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"Historical Carbon Losses in Senegal: Options and Constraints for Sequestration"

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USGS
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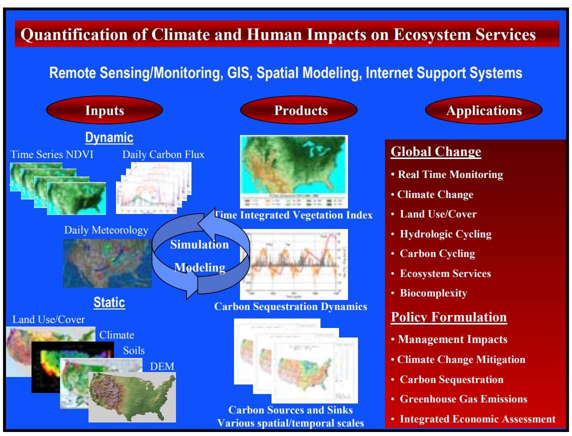
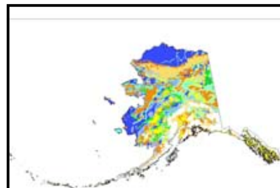
EROS DATA CENTER

International Program

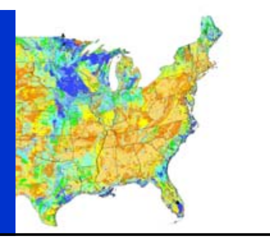
1. Acquire, Archive, Apply, and Distribute **Remote Sensing** Data
2. Support **Global Res. and Dev.** (FEWS, Land Cover, C)
3. Develop **Applications** for Monitoring & **Nat. Res. Mgt.**
4. Implement **Internet Map Serving Systems**
5. Cooperative Projects and **Capacity Building**





Soil Organic Carbon (kg m^{-2})
Class: All lands
Area: 9,197,583 km^{2}
Soil depth: Total Profile
Carbon total: 81.07 Petagrams
Carbon average: 8.81 kg m^{-2}

- **Carbon mapping**
  - **DOI: 22% of area; 22% of SOC**
  - **74% of DOI SOC in Alaska**
  - **Cont US DOI 4.2 kg C m^{-2}**
  - **Alaska DOI 14.0 kg C m^{-2}**
  - **Cont US BLM 2.6 kg C m^{-2}**
  - **Alaska BLM 21.6 kg C m^{-2}**



Carbon Sequestration Projects

1. **"Sequestration of Carbon in Soil Organic Matter (SOCSOM)" in Senegal** *(& the Sahel)*
   Funded by: USAID/AFR, Rockefeller Fd., WB
2. **Central Asia Carbon –Flux Models**
   Funded by: USAID/G, USDA/ARS, USGS
3. **USDA/ARS C Flux Network: NACP**
   Funded by: USAID/G, USDA/GCRP, USGS

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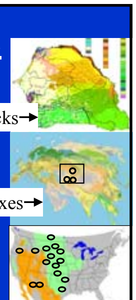
4. **U.S. Carbon Trends**
5. **U.S. Soil Carbon Mapping**

Stocks→

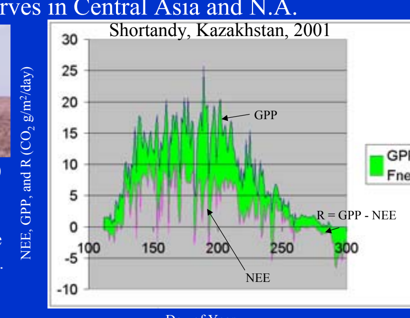


Fluxes→

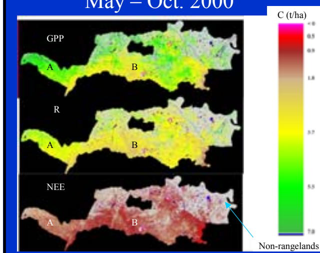
-Remote Sensing
-Biogeochemical & Spatial Modeling
-Extrapolation

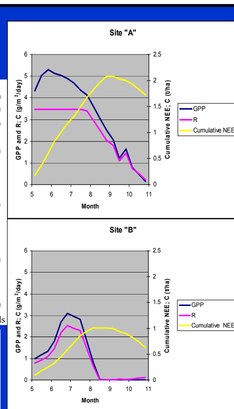
Carbon Flux Modeling and Extrapolation: GPP, R, and NEE via Ecosystem Light-Response Curves in Central Asia and N.A.

-derived from 20 minute data
-point data are expensive, rare
-3 towers in C.A.
-"Rovers" for validation



Simulated GPP, Respiration, and NEE for the Kazakh Steppe May – Oct. 2000





Growing Season Rangeland C Flux
NEE = 1.27 t C/ha
1 km to .25 km resolution
daily time step, 4 yrs
User accessible

SOCSOM: "Integration of Remote Sensing, GIS, Biogeochemical Modeling, & Field Data to Assess Carbon Loss and Potential Sequestration in Senegal"

Acknowledge:

Multi-donor:

AID, WB, FAO, UNEP, RF, IFAD, SCF, Industry

Multi-institution:

USGS/EDC, CSE, ISRA

Senegal Carbon Specialist Team

Univ. Nairobi, Arizona, Colo.St., Lund; IRD, >12 countries, other….

