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Understanding the drivers of agricultural land use change in south-central Senegal

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Abstract

Described is (1) the land use and land cover changes that have taken place in the Department of Velingara, an area of tropical dry woodland in south-central Senegal, (2) the biophysical and socio-economic drivers of those changes with an emphasis on transition to agricultural use, and (3) an assessment of the likelihood of intensification of agriculture in the Department. Results indicate that land devoted to agriculture, either in active cultivation or short-term fallow, is increasing. There is little evidence of agricultural intensification in most of Velingara, with extensification coming largely at the cost of reduction in both upland woodlands and riparian forest.

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1. Introduction

There is significant research linking land use and land cover change with changes in global carbon stocks (Houghton, 1994; IGBP, 1999; Priess et al., 2001). Yet there is a need to better understand the relationship between land use and land cover changes, and the various land management decisions that drive them. With a more complete understanding of those drivers, it is possible to predict changes that are likely to occur, proposed management options that might be successful for a given biophysical/socio-economic/political situation, and what the potential impacts on carbon stocks (IGBP, 1993; Woomer, 1993).

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In this paper we describe (1) land use and land cover changes that have taken place in the Department of Velingara, a rapidly changing area of tropical dry woodland in south-central Senegal; (2) biophysical and socio-economic drivers of those changes with an emphasis on transition to agricultural use; and (3) an assessment of the likelihood of intensification of agriculture in the Department. A companion paper details the carbon dynamics of Velingara using the CENTURY based GEMS model (Reiners et al., 2002; Liu et al., 2003). It demonstrates the model's flexibility in using large national spatial databases that are critical to modeling carbon sequestration potential on a regional basis (e.g. Sahel-wide).

This paper emphasizes agricultural expansion because it is generally recognized as a primary driver of land use/land cover change in much of Senegal and West Africa. We consider agricultural expansion important for two reasons: (1) intensification of agriculture can result in higher rates of carbon sequestration (Woomer et al., 1997; IPCC, 2000) and (2) agricultural expansion or extensification is a key driver for removal of forested land, which is the major carbon stock in many regions including southern Senegal. The other major carbon loss in southern Senegal is the degradation of forests, largely due to fuelwood harvesting and charcoal production.

This study described in this paper builds on work previously carried out under a USAID-funded project to develop an environmental monitoring capacity for the country of Senegal (Tappan and Wood, 1995; Tappan et al., 2000b), and it includes related research on modeling agricultural expansion in southern Senegal (Wood et al., 1998; Wood, 2002).

2. Background

Over the last decade there has been increasing interest in the impacts of global land use and land cover change. This rapidly accelerating change in the landscape is associated with a wide variety of issues, including declining biodiversity (Darkoh, 2003), global climate change and food security, and land degradation as it applies to soils, vegetation, and water. Much of the land use and land cover change is a result of human activity (Houghton, 1994; Lambin, 1994; Riebsame et al., 1994; de Koning et al., 1999; Kok et al., 2001) and currently recognized as one of the critical gaps in our knowledge of the terrestrial carbon cycle, which in turn has implications for greenhouse gas accumulation in the atmosphere and potential climate change (IGBP, 1999). The IPCC (2000) states that expansion of agriculture through conversion of forests and grassland during the past 140 years has led to a net release of about 121 gigatons of carbon, of which about 60% has been emitted in the tropics, mostly during the last 50 years.

A key approach for reversing this trend is intensification of agriculture (Lambin, 1994; Woomer et al., 1997; Tiessen et al., 1998). Agricultural production systems have been analysed in the context of intensification versus extensification (Boserup, 1965; Pingali and Binswanger, 1988; Lele and Stone, 1989; Turner II et al., 1993; Cleaver and Schreiber, 1994), with extensification defined here as opening of new

land from forests, wetlands, hillsides, or pastures for cultivation. Intensification is more complicated, but can be considered as an increase in productivity from increased inputs to land already under cultivation. The nature of these inputs often determines if the intensification is sustainable. Reardon et al. (1999) suggest that agricultural intensification can be defined as “sustainable” using two criteria: (1) the environmental criteria that the technology protects or enhances the farm resource base, and (2) the economic criteria which requires that the farming system meets the farmer’s production goals (food and/or cash) and is profitable. Both require capital-led intensification, which implies the use of non-labor inputs and such as chemical inputs, organic matter, equipment, and land-conservation infrastructure (Reardon, 1997; Clay et al., 1998). In contrast, capital-deficient intensification utilizes the inputs of family or hired labor, but without channeling the surplus labor towards creation of fixed capital inputs. Without these capital inputs use of surplus labor leads to extensification or unsustainable intensification, examples of which include reduced fallow periods, expansion to marginal lands, and excessive planting density (Kelly et al., 1996; Reardon et al., 1999).

