Berkeley Faculty Roundtable on Environmental Services in Rangeland Production Systems
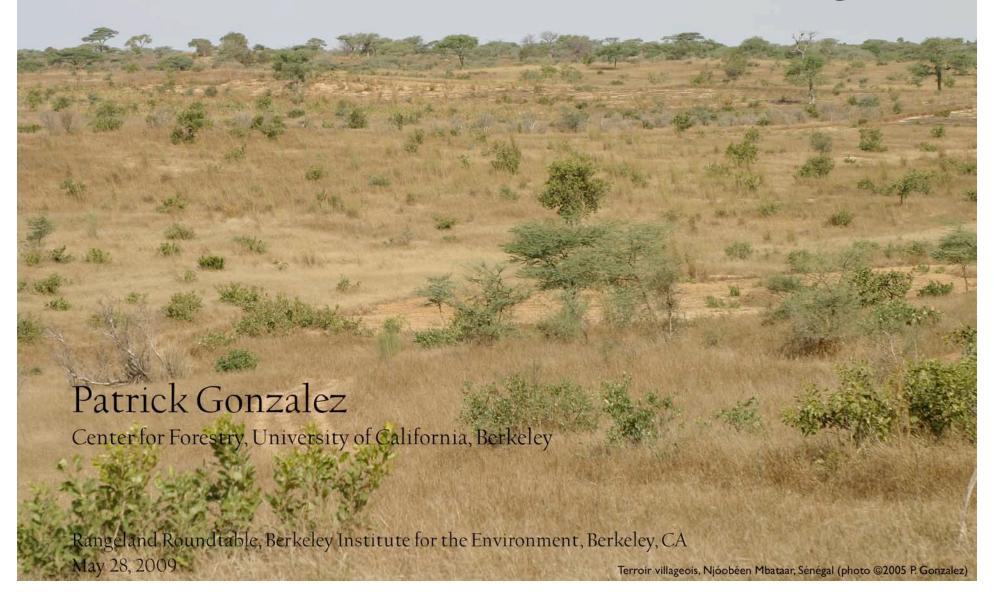
Presentation and Discussion Notes from the Third Roundtable: May 28, 2009
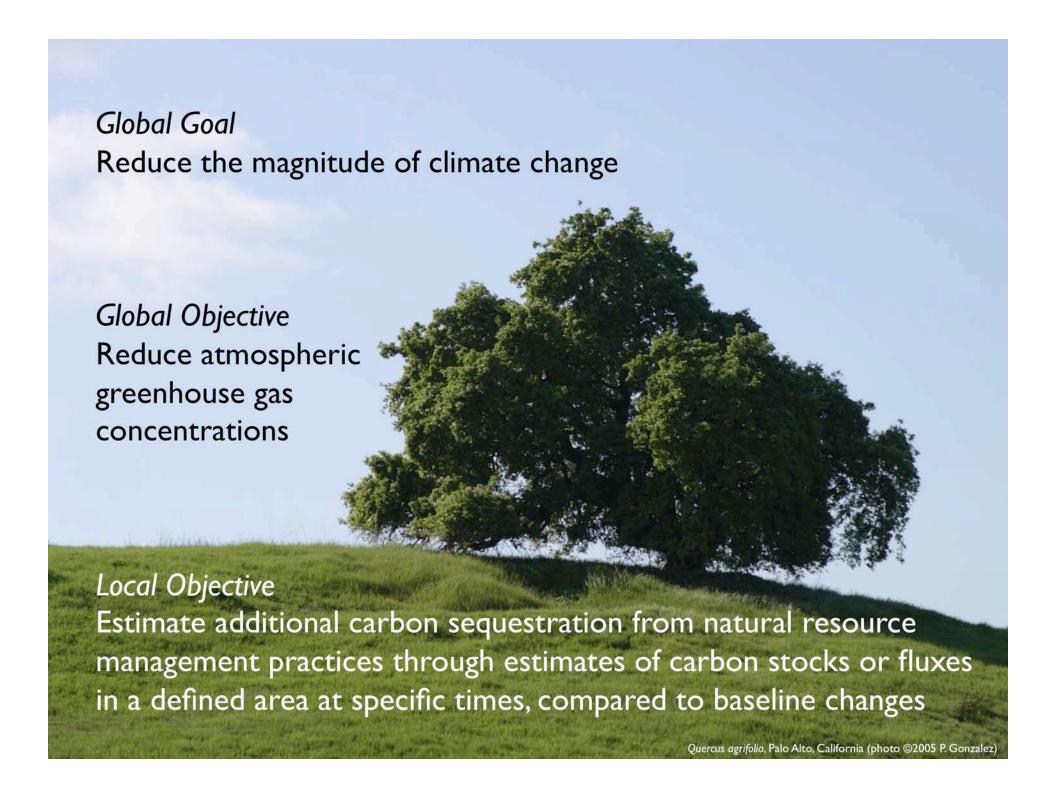

PATRICK GONZALEZ

MONITORING CARBON IN SAVANNAS AND WOODLANDS WITH FIELD INVENTORIES AND REMOTE SENSING

Berkeley Faculty Roundtable on Environmental
Services in Rangeland Production Systems

Part I:
Powerpoint Presentation by Patrick Gonzalez

Terroir villageois, Njóobéen Mbataar, Sénégal (photo ©2005 P. Gonzalez)

Global Goal
Reduce the magnitude of climate change

Global Objective
Reduce atmospheric greenhouse gas concentrations

Local Objective
Estimate additional carbon sequestration from natural resource management practices through estimates of carbon stocks or fluxes in a defined area at specific times, compared to baseline changes

Quercus agrifolia, Palo Alto, California (photo ©2005 P. Gonzalez)

Monitoring Carbon in Savannas and Woodlands with Field Inventories and Remote Sensing

Presentation Outline

1. Carbon estimation and monitoring process

2. Example from the African Sahel

3. Baseline estimation and sequestration projection

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Greenhouse Gas Categories and Methods

Land Use[A]
Forest land
Cropland
Grassland
Wetland
Settlements
Other land

Greenhouse Gases[A]
CO_2
CH_4
N_2O
HFCs
PFCs
SF_6

Carbon Pools[A]
Aboveground biomass
Deadwood
Litter
Harvested wood products
Belowground biomass
Soil organic carbon[B]

Aboveground Biomass[D]
Mature trees
Understory trees
Shrubs
Grasses

Carbon Methods[A]
Gain-Loss (fluxes)[C]
Stock difference[D]

Uncertainty Methods[A]
Simple error propagation
Monte Carlo

Sources

A. IPCC 2006. National Greenhouse Gas Inventory Guidelines
B. W. Silver, March 6, 2009, Rangeland Roundtable
C. D. Baldocchi, March 20, 2009, Rangeland Roundtable
D. P. Gonzalez, May 28, 2009, Rangeland Roundtable

Center for Forestry, University of California, Berkeley

Research Objective

Estimate additional carbon sequestration ($\Delta C_{\text{additional}}$) from natural resource management practices through estimates of carbon stocks (C_t) or fluxes in a defined area at specific times (t), compared to baseline changes ($\Delta C_{\text{baseline}}$)

$$\Delta C_{\text{additional}} = \frac{C_2 - C_1}{t_2 - t_1} - \Delta C_{\text{baseline}}$$