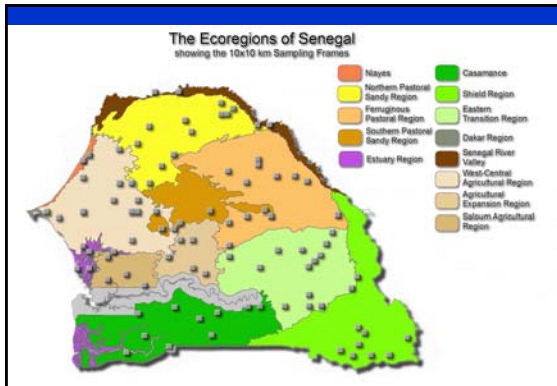
Multi-P.I.: Publications, JAE, CDs, Web Sites @EDC & CSE,

Sequestration of Carbon in Soil Organic Matter (SOCSOM) in Senegal

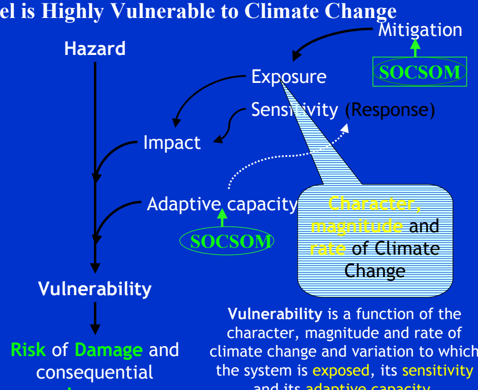
SOCSOM Goal:

"…provide quantitative analyses of the environmental, ecological, and economic potential for the sequestration of carbon in soil organic matter in spatially explicit sites and to define the necessary socioeconomic enabling conditions and policies to implement successful projects."

Site Specific
Bottom Up
Feasibility ⟶ Real Projects ($$)
Participate in TCO, GCP, etc.



Sahel is Highly Vulnerable to Climate Change



Vulnerability is a function of the character, magnitude and rate of climate change and variation to which the system is exposed, its sensitivity and its adaptive capacity.

Sub-Saharan Africa is Vulnerable to Climate Change, e.g., IPCC and GCM

Exposure	**= Great**
Sensitivity	**= High**
Adaptation Capacity	**= Low**

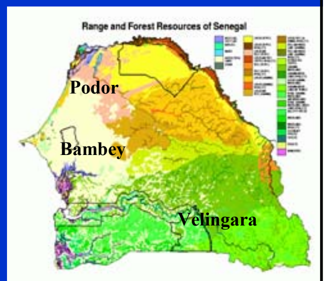
- Present:
  - Mean temps have increased
  - Increase has impacted agriculture & natural systems
  - Due to human activities
- Future:
  - Temp increases are large, e.g., 1 to 5 C
  - Evapotranspiration increases due to low ppt increases
  - Greater interannual variability
  - Higher frequency of extreme events
  - Especially severe impacts in semiarid areas, e.g., Sahel

Specific Objectives in SOCSOM

The Biophysical

1. Quantify the carbon status and sequestration potential across agroecological zones in Senegal to define the biophysical potential, evaluate possible management impacts, and approach a full assessment in three representative areas.

1. Detailed C Stocks
2. Simulated Mgt Impacts
3. Quantitative Assessments
4. Nationalized Estimates



Specific Objectives in SOCSOM

The Socioeconomic/Cultural

2. Understand and quantify the socioeconomic incentives and requirements as well as policy issues necessary to implement a project level (100,000 t C) activity.

1. Details in Bambey
2. Assessment of Options
3. Cost Benefits Analysis
4. No Easy Prescriptions
5. New Approach to Funding

Bambey area was emphasized

Expected Requirements:

-broad-based community support

-enhanced smallholder livelihoods

-100,000+ t C, to approximate a sale of $1 million US

-attractive to potential carbon traders

Specific Objectives in SOCSOM

Capacity Building & Training

3. Develop national capacity for measuring, monitoring, simulating, and implementation.

1. Biogeochemical Models
2. Remote Quantification of Biomass
3. "Manuals" and on-line Assistance
4. FAO Participant Support for 10+ Countries
5. Project Implementation & transaction Requirements

Joint collaboration in field work, analysis, interpretation, and publication

"Landscape Carbon Sampling and Biogeochemical Modeling" (Woomer et al. 2001)

National Carbon Team

"Carbon Specialist Team"

-sampling/analyses

-project design

-simulation analyses

-project implementation

Specific Objectives in SOCSOM

Prototype and Diffusion

4. Generalize the results to national and regional scales.

Real Implementation

(5. Prepare for Real Carbon Project Implementation with transfer of C credits, payments, and community benefits.)

- 6(3) Projects from Senegal;
- 5 Projects from FAO participants

Major agroecological zones are included

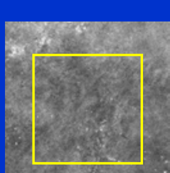
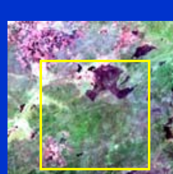
Sahel land cover performance based on Senegal prototype to be undertaken with 22-year archive

Poised for Sahel-wide quantification and further transfer of capacity with Senegalese partners

Launched by National Carbon Team and Project Sub-teams through the International Dakar workshop, 2001!!

