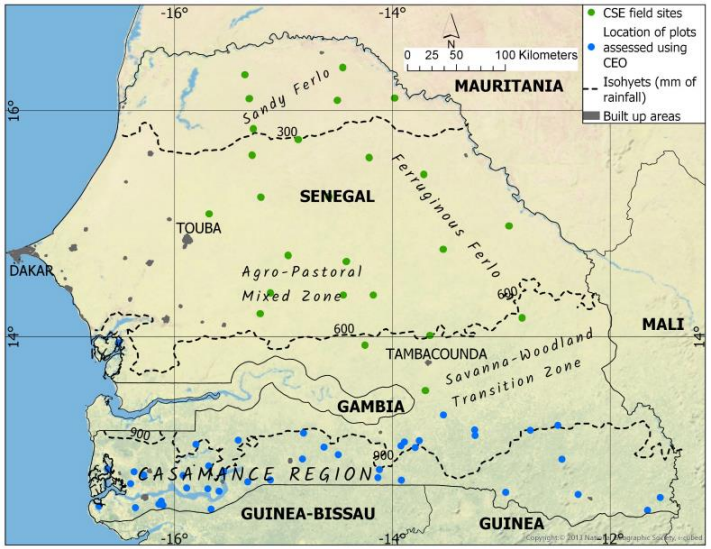
Assessment of the woody canopy cover

Methodology used to model woody canopy cover (%WCC)

Overall flowchart



Anchang et al. 2020



Collect Earth Online (https://collect.earth/)

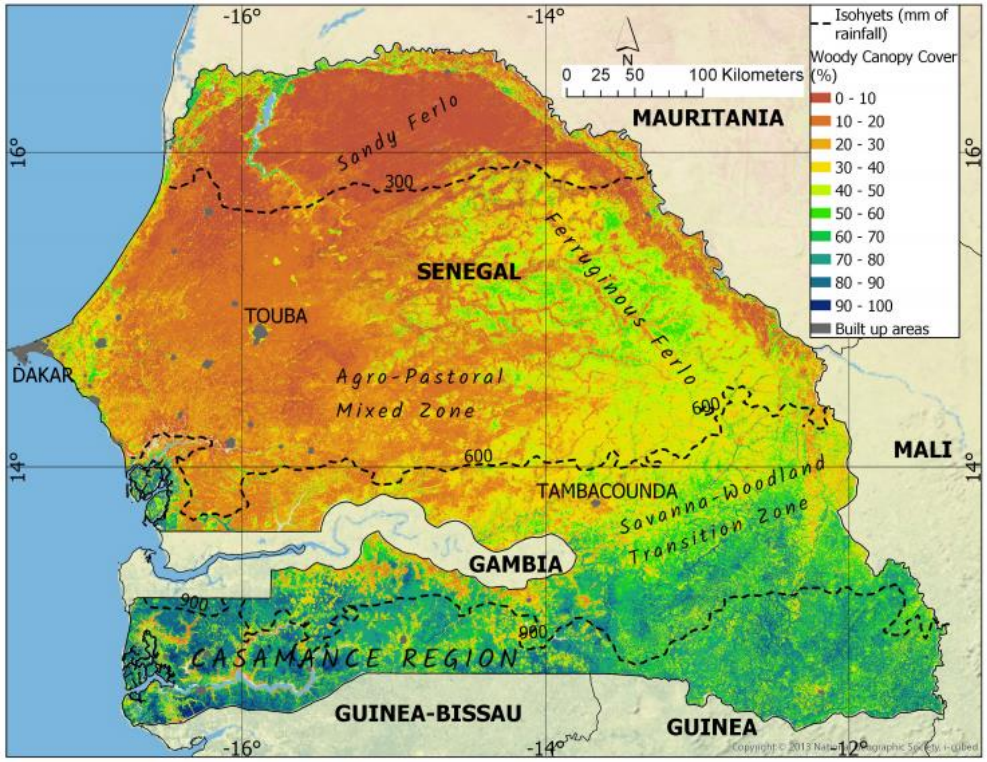
CEO: Collect Earth Online
VV: Vertical-Vertical polarization
VH: Vertical-Horizontal polarization