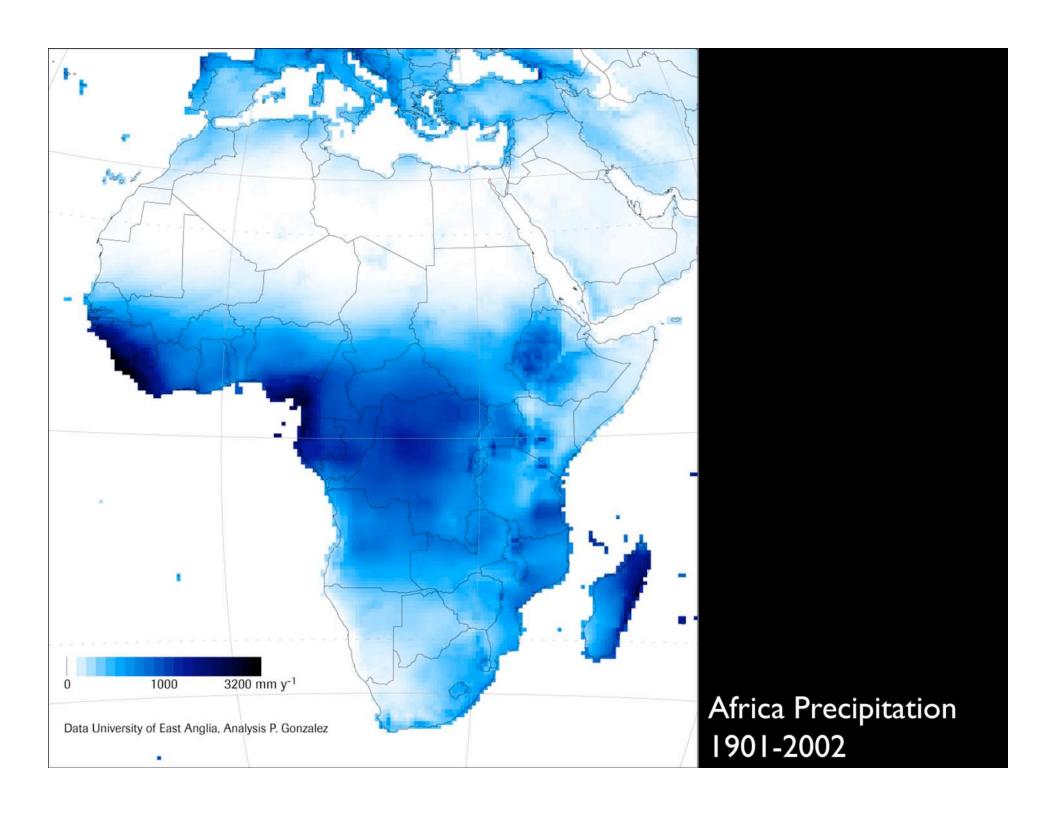| t_1	t_2	$\Delta C_{\text{additional}}$	$\Delta C_{\text{baseline}}$
30 years ago	this year	observed trend	0
last year	this year	monitoring	0
this year	30 years from now	projection	projection

Carbon Estimation and Monitoring Process

1. Delineate area (landscape or project)

2. Estimate current carbon stock

3. Monitor stocks over time by repeating methods

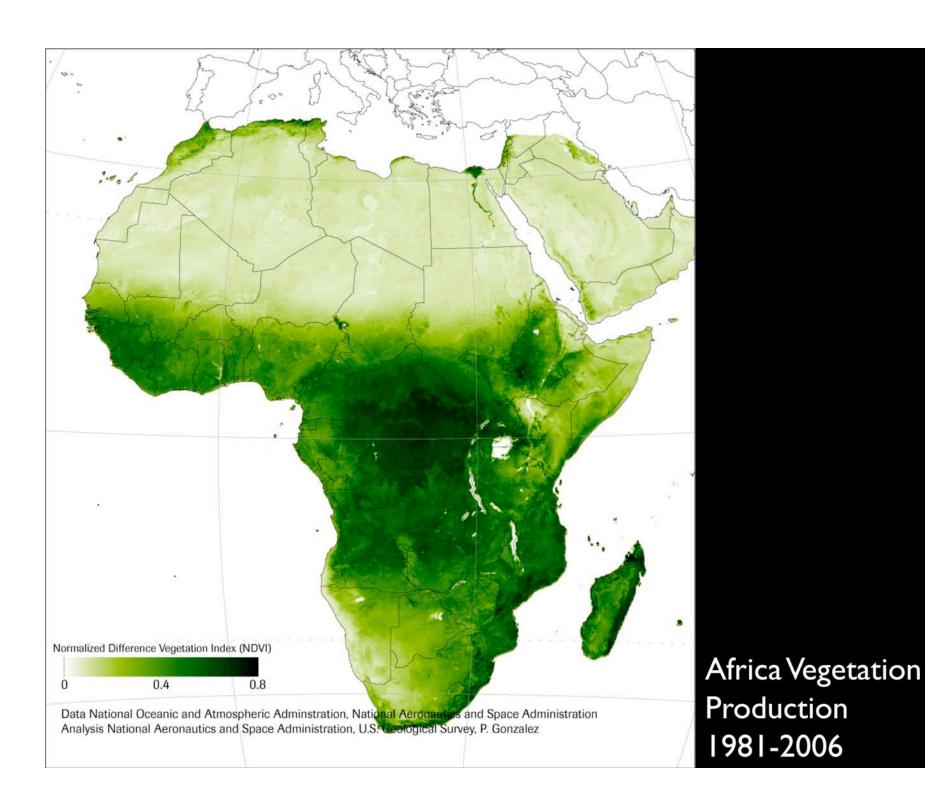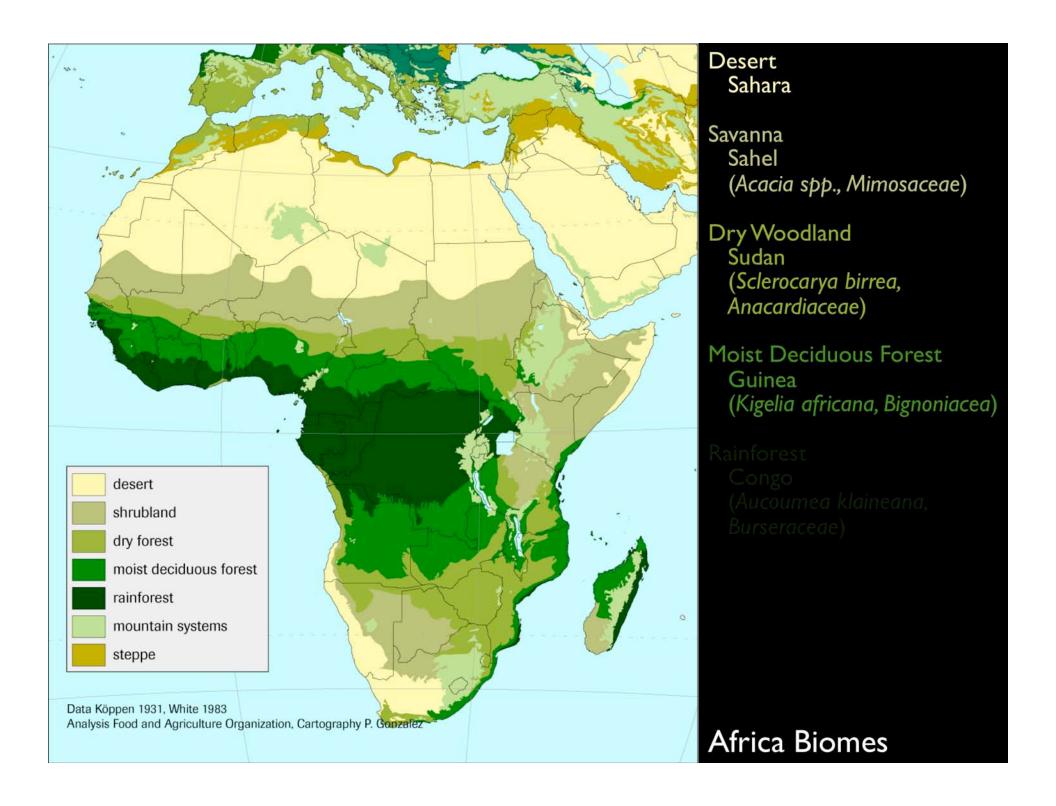4. Estimate baseline sequestration