Time Series Analyses of Land Cover/Use In each Ecoregion of Senegal

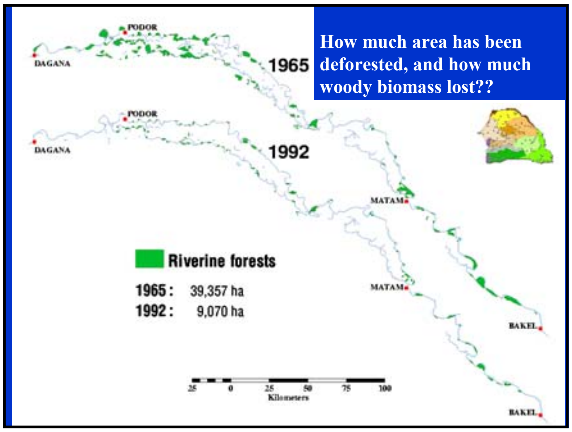
Example of Sample Frame in the Casamance

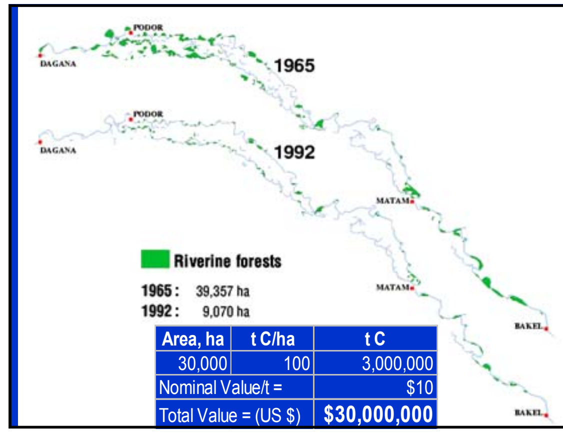
Corona 1965	Landsat TM 1985	Landsat ETM 2000
		
10 X 10 km	10 X 10 km	10 X 10 km

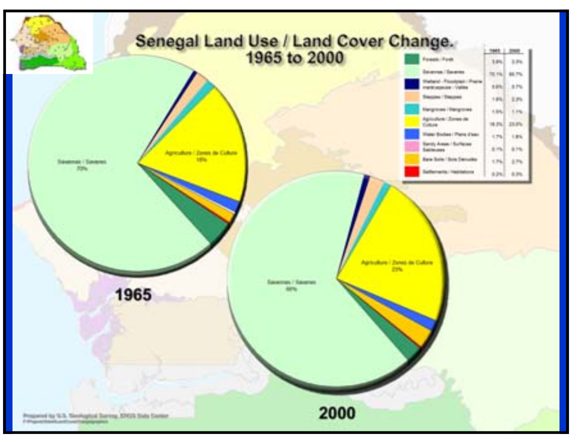
Protected Areas and Exclosures

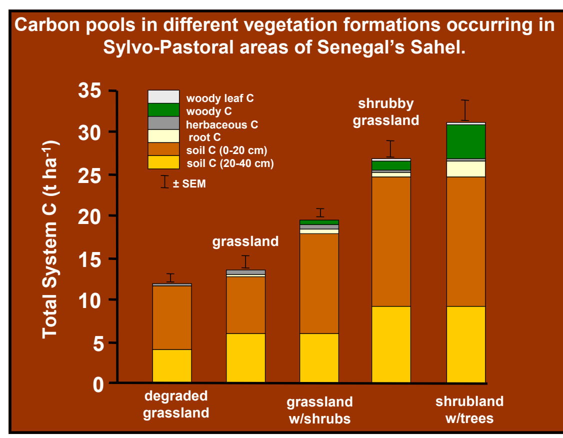
Forêt Classée de Sangako Landsat Nov. 1999

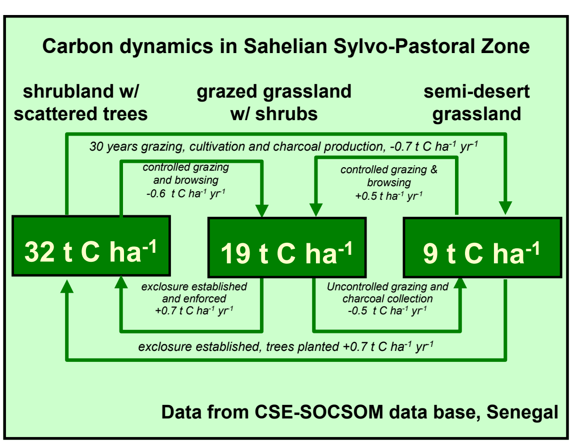
Local Exclosure, Saloum

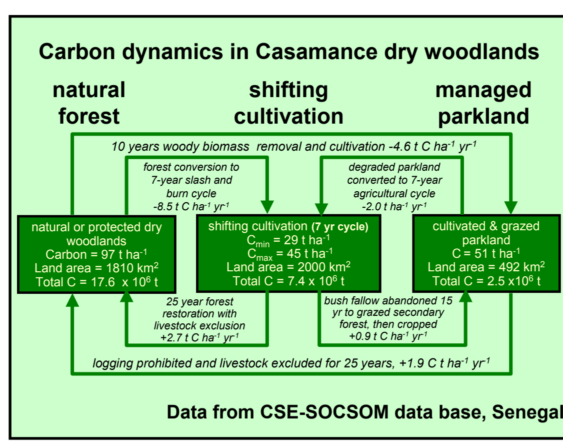

How much area has been deforested, and how much woody biomass lost??
PODOR
DAGANA
1965
PODOR
DAGANA
1992
MATAM
MATAM
BAKEL
BAKEL
Riverine forests
1965 : 39,357 ha
1992 : 9,070 ha
25 0 25 50 75 100
Kilometers