Rue Léon Gontran Damas, Fann Résidence, Dakar - BP : 15 532 Dakar Fann (Sénégal) - Fax : +221 33 825 81 68
Tel. : +221 33 825 80 66 / +221 33 825 80 67 - Courriel : contact@cse.sn - Site web : www.cse.sn

Centre de Suivi Ecologique

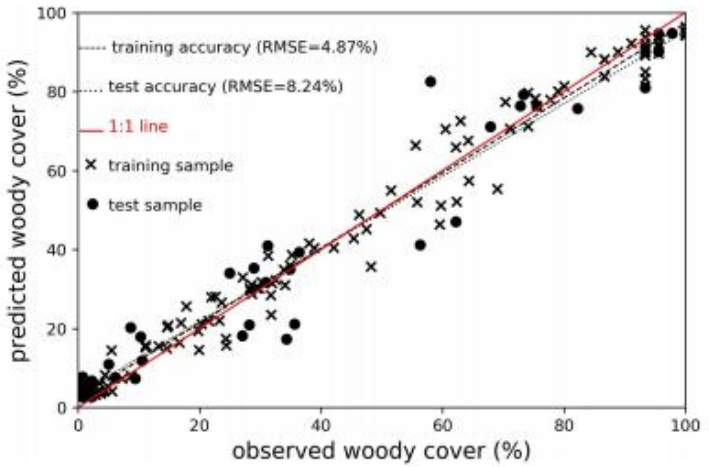
Assessment of the woody cover

Model performance and computed product



Map of percent %WCC in Senegal, predicted from combined radar and optical remote sensing metrics (40 m x 40 m)

Anchang et al. 2020



Random forest model training (N = 104) and validation (N = 39) accuracy for %WCC estimates in Senegal

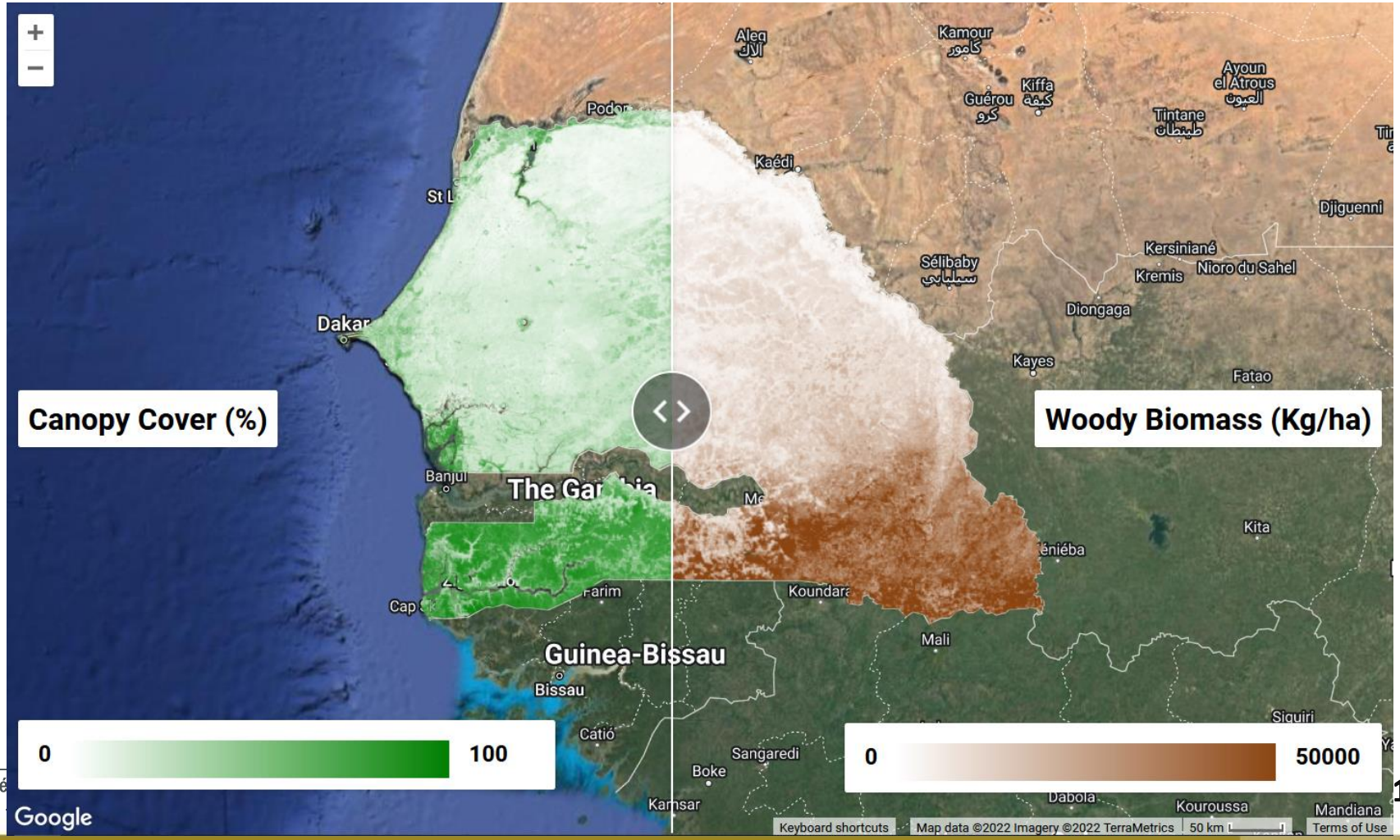
Useful product for forest cover monitoring and land degradation assessment