5. Project future sequestration

Monitoring Carbon in Savannas and Woodlands with Field Inventories and Remote Sensing

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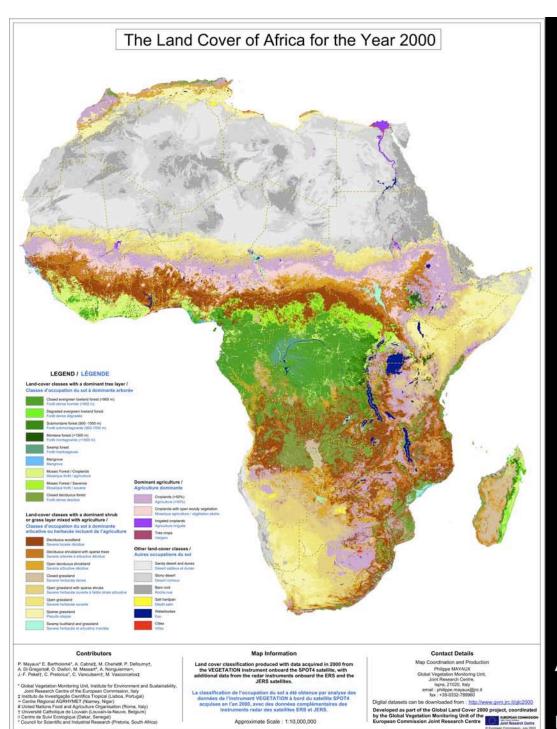1. Carbon estimation and monitoring process

2. **Example from the African Sahel**
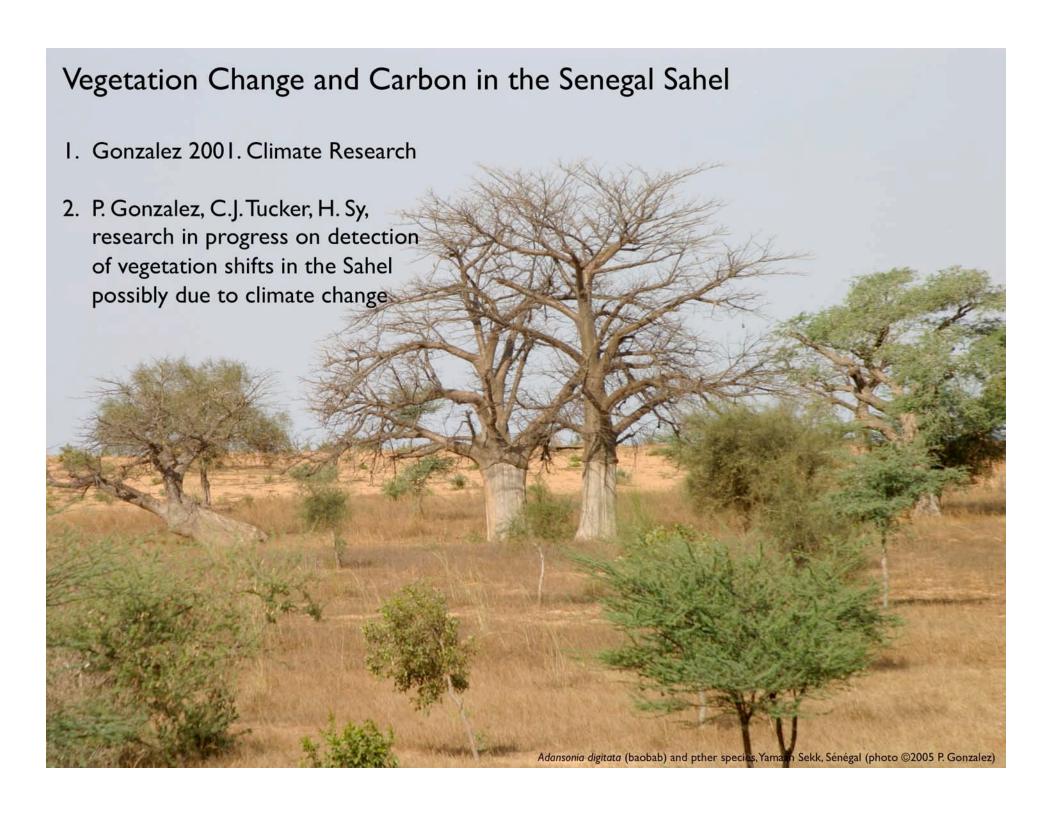
3. Baseline estimation and sequestration projection

Data University of East Anglia, Analysis P. Gonzalez

Africa Precipitation
1901-2002

Normalized Difference Vegetation Index (NDVI)

0   0.4   0.8

Data National Oceanic and Atmospheric Adminstration, National Aeronautics and Space Administration
Analysis National Aeronautics and Space Administration, U.S. Geological Survey, P. Gonzalez

Africa Vegetation
Production
1981-2006

Africa Biomes

Desert
Sahara

Savanna
Sahel
(*Acacia spp., Mimosaceae*)

Dry Woodland
Sudan
(*Sclerocarya birrea,
Anacardiaceae*)

Moist Deciduous Forest
Guinea
(*Kigelia africana, Bignoniacea*)

Rainforest
Congo
(*Aucoumea klaineana,
Burseraceae*)

Legend:
- desert
- shrubland
- dry forest
- moist deciduous forest
- rainforest
- mountain systems
- steppe

Data Köppen 1931, White 1983
Analysis Food and Agriculture Organization, Cartography P. Gonzalez

Africa Land Cover

Bartholomé and Belward 2005. Int.'l J. Remote Sensing

Vegetation Change and Carbon in the Senegal Sahel

1. Gonzalez 2001. Climate Research

2. P. Gonzalez, C.J. Tucker, H. Sy, research in progress on detection of vegetation shifts in the Sahel possibly due to climate change

Adansonia digitata (baobab) and pther species, Yamaan Sekk, Sénégal (photo ©2005 P. Gonzalez)
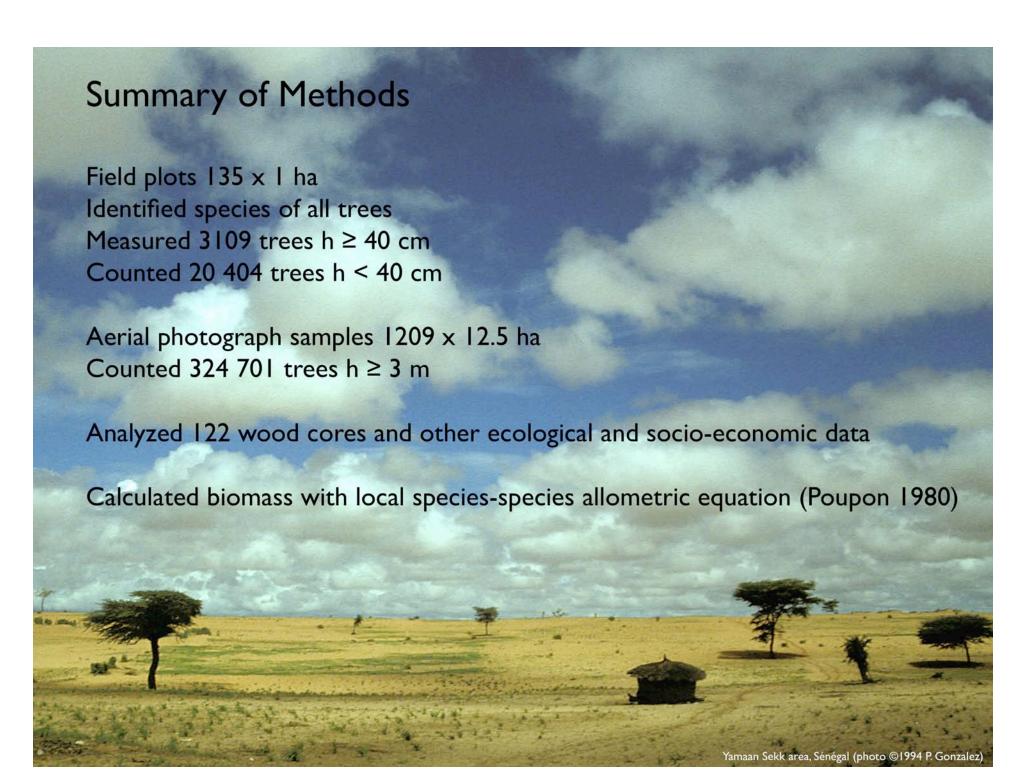
Research Area, Northwest Senegal, 7600 km²