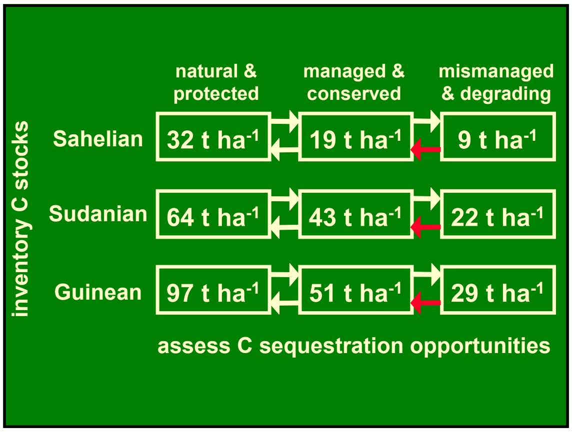

PODOR
DAGANA
1965
PODOR
DAGANA
1992
MATAM
MATAM
BAKEL
BAKEL
Riverine forests
1965 : 39,357 ha
1992 : 9,070 ha
Area, ha | t C/ha | t C
30,000 | 100 | 3,000,000
Nominal Value/t = | $10
Total Value = (US $) | $30,000,000


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

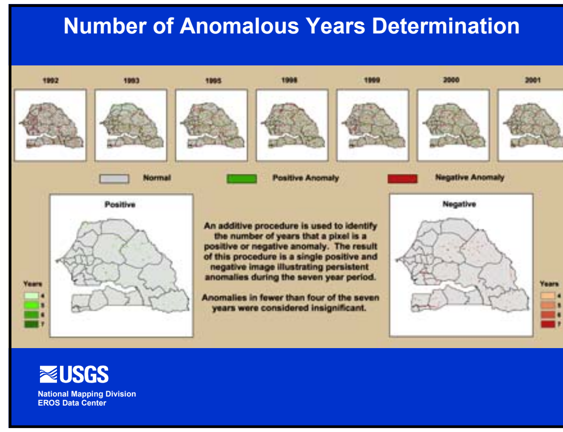

Carbon pools in different vegetation formations occurring in Sylvo-Pastoral areas of Senegal's Sahel.
Total System C (t ha-1)
35
30
25
20
15
10
5
0
woody leaf C
woody C
herbaceous C
root C
soil C (0-20 cm)
soil C (20-40 cm)
± SEM
degraded grassland
grassland
grassland w/shrubs
shrubby grassland
shrubland w/trees


Carbon dynamics in Sahelian Sylvo-Pastoral Zone
shrubland w/ scattered trees
grazed grassland w/ shrubs
semi-desert grassland
30 years grazing, cultivation and charcoal production, -0.7 t C ha-1 yr-1
controlled grazing and browsing -0.6 t C ha-1 yr-1
controlled grazing & browsing +0.5 t ha-1 yr-1
32 t C ha-1
19 t C ha-1
9 t C ha-1
exclosure established and enforced +0.7 t C ha-1 yr-1
Uncontrolled grazing and charcoal collection -0.5 t C ha-1 yr-1
exclosure established, trees planted +0.7 t C ha-1 yr-1
Data from CSE-SOCSOM data base, Senegal

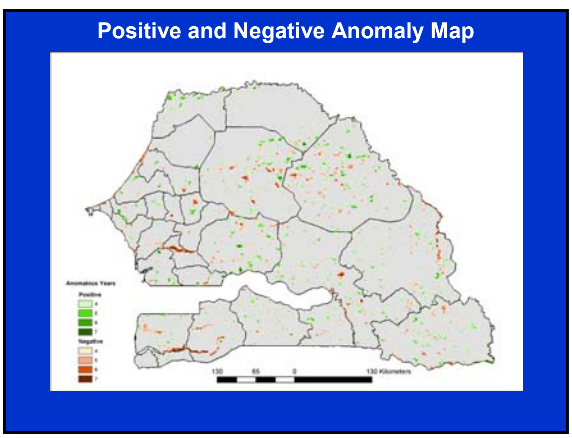

Carbon dynamics in Casamance dry woodlands
natural forest
shifting cultivation
managed parkland
10 years woody biomass removal and cultivation -4.6 t C ha-1 yr-1
forest conversion to 7-year slash and burn cycle -8.5 t C ha-1 yr-1
degraded parkland converted to 7-year agricultural cycle -2.0 t ha-1 yr-1
natural or protected dry woodlands Carbon = 97 t ha-1 Land area = 1810 km2 Total C = 17.6 x 106 t
shifting cultivation (7 yr cycle) Cmin = 29 t ha-1 Cmax = 45 t ha-1 Land area = 2000 km2 Total C = 7.4 x 106 t
cultivated & grazed parkland C = 51 t ha-1 Land area = 492 km2 Total C = 2.5 x106 t
25 year forest restoration with livestock exclusion +2.7 t C ha-1 yr-1
bush fallow abandoned 15 yr to grazed secondary forest, then cropped +0.9 t C ha-1 yr-1
logging prohibited and livestock excluded for 25 years, +1.9 C t ha-1 yr-1
Data from CSE-SOCSOM data base, Senegal