Rue Léon Gontran Damas, Fann Résidence, Dakar - BP : 15 532 Dakar Fann (Sénégal) - Fax : +221 33 825 81 68
Tel. : +221 33 825 80 66 / +221 33 825 80 67 - Courriel : contact@cse.sn - Site web : www.cse.sn

Centre de Suivi Ecologique

Assessment of the woody cover

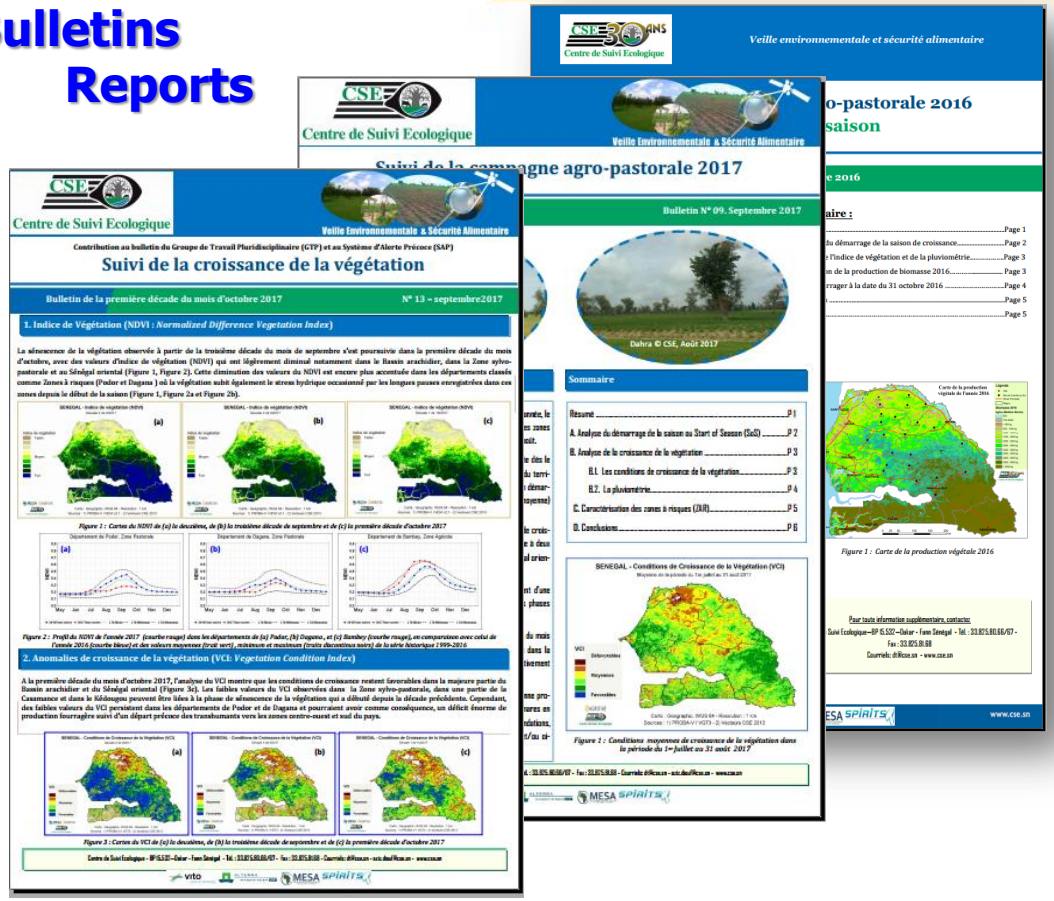
Google Earth Engine application



Centre de Suivi Ecologique

Targets and end-users

Bulletins
Reports



- Multidisciplinary working group (GTP)
- National Technical Committee on Early Warning System
- Directorate of Water and Forests (DEFCCS)
- Directorate of livestock
- NGOs
- Farmers' organizations
- Projects: PRAPS, …
- AUC, WAEMU, ECOWAS,

For more information, please see in following web site
www.cse.sn