Gonzalez 2001. Climate Research

16°N

15°N

16°W

MODIS, October 19, 2001, J. Descloitres, NASA

Precipitation 1855-2003, St. Louis (Ndar), Sénégal

latitude 16.1°N, longitude 16.5°W, elevation 4 m

data Direction de la Méteorologie Nationale du Sénégal; Aubréville, A. 1938. La forêt coloniale–Les forêts de l'Afrique Occidentale Française. Société d'Éditions Géographiques, Maritimes, et Coloniales, Paris, France; le Borgne, J. 1988. La pluviométrie au Sénégal et en Gambie. Office de la Recherche Scientifique et Technique Outre-Mer, Dakar, Senegal. *analysis* P. Gonzalez

$y = 2851 - 1.29\ x;\ r^2 = 0.11,\ n = 137,\ p < 0.0001$

mean ± standard deviation = 360 ± 160 mm y^{-1}

Summary of Methods

Field plots 135 x 1 ha
Identified species of all trees
Measured 3109 trees h ≥ 40 cm
Counted 20 404 trees h < 40 cm

Aerial photograph samples 1209 x 12.5 ha
Counted 324 701 trees h ≥ 3 m

Analyzed 122 wood cores and other ecological and socio-economic data

Calculated biomass with local species-species allometric equation (Poupon 1980)

Yamaan Sekk area, Sénégal (photo ©1994 P. Gonzalez)

dead *Prosopis africana*
photo ©1993 P. Gonzalez

Forest Species Loss

ca. 1945	64 ± 2 species
1993	43 ± 2 species
change	-33% ± 5%
significance	$p < 0.001$
sample	$n = 135 \times 4 \text{ km}^2$

Sahel, Sudan, Guinean zones
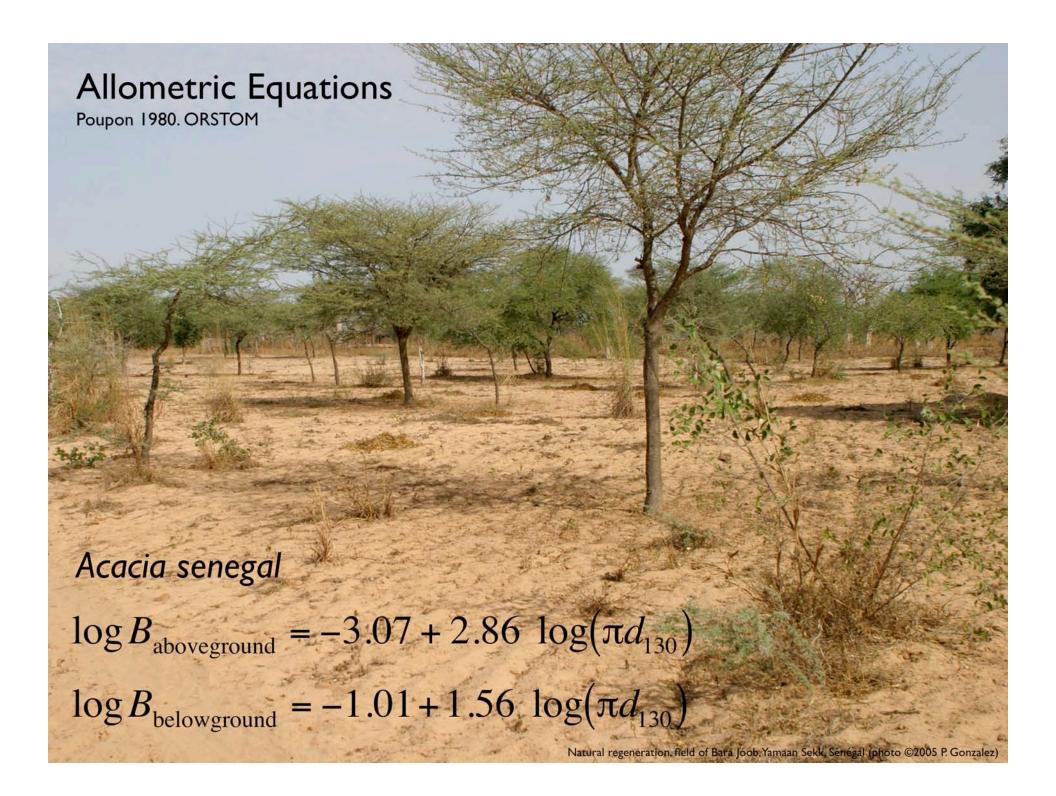shift SW 25-30 km
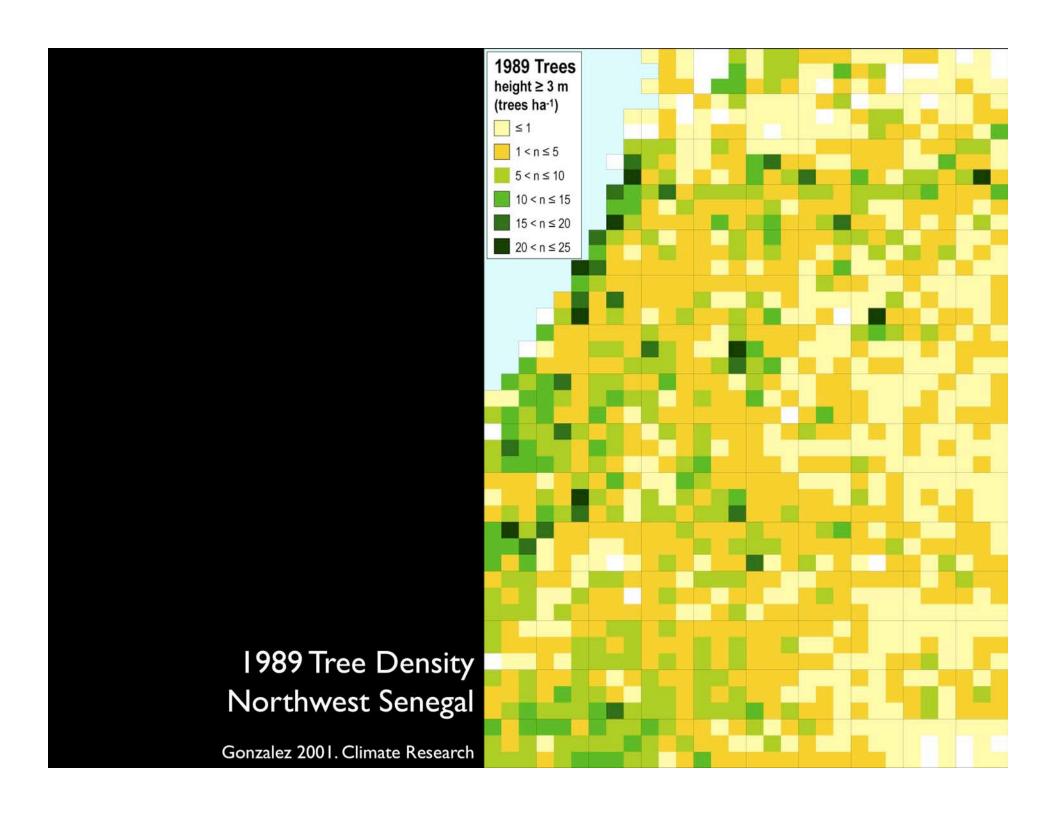
Gonzalez 2001. Climate Research