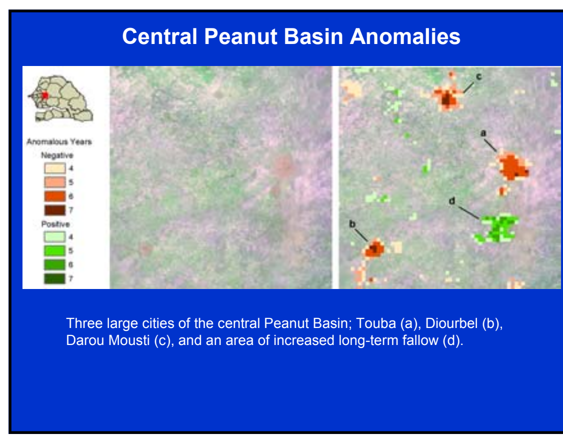
natural & protected
managed & conserved
mismanaged & degrading
inventory C stocks
Sahelian
32 $t\ ha^{-1}$
19 $t\ ha^{-1}$
9 $t\ ha^{-1}$
Sudanian
64 $t\ ha^{-1}$
43 $t\ ha^{-1}$
22 $t\ ha^{-1}$
Guinean
97 $t\ ha^{-1}$
51 $t\ ha^{-1}$
29 $t\ ha^{-1}$
assess C sequestration opportunities



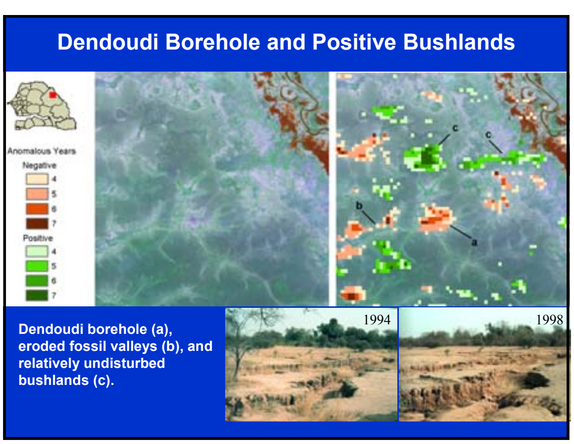
Number of Anomalous Years Determination
1992
1993
1995
1998
1999
2000
2001
Normal
Positive Anomaly
Negative Anomaly
Positive
Negative
Years
An additive procedure is used to identify the number of years that a pixel is a positive or negative anomaly. The result of this procedure is a single positive and negative image illustrating persistent anomalies during the seven year period.
Anomalies in fewer than four of the seven years were considered insignificant.
USGS
National Mapping Division
EROS Data Center



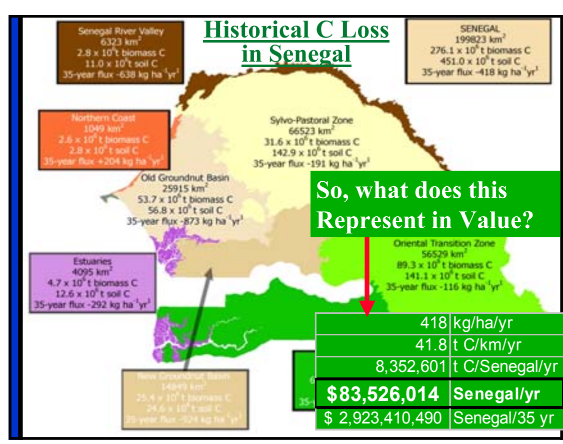
Positive and Negative Anomaly Map



Central Peanut Basin Anomalies
Anomalous Years
Negative
Positive
c
a
d
b
Three large cities of the central Peanut Basin; Touba (a), Diourbel (b), Darou Mousti (c), and an area of increased long-term fallow (d).

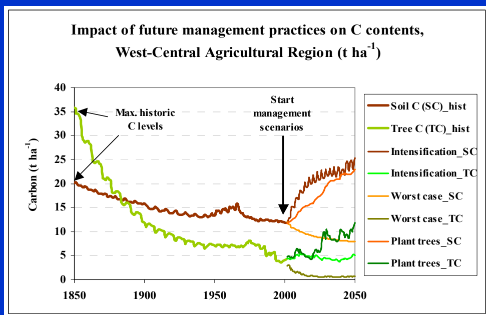


Dendoudi Borehole and Positive Bushlands
Anomalous Years
Negative
Positive
1994
1998
Dendoudi borehole (a), eroded fossil valleys (b), and relatively undisturbed bushlands (c).



Historical C Loss in Senegal
Senegal River Valley
6323 km^2
35-year flux -638 kg $ha^{-1}yr^{-1}$
SENEGAL
199823 km^2
35-year flux -418 kg $ha^{-1}yr^{-1}$
Northern Coast
1049 km^2
35-year flux +204 kg $ha^{-1}yr^{-1}$
Sylvo-Pastoral Zone
66523 km^2
35-year flux -191 kg $ha^{-1}yr^{-1}$
Old Groundnut Basin
25915 km^2
35-year flux -873 kg $ha^{-1}yr^{-1}$
So, what does this Represent in Value?
Oriental Transition Zone
56529 km^2
35-year flux -116 kg $ha^{-1}yr^{-1}$
Estuaries
4095 km^2
35-year flux -292 kg $ha^{-1}yr^{-1}$
New Groundnut Basin
418 kg/ha/yr
41.8 t C/km/yr
8,352,601 t C/Senegal/yr
$83,526,014 Senegal/yr
$ 2,923,410,490 Senegal/35 yr

Evaluating Potential Future C Levels: (CENTURY Biogeochemical Simulations)

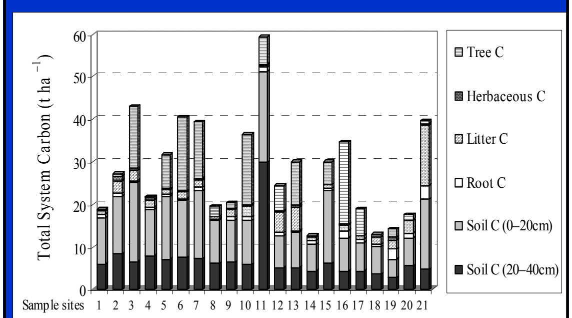


Detailed Socioeconomic Assessment in Bambey Region

Highly participatory!!