Rue Léon Gontran Damas, Fann Résidence, Dakar - BP : 15 532 Dakar Fann (Sénégal) - Fax : +221 33 825 81 68
Tel. : +221 33 825 80 66 / +221 33 825 80 67 - Courriel : contact@cse.sn - Site web : www.cse.sn

ISO 9001 BUREAU VERITAS Certification

Centre de Suivi Ecologique

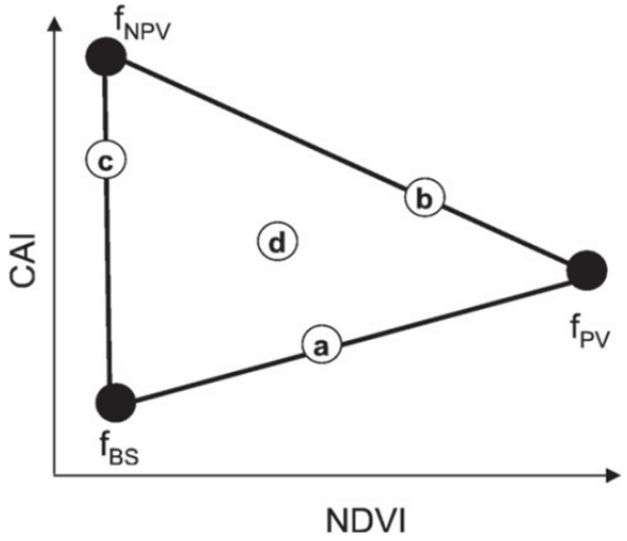
Ongoing research activities

Centre de Suivi Ecologique

Monitoring of dry season forage biomass

Google Earth Engine application

CAI : Cellulose Absorption Index
NDVI : Normalized Difference Vegetation Index



f_{PV}: SM_{NDVI}=0.814; $SM_{SWIR3/SWIR2}$=0.318
f_{NPV}: SM_{NDVI}=0.297; $SM_{SWIR3/SWIR2}$=0.490
f_{NPV}: SM_{NDVI}=0.170; $SM_{SWIR3/SWIR2}$=1.02

Guerschman et al. 2009

Unmixing process (démélange)