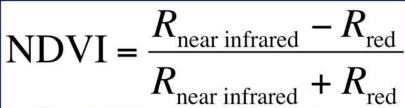# Tree Dieback, Northwest Senegal, 1954-1989,
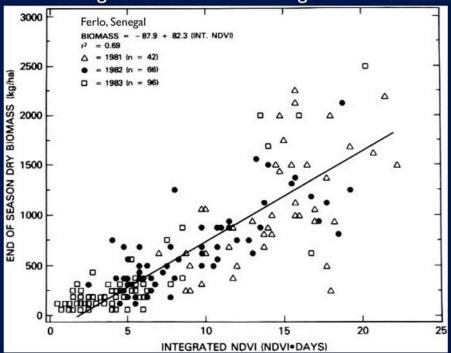
Trees of height > 3 m

1954 average density = **10.1 ± 0.3 trees ha^{-1}**
1954 density = -0.09 x (distance) + 13.6, r^2 = 0.30, n = 1209

- ◆ 1954 counted
- —— 1954 regression
- ◇ 1989 counted
- ----- 1989 regression

Change -22% ± 5%
Significance p<0.001

density (trees ha^{-1})

1989 average density = **7.8 ± 0.3 trees ha^{-1}**
1989 density = -0.08 x (distance) + 10.8, r^2 = 0.28, n = 1209

distance to sea (km)

Gonzalez 2001. Climate Research

1954 Trees
height ≥ 3 m
(trees ha^{-1})

- ≤ 1
- 1 < n ≤ 5
- 5 < n ≤ 10
- 10 < n ≤ 15
- 15 < n ≤ 20
- 20 < n ≤ 25

1954 Tree Density
Northwest Senegal

Gonzalez 2001. Climate Research

1989 Tree Density
Northwest Senegal

Gonzalez 2001. Climate Research

Allometric Equations
Poupon 1980. ORSTOM

Acacia senegal

$$\log B_{\text{aboveground}} = -3.07 + 2.86 \, \log(\pi d_{130})$$

$$\log B_{\text{belowground}} = -1.01 + 1.56 \, \log(\pi d_{130})$$

Natural regeneration, field of Bara Jóob, Yamaan Sekk, Sénégal (photo ©2005 P. Gonzalez)

Normalized Difference Vegetation Index (NDVI)

$$NDVI = \frac{R_{\text{near infrared}} - R_{\text{red}}}{R_{\text{near infrared}} + R_{\text{red}}}$$

Tucker 1979. Remote Sensing of Environment

Aboveground biomass vs. integrated NDVI

Tucker et al. 1985. Remote Sensing of Environment

NDVI 1981-2006 average

Normalized Difference Vegetation Index (NDVI)

0   0.4   0.8

Data National Oceanic and Atmospheric Adminstration, National Aeronautics and Space Administration
Analysis National Aeronautics and Space Administration, U.S. Geological Survey, P. Gonzalez

Other Estimation Parameters

1. Carbon fraction of biomass

2. Root:Shoot ratios

3. Dead tree fraction of live tree

4. Coarse woody debris relationships

5. Litter relationships

6. Wildfire relationships

Boscia senegalensis, Fété Olé, Sénégal (photo ©2002 P. Gonzalez)
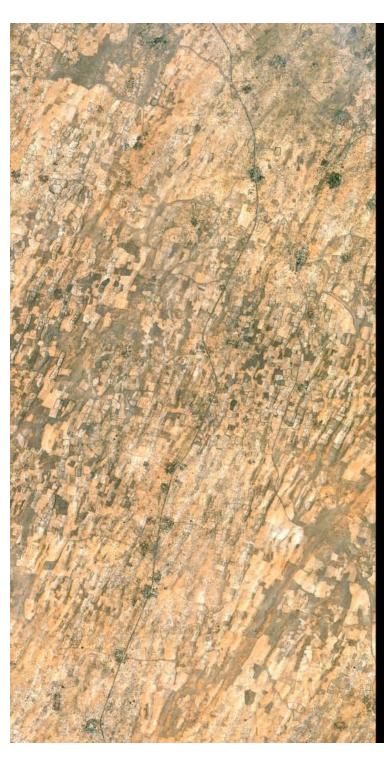
Senegal Sahel Carbon Estimate

	Growth (Mg ha^{-1} y^{-1})	Stock (Mg ha^{-1})	Gross rate (y^{-1})
Total carbon	3.3	41	0.08
Total vegetation			
herbaceous	2.9	3.2	0.91
ligneous	0.2	12	0.02
total	3.1	15	0.20
Aboveground biomass and deadwood			
herbaceous	1.2	1.3	0.91
ligneous	0.2	7.3	0.03
total	1.4	8.5	0.16
Belowground biomass			
herbaceous	1.7	1.9	0.91
ligneous	0.03	4.8	0.01
total	1.8	6.7	0.26
Soil			
Woomer et al. 2004	0.2	25	0.01

Uncertainty (SD) by simple error propagation ±30%

IKONOS sites, Northwest Senegal, 200 km²

P. Gonzalez, C.J. Tucker, H. Sy, research in progress

Fété Olé
Senegal
16.2°N, 15.1°W

Wolum
Mauritanie
16.2°N, 13.7°W

Njóobéen Mbataar
Senegal
15.8°N, 16.2°W

MODIS, October 19, 2001, J. Descloitres, NASA

IKONOS
Njóobéen Mbataar, Senegal
February 17, 2002

Image Space Imaging, Inc., Analysis P. Gonzalez

Njóobéen Mbataar, Sénégal (photo ©2005 P. Gonzalez)