- Group discussions
- Village maps
- Pebble matrices – ranking
- Focus groups
- Venn diagrams
- Agricultural calendars
- Household budgets
- Questionnaires
- Practical training
- Inst. analysis: Conseils Ruraux
- Soil + biomass C measurements
- Environmental theatre

Sample Village Assessment of Carbon Stocks Bambey Region



First-Year Costs, Net Costs, Net Benefits (in $)

Management practices:

1. Compost 2t/ha
2. Conversion to grassland
3. Conversion to grassland + protection *kad*
4. Conversion grassland +prot. *kad* (live hedges)
5. Cow manure 4t/ha
6. Cow manure 4t/ha + fertilizer
7. Sheep manure 5t/ha
8. 3-year fallow + manure + HH waste
9. Sheep manure 10t/ha
10. 3-year fallow + leucaena prunings
11. Kad plantation
12. 10-year fallow + manure + HH waste
13. 10-year fallow + org. matter+ animal fattening
14. 10-year fallow + leucaena prunings
15. Optimum agricultural intensification

First-Year Costs (in $ ha^{-1})

Poor HH	Medium HH	Rich HH
0–3,500	0–2,800	0–2,800

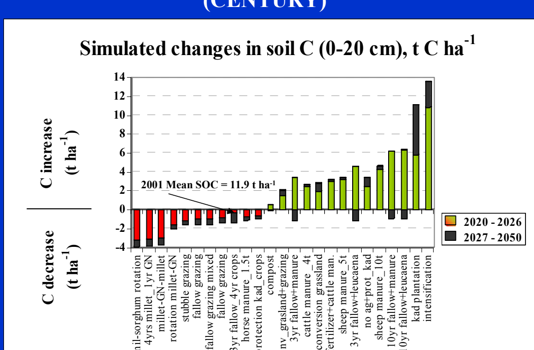
Feasible?

Net costs/Net benefits (in $ tC^{-1})

	Poor HH	Medium HH	Rich HH
Net Costs	200–1,400 (8)	170–330 (5)	100–240 (5)
Net Benefits	80–9,000 (7)	130–9,500 (10)	130–9,500 (10)

Profitable?

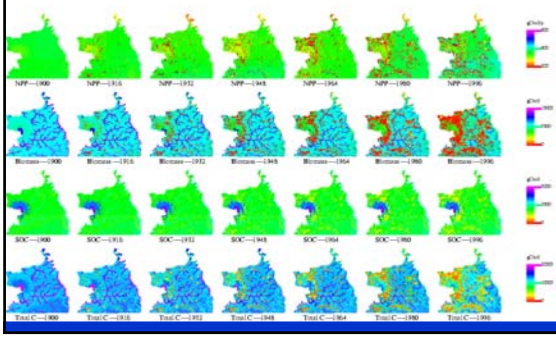
Simulated Impact of Management Practices on SOC (CENTURY)



Data and CENTURY Simulations Suggest:

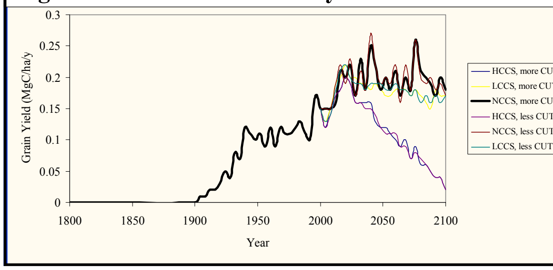
1. Conventional agriculture has **mined** soils of C and nutrients
2. **Poor management:** further C and nutrient losses
3. **Short-term fallowing:** NO increase in C
4. **Conversion of cropland to grassland**: limited gains in C
5. **4-10 tons of manure**: satisfactory increase in C and crop yields
6. **Long-term fallowing**: nice gains in C, no crop yields
7. **N-fixing trees:** large increase in yields and total C, best after 20 years
8. **Combination** of fallow, agroforestry, residue management, and intensification: highest gains in yields and total C
9. **Project implementation** requires initial capitalization

Temporal Change of Spatial Patterns of Carbon (Velingara; 1900-1996; NPP, Biomass, SOC, Total)



Impact of $2XC0_2$ Climate on Grain Yield Velingara; 1900-2100; no adaptation

1. It is assumed that agricultural will not expand in 21st century
2. **High Climate Change Scenario (HCCS) poses a great threat to food security**



SOCSOM Estimates for Senegal (preliminary)

- Realistic Soil C Seq Rate = **0.1 to 0.2 t C/ha/yr**
- New Steady State = 25 years
- Total Sequestration = 2.5 to 5 t C/ha

If a reasonable Project Size is 100,000 t, (ca. $1M) then
Land Area Required/Project = **20,000 to 40,000 ha**
Land Holders Required = 5,000 to 20,000

Constraints:

Culture, Incentives, Organization, Land Ownership, Soil C ownership, Land Tenure, Liability, National Capacity, National Administration