PPI : Pixel Purity Index

EO-1 Hyperion [30m] ✚ **MODIS**

- MOD09GHK [Daily, 500m]
- MOD43B [16days-NBAR, 1km]

$$NDVI = (\rho_{NIR} - \rho_{RED}) / (\rho_{NIR} + \rho_{RED}) \quad (1)$$

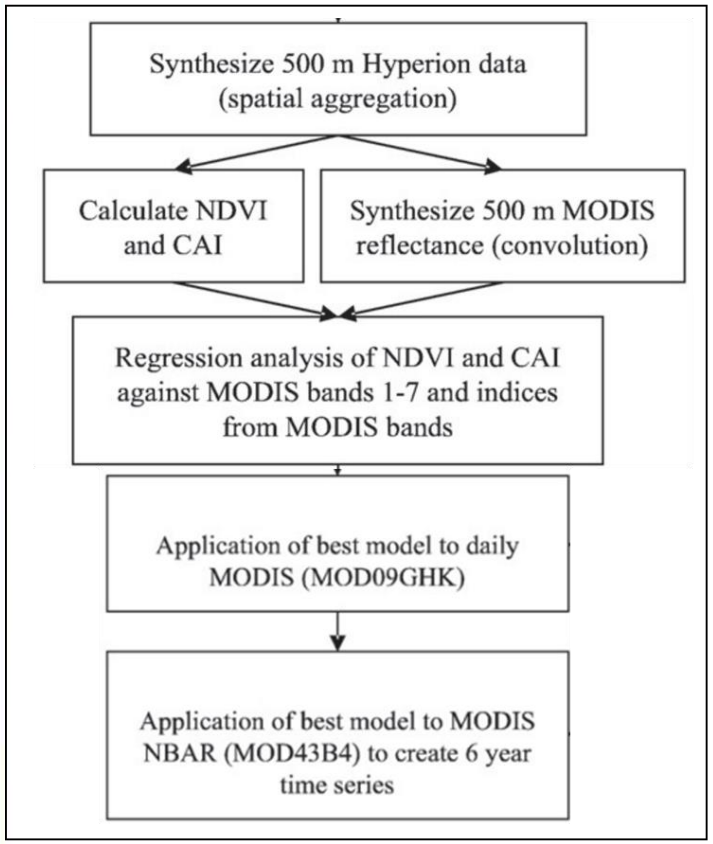
and

$$CAI = [0.5 \cdot (\rho_{2.0} + \rho_{2.2}) - \rho_{2.1}] \cdot 10 \quad (2)$$

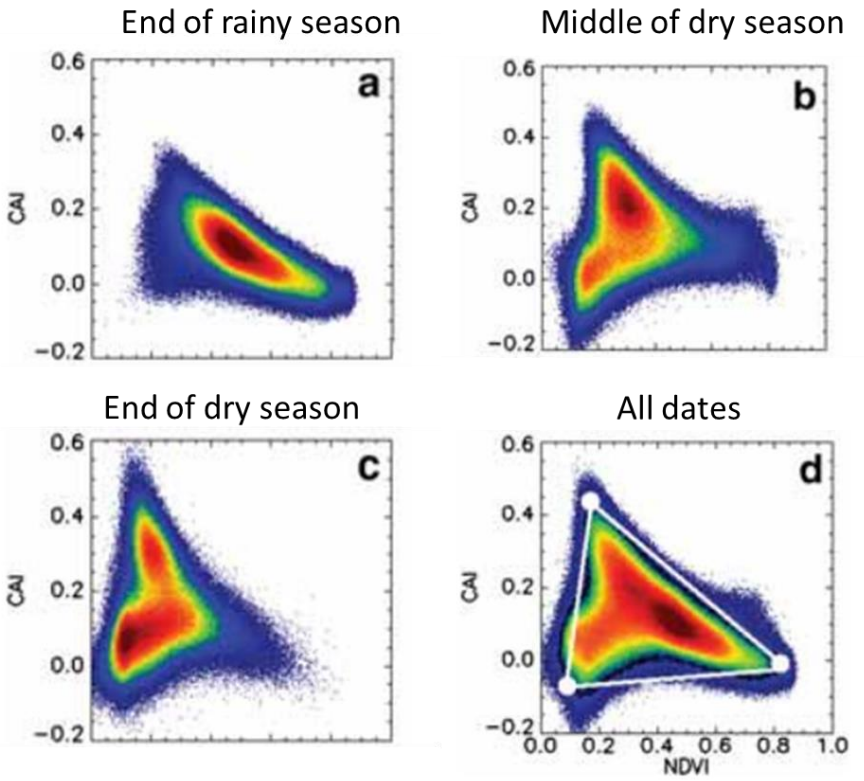