IKONOS
Fété Olé, Senegal
February 22, 2002

Image Space Imaging, Inc., Analysis P. Gonzalez

Fété Olé quadrat, Sénégal (photo ©2002 P. Gonzalez)
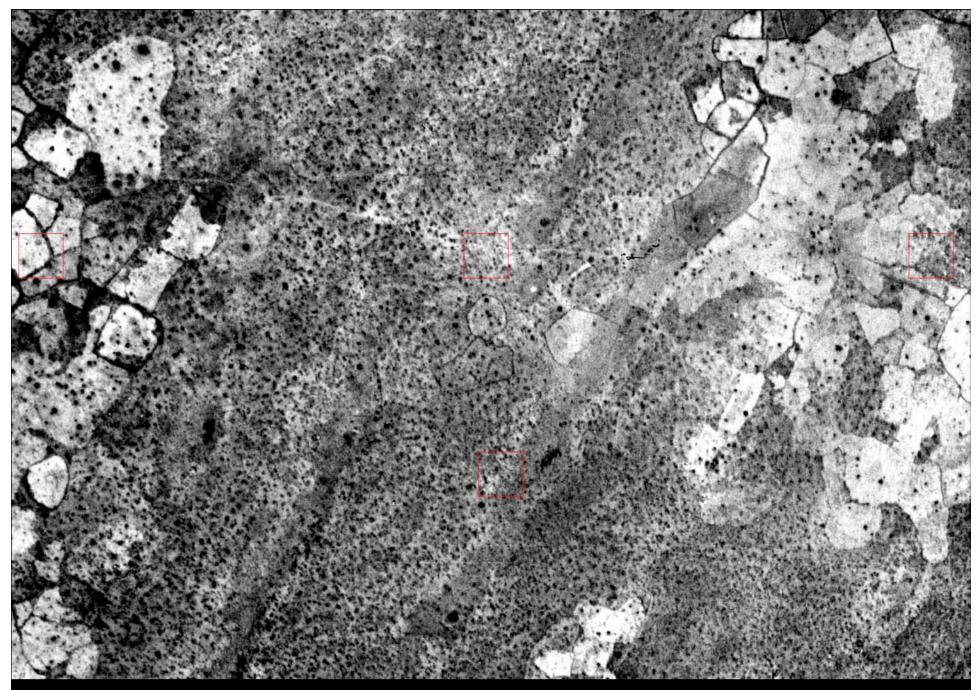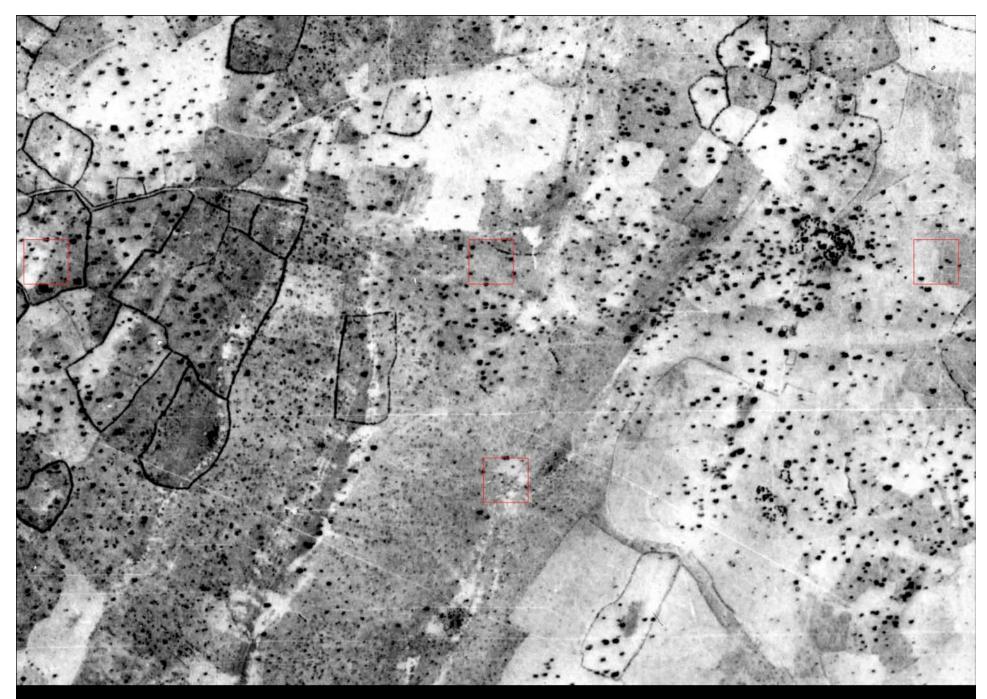
IKONOS
Wolum, Mauritanie
February 22, 2002

Wolum area, Mauritanie (photo ©2002 P. Gonzalez)
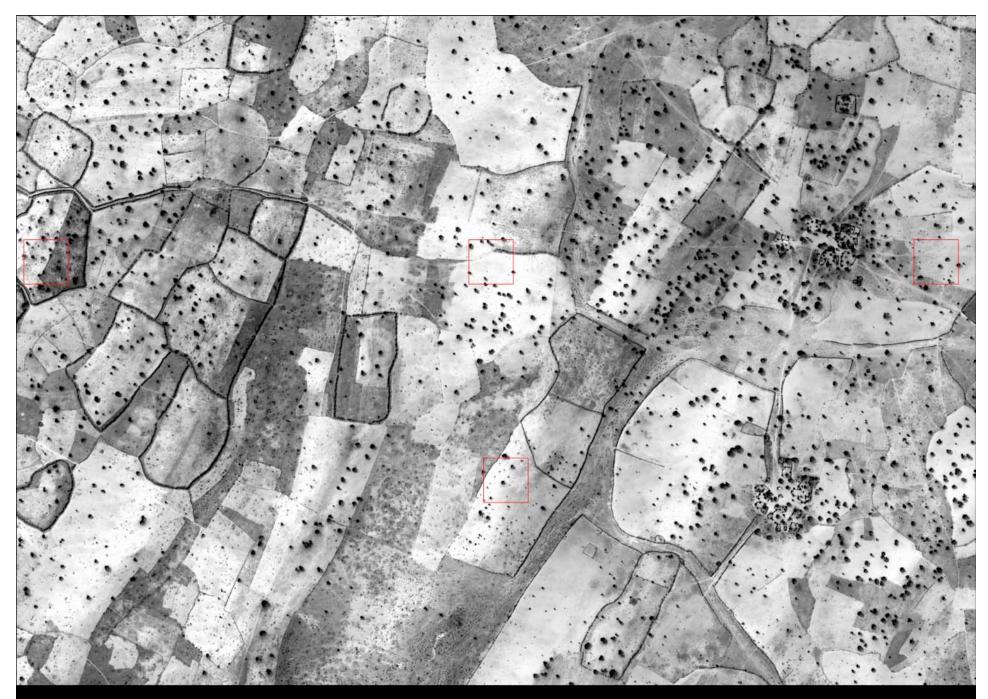
Njageen, Senegal, 1954, aerial photograph, IGN
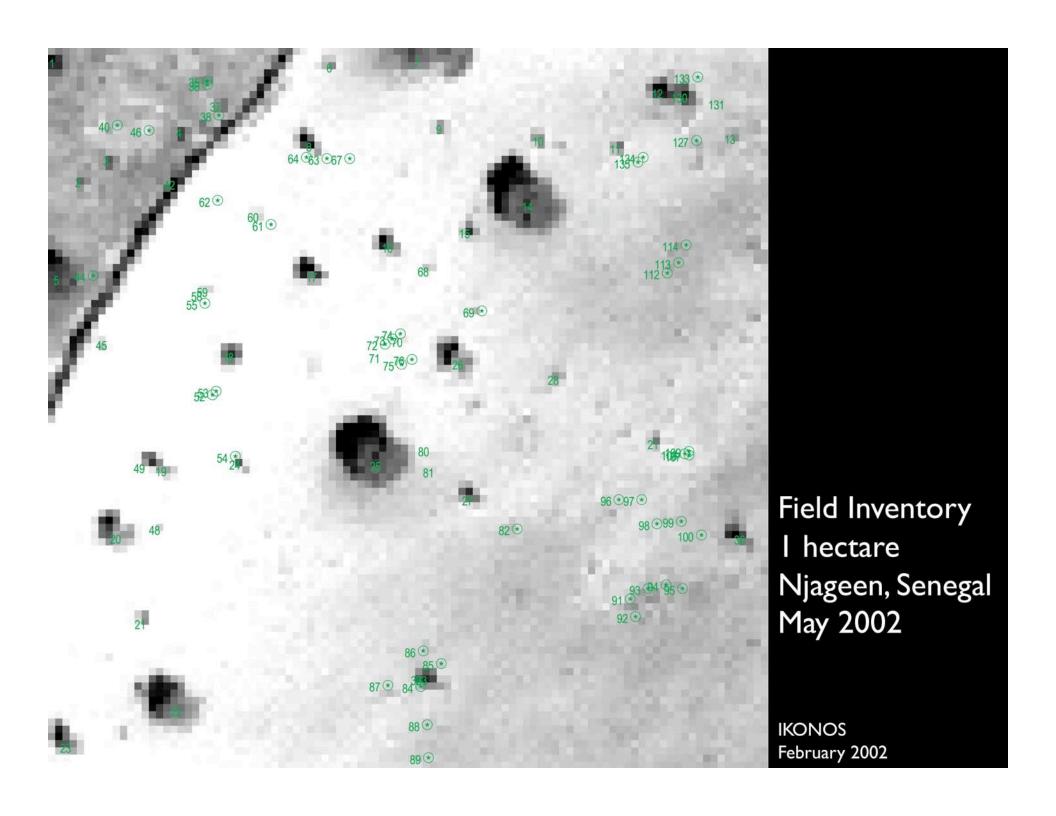
Njageen, Senegal, 1989, aerial photograph, JICA
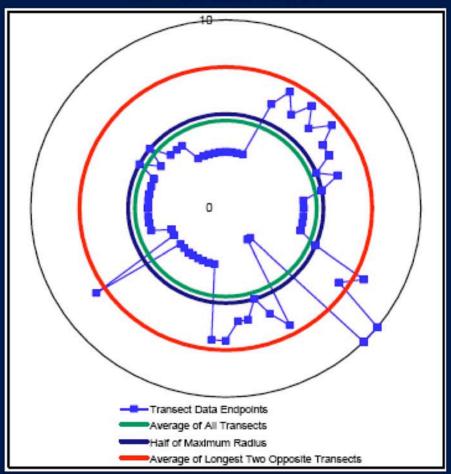
Njageen, Senegal, 2002, IKONOS satellite image