Implementation Projects Developed at The Dakar Workshop

1. Dune Fixation and Community Vegetable Development
2. Degraded Mine Land Rehabilitation
3. Micro-irrigation and Ag Intensification
4. Ag Intensification in the Bambey Region
5. Sustainable Charcoal (Senegal River Basin & Tambacounda)
6. Senegal Agricole
7. Mali
8. Ghana
9. Namibia
10. Benin
11. Kenya (SACRED Africa)

Carbon Sequestration & Credits: Questions to be Answered for Africa

- Can large areas for projects be identified?
- Can economic and environmental cost-benefit analyses by simulated for local and regional applications?
- Can we identify optimal areas for sequestration projects
- Can sequestration improve local economies?
- Can sequestration provide environmental benefits?
- Can local communities be organized to implement required **N**atural **R**esource **M**anagement options?
- Is there a mechanism to insure contracts?
- How do "we" convince buyers to secure contracts?
- Can activities be linked to agroforestry programs?
- Can National Policy issues be resolved?
- Can small, poor countries be "fast" and compete?

Recommendation for Strategic National Positioning in the Offset & Related Markets

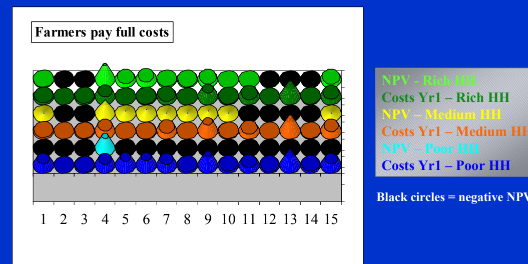
- **Make a Strategic Decision** to "Sell or Hold" or "Negotiate Wisely"
- **Establish Policy** on Activity Projects, Area Projects, National Accounting vs "Private" projects
- Other Administrative Requirements Needed
  - Establish **"Office"** for National "C & Climate Mitigation" Promotion, Education, Advice, Facilitation (need a strong Domestic Infrastructure)
  - Institute Procedural Rules for Implementation
  - Support & Enhance a **Specialist Carbon Team** –national and regional
  - **Clarify** Rules, Verification, Monitoring, Accounting
  - **Standardize** Formats, Baselines, Additionality, Leakage
  - Develop a **Transparent Parcel & C** Identity, Monitoring and Verification System: Start with an active/accurate/accessible Carbon Web Site
  - **Provide Assurance** on Liability and Insurance
  - **Develop Public Relations**, Contact Brokers/Industry, Gain Credibility, Secure a World Bank Bio Carbon Fund or other award

Recommendation for Strategic National Positioning in the Offset & Related Markets

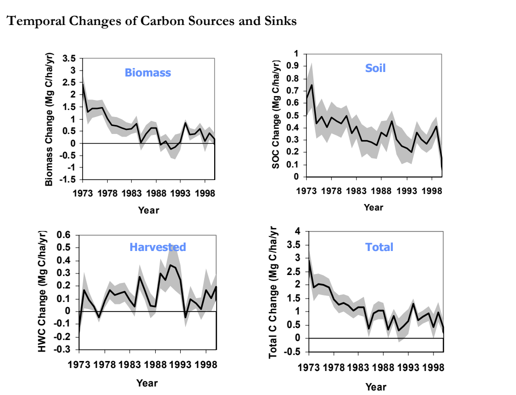
- Other Administrative Requirements Needed (Cont)
  - Conduct a Detailed **Market Analysis**
  - Identify, Enumerate, **Prioritize Potential Projects**
  - **Assurance of Benefits** for Host Country & Local Communities
    - Capacity building to facilitate adaptation
    - Technology transfer
    - Local investments at community levels
    - Environmental
    - Economic
    - Social
    - Sustainable Development
  - Evaluate and Develop a Secure Risk/Transaction Environment
    - Enforcement of Agreements
    - Currency controls
  - Maintain a **Strong Presence** at International Meetings
  - Decide to Become an **Active Participant** and take advantage of Early Actions

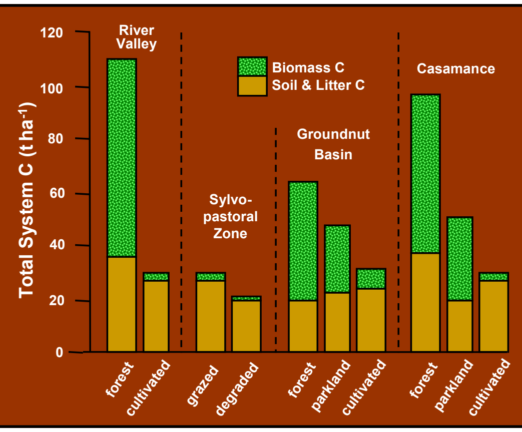
Net Present Values (NPV), 20% Discount Rate

Indicates Profitability



Black circles = negative NPV





Assessing Land Cover Performance in Senegal, West Africa using Integrated NDVI, Local Variance Analysis, and High Resolution Satellite Imagery

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U.S. Geological Survey
National Mapping Division
EROS Data Center

USAID

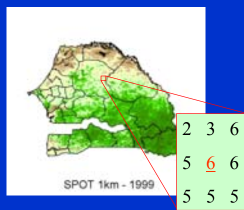
Purpose:

- ❑ Provide an assessment of localized vegetation condition relative to the surrounding area.
- ❑ Identify pixels that show persistently anomalous behavior (positive & negative) and therefore may be representative of either degraded or improved vegetation productivity.
- ❑ Applications include:
  - large-area monitoring of vegetation anomalies
  - 'validation' of efforts to improve productivity
  - 'validation' of efforts to curtail degradation
  - links to variability in NPP >> carbon sequestration

Local Variance NDVI Anomaly Detection

A local variance method was designed to detect local anomalies of NDVI within Senegal.