Centre de Suivi Ecologique

Monitoring of dry season forage biomass

Google Earth Engine application



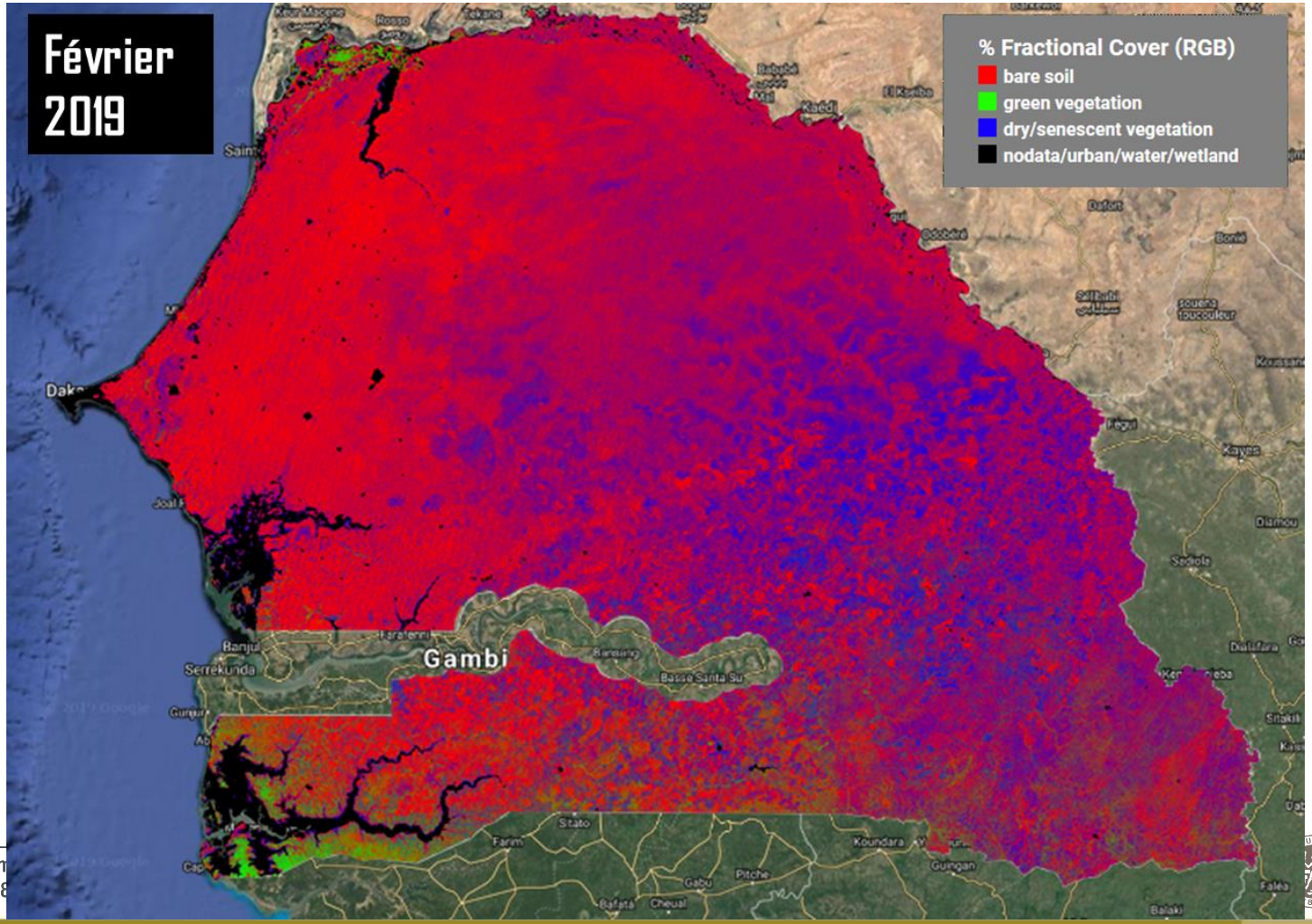
Guerschman et al. 2009



Centre de Suivi Ecologique

Monitoring of dry season forage biomass

Google Earth Engine application

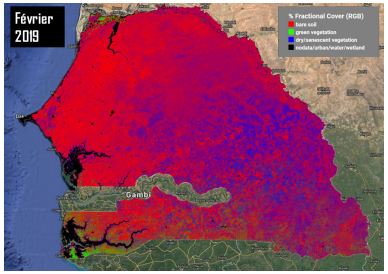


Rue Léon Gontran Dam
Tel. : +221 33 825 8