Field inventory quadrat, Njageen, Sénégal (photo ©2005 P. Gonzalez)

Field Inventory
1 hectare
Njageen, Senegal
May 2002

IKONOS
February 2002
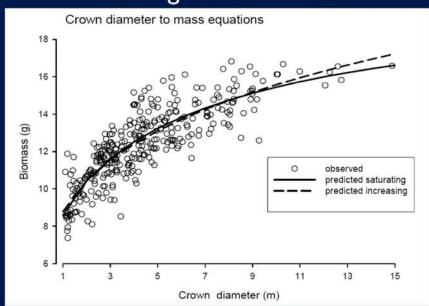
Tree Crown Estimates

Crown delineation

Aboveground biomass

$$\ln(biomass) = 18.613*((1-e^{-0.0757*diameter})^{0.2963})$$
$$n = 331, r^2 = 0.73$$

P. Gonzalez, G.P. Asner, J.J. Battles, M.A. Lefsky, K.M. Waring, M. Palace, manuscript submitted

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1. Carbon estimation and monitoring process

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3. Baseline estimation and sequestration projection

Principles of carbon sequestration project activities

Additionality

Property by which removal or sequestration of greenhouse gases results only from the direct action of a project activity, not from other activities already planned or funded
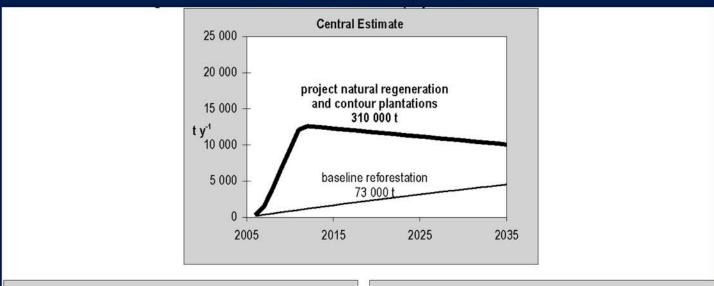
Baseline

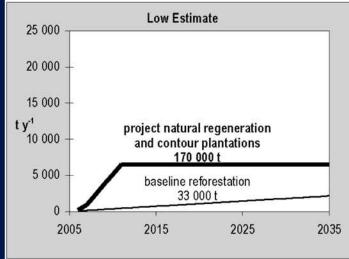Changes in greenhouse gas emissions and removals that would have occurred in the absence of the project activity
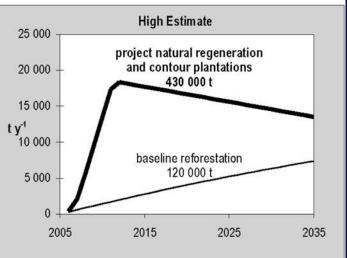
Leakage

Unintended displacement of greenhouse gas emissions to areas outside of the project boundary by actions attributable to the project activity

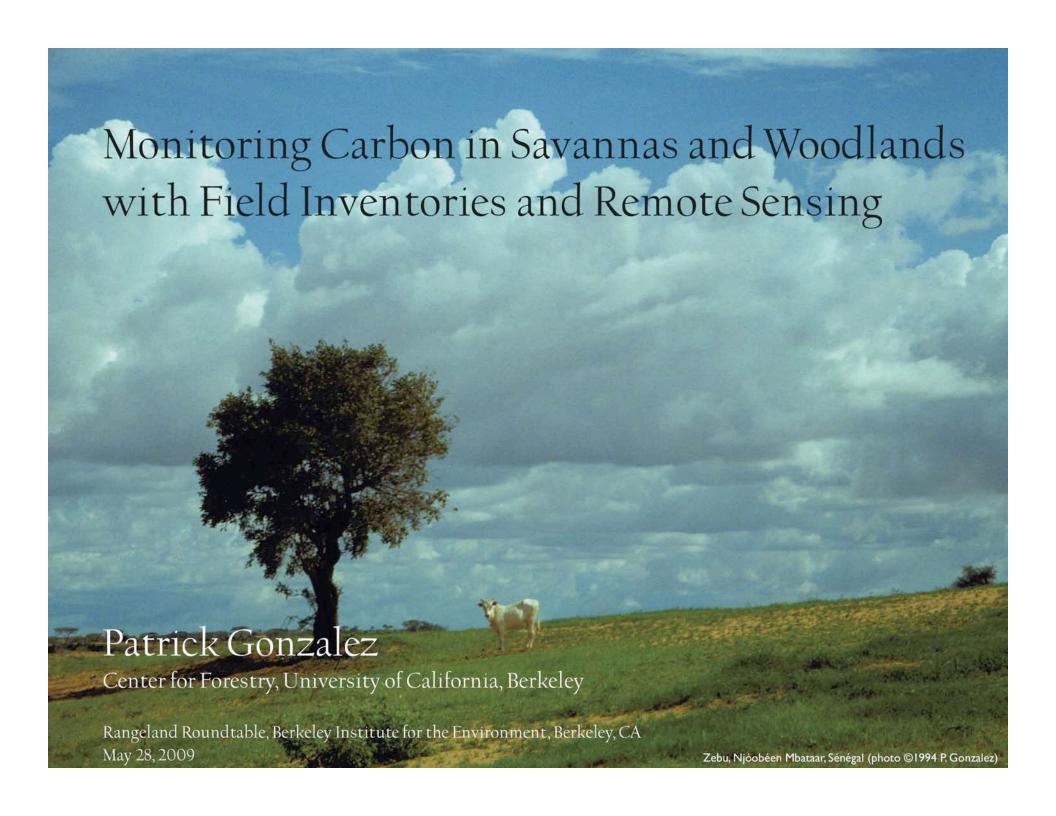# Baseline and sequestration projections for proposed forest project in Selva Central, Peru

P. Gonzalez, B. Kroll, C. Vargas, 2006, Report to U.S. Department of Energy

Recommendations and Research Gaps
for a Rangeland Carbon Monitoring System

1.   Establish permanent field inventory plots
2.   Extract soil samples to monitor soil organic carbon
3.   Use high-resolution satellite images to monitor tree cover
4.   Analyze NDVI to monitor grass cover
5.   Quantify uncertainty through Monte Carlo analyses