There is growing support for the idea that African farmers must intensify their agriculture in order for the continent to improve its food security situation and to participate in the global market economy in a sustainable manner (Lele and Stone, 1989; Reardon and Shaikh, 1995; Reardon et al., 1997). The options for extensification outside of protected areas are becoming limited or impractical and it will soon not be sustainable as a strategy for increasing production. There are, however, numerous constraints to further intensification in Africa, including inadequate market development, inadequate resource allocation, technological limitations, withdrawal of needed labor, tenure insecurity, lack of awareness of issues and alternatives, and environmental degradation (Turner II et al., 1993).

Historically, intensification has not been common in sub-Saharan Africa. First, sub-Saharan Africa was land-rich and, therefore, supportive of extensification, as observed in southern Senegal. Also, intensification can be risky and costly, driven by unforeseen economic factors, and has no guarantee of a positive relationship between intensity and sustainability. Because of the precarious nature of rainfed agriculture in Africa, farmers are often forced to take an approach that maximizes aversion to risk, making intensification a poor alternative (Adams and Mortimore, 1997; Darkoh, 2003).

National resource management policies in Africa have a strong bearing on determining achievable levels of intensification. Farmers require inputs to intensify agricultural production on their land, and have relied on government support in the form of loans and subsidies. Since the mid-1980s, however, there has been pressure from global institutions (e.g. the World Bank, International Monetary Fund) on African governments to eliminate these subsidies as part of structural adjustment (Reardon et al., 1997). To provide the correct environment for capital-led sustainable intensification of agriculture, Reardon et al. (1997) suggest the following requirements: (1) agriculture is commercialized, input and output markets are accessible, and investment returns are high, (2) population pressure is high, (3) labor is available, and (4) farmers have cash to buy inputs.

3. Study area

The landscape of south-central Senegal has changed radically over the past 20 years. The Department of Velingara (hereafter referred to as Velingara) in the eastern Casamance and extreme western extent of the Shield Region (Fig. 1) exemplifies this change (Wood et al., 2000). For an overview of the Casamance and the Shield regions, refer to Tappan et al. (2004) in this issue.

Velingara, an area of approximately 543,000 ha, is relatively flat, ranging from 60 to 70 m in altitude, broken by fossil river valleys. The topography is somewhat more varied in the south-east corner of the Department, which exhibits the most-western extension of the highly folded metamorphic rocks of the Shield Region. Because Velingara falls along the southern fringe of the Sudanian zone, vegetation types are more diverse than in the north, with a mix of species ranging from Sudanian to Guinean (Tappan et al., 2000b). Natural vegetation formations include grasslands on laterite, dense deciduous wooded savannahs, dry upland woodlands, and riparian and evergreen closed-canopy gallery forests along the rivers and fossil river valleys. Approximately 18% of Velingara's 524,000 ha is in reserve status, primarily open woodland designated as forest reserve (*forêt classée*) or national park (Fig. 2).

Agricultural parkland is also a significant land use with agricultural activities including production of millet, maize, peanuts, cotton and rice, animal husbandry, and arboriculture. Outside of the reserves, 360,000 ha of land are considered to be of at least moderate potential for agriculture (USAID/Senegal, 1991). Fig. 3 shows a typical landscape with dry upland forest interspersed with both long-standing and expanding agriculture.

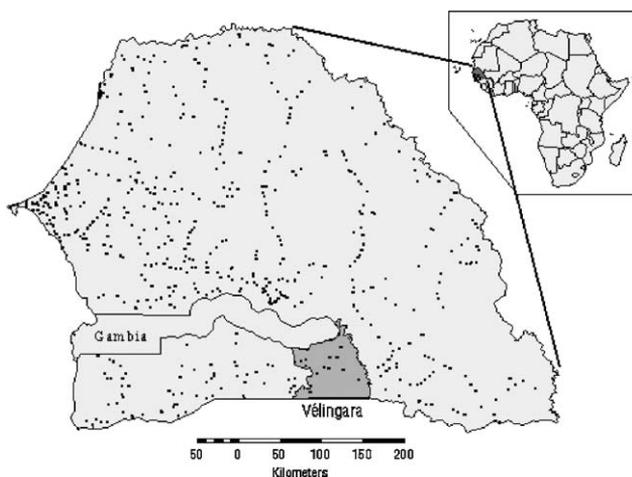


Fig. 1. Senegal showing the location of the study area of the Department of Velingara (dark gray). The dots represent long-term field sites used to monitor biophysical changes.