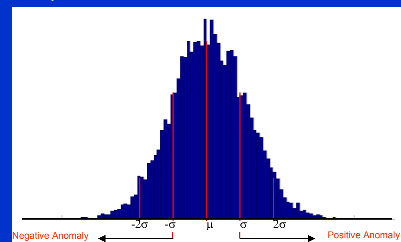
- In an image, each pixel can be considered the center of an *NxN* window.
- Using the iNDVI image for each year, the mean and standard deviation (STD) for a given *NxN* window are calculated on a per pixel basis. This analysis uses a 31x31 window.



- Areas with anomalies in excess of one standard deviation from the mean have been found to be associated with significant environmental effects (Singh & Harrison,1985).

Anomalous Pixel Detection

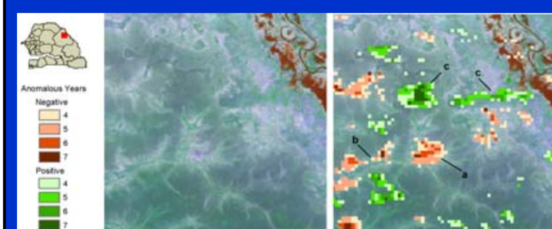
This analysis uses +/- 1 standard deviation to define anomalies.



$$iNDVI > \bar{X} + 1 * std\_T = \text{Positive Anomaly}$$

$$iNDVI < \bar{X} - 1 * std\_T = \text{Negative Anomaly}$$

Dendoudi Borehole and Positive Bushlands



Dendoudi borehole (a), eroded fossil valleys (b), and relatively undisturbed bushlands (c).

Economic Gain/ha from Carbon and Improved Practices

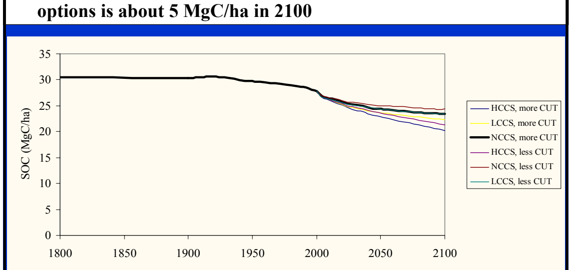
	C gains after 25 yrs (t ha^{-1})	ha necessary to reach 100,000t C sequestered after 25 yrs	**Economic gain after 25yrs ($ ha^{-1}) ***	**Economic gain ($ ha^{-1} yr^{-1})**	**% of income from crops in poor HHs ****	% of income from crops in average HHs **	% of income from crops in rich HHs **
Planting *Faidherbia albida*	2.74	36,561	**41.03**	**1.64**	**2.60**	0.74	0.57
Cattle manure _4t	3.25	30,744	**48.79**	**1.95**	**3.10**	0.88	0.68
Cattle manure_4t + fertilizer	3.97	25,165	**59.61**	**2.38**	**3.78**	1.08	0.82
Sheep manure_5t	4.10	24,398	**61.48**	**2.46**	**3.90**	1.11	0.85
3yr fallow + 2t manure_4yr cropping	4.12	24,245	**61.87**	**2.47**	**3.93**	1.12	0.86
Sheep manure_10t	5.19	19,259	**77.89**	**3.12**	**4.95**	1.41	1.08
3yr fallow + 2t leucaena_4 yr cropping	5.57	17,958	**83.53**	**3.34**	**5.30**	1.51	1.16
10yr fallow + manure_6 yr cropping	6.52	15,330	**97.85**	**3.91**	**6.21**	1.77	1.35
10yr fallow + 2t leucaena_6yr cropping	6.82	14,653	**102.37**	**4.09**	**6.50**	1.85	1.42
Intensification	12.66	7,900	**189.88**	**7.60**	**12.06**	3.44	2.63
Mean	5.50	21,621	**82.43**	**3.30**	**5**	1.49	1.14

* Assuming 1t C = $15

* Average income from crops/year: $63 (poor HHs), $221 (average HHs), $289 (richer HHs)

Impact of 2X CO_2 on Soil Organic Carbon; -2100

1. SOC stock in undisturbed dry and moist tropical forest is 29 and 35 MgC/ha, respectively
2. SOC stock has decreased by 9% from 1900 to 2000 in Velingara
3. The max difference caused by management and climate change options is about 5 MgC/ha in 2100



Summary

- The approach and model developed in this study is generic and can be easily adapted for the simulations of C dynamics in other areas.
- Establishing a C sequestration project on the basis of a sustainable fuelwood and charcoal production system is the most feasible and practical option in the region at present.
- The impact of agricultural sector on regional C dynamics is limited due to its limited spatial coverage. Consequently, few significant choices exist for setting up agriculture-based C sequestration projects in the region.
- Agricultural sector might become an important player if agricultural land is expanded under pressure.

SOCSOM Accomplishments

1. Quantitative Documentation of Changes in **C**
2. Procedures to Document Land Cover Performance
3. Quantitative Analysis of **C** Sequestration 3 Areas
    1. Management options
    2. Rates of sequestration
4. Socioeconomic & Cultural Requirements for Action
5. Functional & Participatory “National Carbon Team”
6. Extensive & Collaborative Training/Capacity Dev.
7. Engaged an International Community & Donors
8. **5 Projects Developed in Senegal; 6 elsewhere**
9. **3+ Ph.Ds awarded !!!!!**