Andrew Molera State Park, California (photo ©2007 P. Gonzalez)

Monitoring Carbon in Savannas and Woodlands with Field Inventories and Remote Sensing

Patrick Gonzalez

Center for Forestry, University of California, Berkeley

Rangeland Roundtable, Berkeley Institute for the Environment, Berkeley, CA
May 28, 2009

Zebu, Njóobéen Mbataar, Sénégal (photo ©1994 P. Gonzalez)

Berkeley Faculty Roundtable on Environmental Services in Rangeland Production Systems

**Part II:
Discussion**

Notes compiled and synthesized by Kayje Booker, Roundtable GSR

Berkeley Faculty Roundtable on Environmental Services in Rangeland Production Systems

I. Issues and questions in response to Patrick's presentation:

- Vegetation Indexes: There are many indexes for measuring and monitoring vegetation. One drawback of NDVI is that it can saturate. Do you recommend NDVI?
  - NDVI works well for California rangelands because, although it can saturate if there are multiple stories, that situation is rare in rangelands.
  - EVI is another vegetation index using MODUS, but the advantage of NDVI is that there is data going back to 1980.
- Calculations of belowground biomass: Because the root to shoot ratio of trees and grasses are different, with grasses having relatively more of their biomass belowground, shouldn't the estimation of belowground biomass reflect that? Couldn't you turn the graph on slide 22 (Aboveground biomass vs. integrated NDVI) to a graph of total biomass by adding a line for belowground biomass that would be greater and have a steeper slope on the left hand side of the graph, where aboveground biomass is lower (because there most aboveground biomass would be grasses) then become flatter and lower at higher end of aboveground biomass (because there most aboveground biomass would be trees)? Has anyone validated that prediction?
  - It seems that that would be what you would expect and that such a regression and prediction would be possible. However, it has not been validated (as far as Patrick knows), and he advised caution on drawing too many conclusions from the regression.
- Photo resolution: What is the resolution on the 1954 aerial photos? Is it adequate for comparison with modern photos?
  - Resolution is limited on the older aerial photos. It improved greatly from 1954-1989, and IKONOS even better. The improvement of the resolution normally would create a problem in comparing across years because you can detect more trees now. In this case, however, it may be less of a problem, because Patrick has detected a trend of decreasing cover. If he is seeing decreasing tree cover even with better resolution, that finding is actually more robust. Still, he is working on standardizing between the different methods within the next two months.
- Species Richness: How do you detect species richness changes?
  - Field work with direct observation and interviews
  - The Wooloff have a profound knowledge of natural history. He did interviews with village elders and found less than 10% error in their recollections and recorded observations, so the interviews are quite accurate.

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II. Broader discussion
Patrick started off the discussion by posing the following question: Given the low rate of increase of carbon in rangelands, is it worth it to pursue this option or would the money be better used in other carbon mitigation activities? Discussion centered around the following three broad themes: measurement and monitoring of carbon, forest regeneration, and managing for multiple uses including livestock grazing and carbon sequestration.

A. Measurement and monitoring of carbon

- Given the low rate at which carbon is sequestered in rangelands and the extreme heterogeneity of rangelands, isn't this whole discussion moot because the cost of monitoring carbon in rangelands outstrips the value?
- Depends on scale. If you could scale up to whole state of California, instead of monitoring plot by plot, and use remote sensing, rangelands as a whole in California could break even. For local sites, even in high biomass sites in tropical forest, it is hard to make money off of carbon because of management and monitoring costs. The smaller the project, the worse the money works out.
- As far as tools for that monitoring, Patrick thought that Landsat would be a good tool but that MODUS, at the state level, would probably not be adequate. It depends on the policy – the level of allowable uncertainty dictates the resolution required.
- California Climate Action Registry (CCAR) has been developing a forest protocol, and the lines between science, politics, and policy are pretty fuzzy. There are many competing protocols. Are you seeing a standardization in measurement and error estimation?
- There is a need for standard methods and calculations internationally, and the IPCC plays that role globally. In the US federal system, however, the national government is letting the states be laboratories in developing these protocols, so there is less consistency in the U.S.
    - o IPCC has the best available science with lots of review, so following their protocols is generally a good idea.
    - In US, parallel processes are producing some unfortunate things. For example, Chicago Climate Exchange guidelines are very lax by international standards. As another example, the CCAR has decided on a baseline methodology that is very different from UNFCCC rules and very specific to California. The baseline under CCAR is a projection of how much tree cover would be predicted based on common practice and legal and financial constraints. The UNFCCC, however, UNFCCC requires documenting how land cover has changed, using, for example, LandSat photos, then using those trends to project into the future.
    - There is a chance, under the new administration, that there will be a national program.

B. Forest regeneration
- From the work presented this week and elsewhere, it appears that to store more carbon in rangelands, we will need more trees, but what about limits? There are places where you could plant more trees but others were they've already reached their max based on precipitation.
- However, many places in the regions that Patrick studies in Africa, for example, are not anywhere near their maximum density. Some ethnic groups in the area do planting and regeneration activities, and in those areas you can see a doubling in the density of mature trees.

Berkeley Faculty Roundtable on Environmental Services in Rangeland Production Systems

- In these areas that are seeing shifts in patterns of rainfall, such as the study areas, it may be that passive regeneration could occur (which Patrick has seen in old fields left to revert to forest) but with the replacement of the more mesic species by the drought tolerant species. So regeneration can occur, even in these areas, but the species mix will be different. It is important to note, too, that the broad trends in precipitation shifts hide more local effects, so there are actually some areas in which the rainfall has not changed much, and in those areas regeneration of mesic species may be possible.
- The extent to which regeneration is possible depends, too, on whether we want active or passive regeneration. In California, people are planting oaks, and they can grow without irrigation, but in other places, replanting forests (or planting them in areas where they did not exist previously) may require irrigation, which may not be acceptable.
- Finally, it is important to remember that while the most effective way to store carbon on rangelands is probably to plant forests, there are management activities on rangelands that could increase carbon without conversion to forest.

C. Managing for multiple uses – livestock grazing and carbon sequestration
- Groups like the California Rangeland Coalition are seeking to protect working landscapes. Can this type of science be used for groups like this to argue for protection of working landscapes?
- Working landscapes are important because eating is necessary, meaning that there is a need to manage landscapes for productive agricultural use as well as other benefits. We need to learn more about these landscapes and how to support both carbon and other productive land uses to conserve them. In both the Sahel and California, we should look at traditional agroforestry systems to learn how those systems succeed (or do not) in producing multiple benefits. We at the university focus on how the system works, but it is also necessary and worthwhile to take that information and apply it in support of goals such as conservation of working landscapes. As of now, we still do not fully understand the balance and trade-offs involved in different land uses as far as their carbon impacts.
- We've talked in the roundtable about how grazing affects carbon, but in places with woody plants, it seems clear that wood is better. In places where there are some woody species, such as oak woodlands, it seems that we could use grazing animals to help manage for trees – for example to redistribute nutrients for tree growth. It would just be a question how to plan that grazing spatially and temporally to generate and credibly measure carbon gain for credits.
- However, adding livestock to a landscape would also mean methane emissions, so how would management practices of sequestering carbon (in soil and biomass) using livestock balance with the methane produced by the animals? When does the methane start to overwhelm the benefits?
- Livestock and methane emissions could quickly swamp out woody biomass gains. However, to really understand the interaction, it also matters where these livestock would have been and whether their emissions are really additional.
- We need good life-cycle assessments of these activities to better compare different land uses and alternatives, such as this question of livestock and trees or the issue of harvesting or leaving trees, as we discussed last time. The key is to keep multiple ecosystem services intact so that these systems are more resilient in the face of climate change.