Centre de Suivi Ecologique

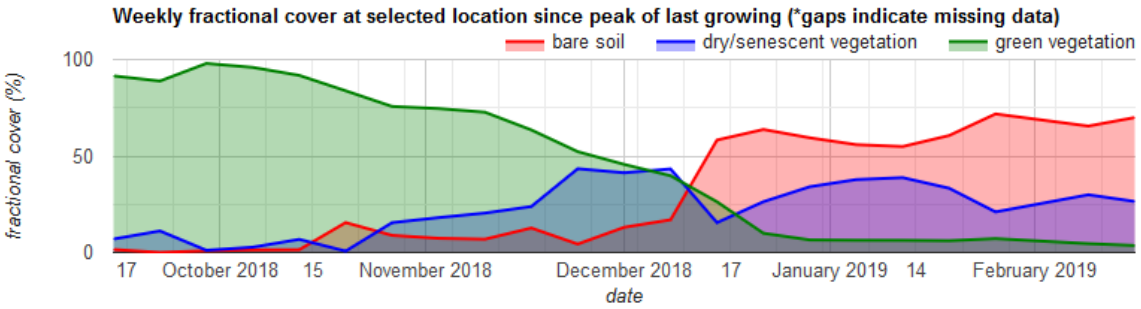
Monitoring of dry season forage biomass

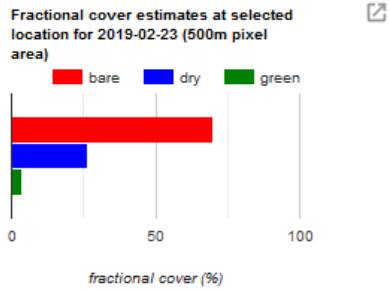
Google Earth Engine application

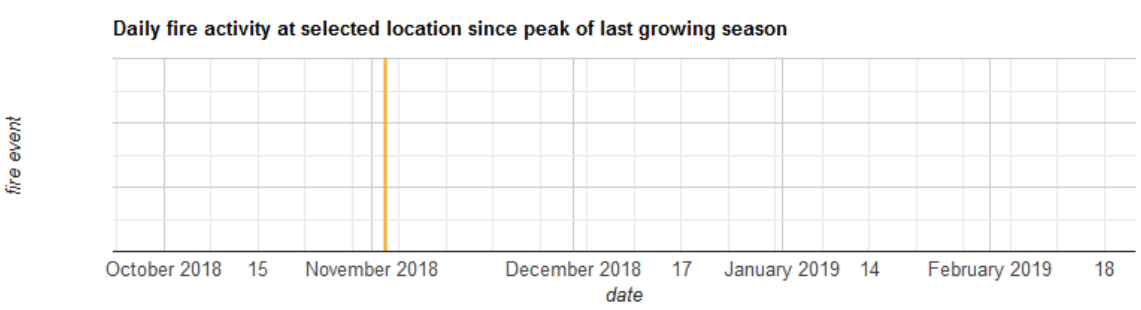


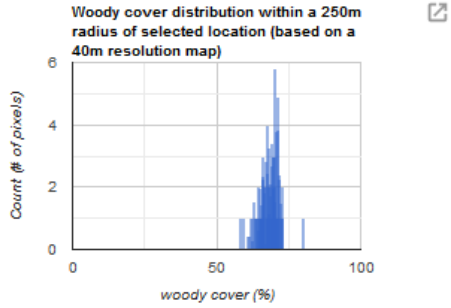
Qualitative monitoring of forage biomasse availability during the dry season in Senegal