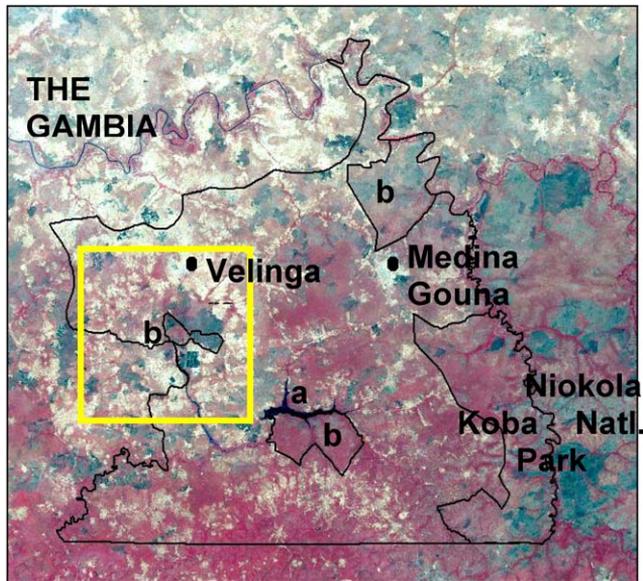


Fig. 2. This 2001 Landsat ETM+ image covers the Department of Velingara (outlined). Dark colors indicate vegetation, light colors are agriculture, towns (e.g. Velingara and Medina Gouna), or bare soil. The yellow box represents the general location of the Anambe Basin, an agricultural development project. Note the area of intense agriculture along the border with The Gambia and the newly created Kayanga reservoir (a). The relatively undeveloped eastern side of the Department includes a portion of the Niokola Koba National Park. The boundaries of the forest reserves are designated by internal black line work (b).



Fig. 3. Typical Sudanian zone landscape in the Department of Velingara.

Although the impacts of climate change in the Casamance Region have been much less severe than in the northern portions of the country, the average annual rainfall for Velingara has been decreasing over the past 60 years, from over 1200 mm to currently less than 1000 mm. The rainy season extends from June to October.

Table 1

Comparison of population growth rates between the 1976 and 1988 censuses and an estimation for 2000 (République du Sénégal, 1988)

	1976	1988	1976–88	Est. 2000
<i>Population size and annualized growth rates</i>				
Senegal				
Urban	1,694,000	2,659,000	3.83%	4,183,000
Rural	3,304,000	4,223,000	2.07%	5,910,000
Total	4,998,000	6,882,000	2.70%	10,093,000
Department of Velingara				
Urban	14,900	29,300	4.01%	46,900
Rural	80,400	97,700	2.25%	120,500
Total	95,300	127,000	2.43%	167,400

The soils of the Upper Casamance are similar to the dominant soils of eastern Senegal and are characterized by shallow soils on lateritic hardpans. They are a form of tropical ferruginous soils and are among the most leached of their type in Senegal (Ruthenberg, 1976; Chase, 1982; Stancioff et al., 1986). The soils in the Shield region are shallow, gravelly, highly leached ferruginous soils over laterite and Precambrian parent material (Stancioff et al., 1986; Tappan et al., 2004).

Pélissier (1966) notes that, as late as 1960, less than 5% of the land was in agriculture, which correlates strongly with sparse rural population. He describes continuous woodland, broken only by rivers and small villages, with the eastern half of Velingara nearly devoid of population. This was due in part to the diseases trypanosomiasis and onchocerciasis. Also, since the 1950s, a large portion of the eastern third of the Department has been placed in forest reserve status. With the control of disease, increased population pressure, and better road access, settlers have moved into the eastern half of the Department.

In 1988, the population density of Velingara was 23 persons km⁻² (Table 1), with the overall population density of the *Communauté Rurale* ranging from 17 to 39 persons km⁻² (République du Sénégal, 1988).

4. Objectives/methods

The primary objectives of this research are:

- Identifying changes in land use and land cover over time.
- Identifying the key drivers of these changes.
- Discussing the implications of these results for agriculture and natural resource policy.

This team used a key baseline data set from previous research carried out between 1994 and 1999 (Tappan et al., 2000b). Field revisits were made at 320 of 600 original

ground sites established throughout Senegal between 1982 and 1984 (Stancioff et al., 1986; Tappan and Wood, 1995), with the 320 chosen to represent the diversity of agro-ecological zones in Senegal. Seventeen of those revisited sites are located in the Velingara study area. Data collection at each site included a full vegetation inventory, preliminary soil profiles, assessment of natural resource condition and management practices, and site photographs (Wood et al., 1998). Semi-structured interviews were used to collect additional socio-economic data during visits to villages throughout the Department, including farmers' perceptions on the state of agriculture in the Department. A week-long rapid rural appraisal (RRA) study was carried out in the *terroir* of Kandia in the northern part of the Department (Freudenberger and Tappan, 1996).