% Fractional Cover (RGB)
- bare soil
- green vegetation
- dry/senescent vegetation
- nodata/urban/water/wetland









Centre de Suivi Ecologique

Monitoring of dry season forage biomass

PhD research for improving the approache (Mrs Lo)

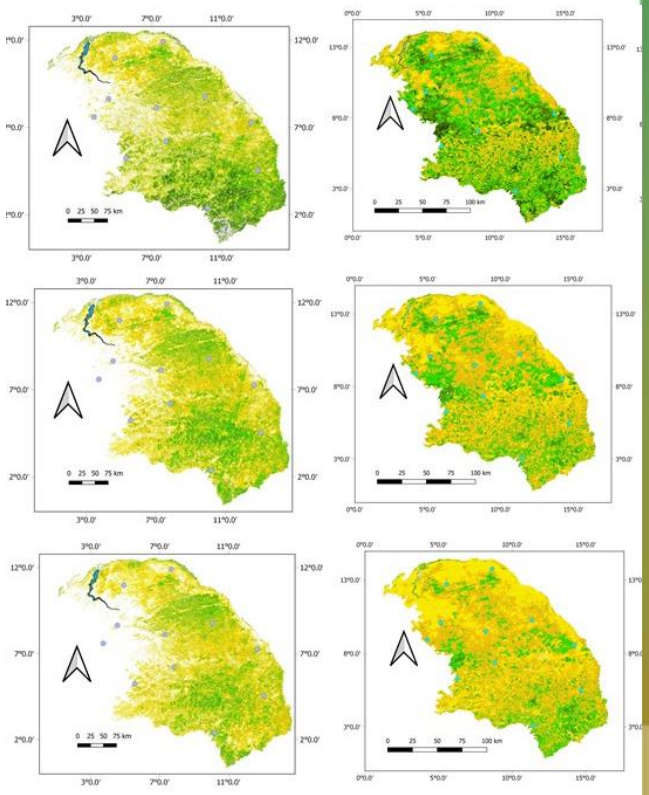
DRY SEASON FODDER ASSESSMENT ACROSS SENEGALESE RANGELANDS USING SENTINEL-2, LANDSAT-8 AND MODIS DATA

Field data collection

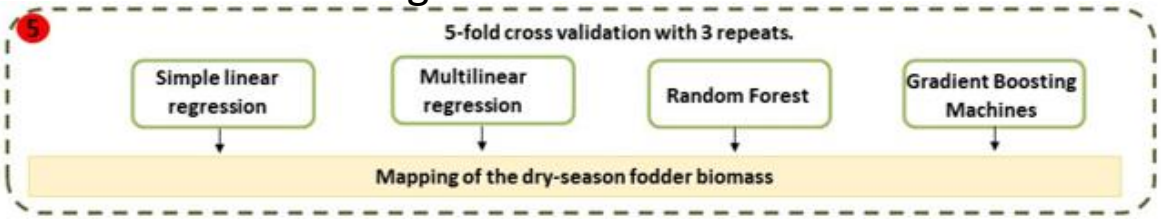
Taking photo on the sample plot and collecting the biomass

Dry season forage biomass for more accurate feed balance calculation

Jan – Mar – May



Statistical modeling



Centre de Suivi Ecologique

THANK YOU

Rue Léon Gontran Damas, Fann Résidence, Dakar - BP : 15 532 Dakar Fann (Sénégal) - Fax : +221 33 825 81 68
Tel. : +221 33 825 80 66 / +221 33 825 80 67 - Courriel : contact@cse.sn - Site web : www.cse.sn

ISO 9001 BUREAU VERITAS Certification