Other key data sets used for characterizing land use and land cover change included:

- *Climate*: monthly precipitation estimates were derived from a variety of data sets (e.g. AGRHYMET, USAID's Famine Early Warning System).
- *Population density*: data were compiled from the Government of Senegal censuses from 1976 to 1988, the last census available at the time of this study (République du Sénégal, 1988).
- *Access to markets*: distance to roads, towns, and major market centers was established and functioned as a proxy indicator for market access.
- *Soil capacity*: two soil indices were developed for determining agricultural capacity. The first was based on a regional expert characterization of FAO and local soil surveys. The second was based on empirical evidence of the occurrences of transition to agriculture on specific soils (Wood, 2002).
- *Tree condition assessment matrix* (Department of Velingara): qualitative indices of the condition of tree cover were developed from forest inventories taken at 11 of the 17 long-term monitoring sites in Velingara (Tappan et al., 2000b). Number and quality of species were assessed. This, in combination with percent tree cover and pressure on the forest (only primary pressures are listed in the table) were used to determine an "overall state" for the tree cover at that site.
- *Satellite imagery*: A time-series of early dry season Landsat MSS, TM, and ETM+ satellite imagery of Velingara was created for the years 1973, 1978, 1984, 1990, and 1999. They were geometrically registered to the 1:200,000 scale topographic maps of the area (Government of Senegal map series). Land use and land cover was classified from the images using a hybrid manual and spectral-based approach. Data for ground referencing for the classification came from several sources that included extensive field observations, 1982 aerial photographs, 35-mm aerial photographs taken during a national videography mission in 1994, and the Corona satellite photography (Tappan et al., 2000a; Wood et al., 2000). The land use and land cover nomenclature was based on the life-form based "Yangambi" classification system, which is specifically tailored to tropical West Africa and uses as primary criteria, number and height of strata and woody tree density (Trochain, 1957). The results were then analysed using post-classification differencing (Lillesand and Kiefer, 2000).

We used the Reardon et al. (1997) approach for assessing the potential for sustainable, capital-led agricultural intensification in Velingara. Using the data described above, we then determined if the four criteria established had been met. In addition, these data were also analysed to determine which were the most significant drivers of agricultural and other land use change in the Department.

5. Results

The results of the land use and land cover classification for the time-series are presented in Table 2. The quantity of land in both cultivation and short-term bush/fallow best describes the impact of agriculture in the conversion of previously “natural” lands. Fig. 4 illustrates the increase in the amount of land that has been brought into the agricultural production system between 1973 (82,855 ha) and 1999 (188,719 ha), an increase of 127.8%. The bush/fallow class represents young second growth, which, in Velingara, is indicative of agriculture land either recently abandoned or put into fallow.

Several observations can be made from the time-series in Fig. 4: (1) expansion of agriculture follows a general west to east trend, (2) expansion is concentrated around the Department’s two large towns of Velingara and Medina Gounass and the Anambe Basin, an agricultural development project initiated in the early 1970s, (3) cultivation of heavy soils increased in fossil river valleys, (4) increased activity near forest reserves, and (5) agricultural development along the Gambia border to the north is much greater than along the southern borders with Guinea or Guinea Bissau.

It is also important to note the amount of land that was in agriculture but which has subsequently been removed from agricultural use. For example, 59,894 pixels

Table 2
Percentage of landscape in each land use and land cover class

Class	1973	1978	1984	1990	1999
Intensive rainfed agriculture with some fallow	6.4	8.4	13.6	16.7	8.2
Extensive rainfed agriculture with significant fallow	8.8	10.5	8.3	8.5	13.3
Mechanized, irrigated agriculture	0.0	0.0	0.0	0.2	0.4
Bushland, old fields	0.0	0.3	5.1	3.4	12.6
Savanna woodland	8.0	7.5	6.3	6.0	5.1
Dense savanna woodland	30.2	28.7	25.5	24.8	21.4
Dense savanna woodland with bowe	15.0	14.5	14.1	14.0	13.6
Dry deciduous woodland	22.5	21.1	17.8	17.3	16.2
Moist semi-evergreen woodland/gallery forest	3.9	3.8	3.5	3.4	3.2
Riparian and fringing semi-evergreen woodland	2.7	2.7	3.0	3.0	2.2
Shrub savanna	2.1	2.1	2.1	2.1	2.1
Aquatic grassland	0.3	0.3	0.3	0.3	0.3
Intermittent lake	0.1	0.1	0.1	0.1	0.1
Water	0.0	0.0	0.3	0.3	1.0
Town	0.1	0.1	0.1	0.1	0.5

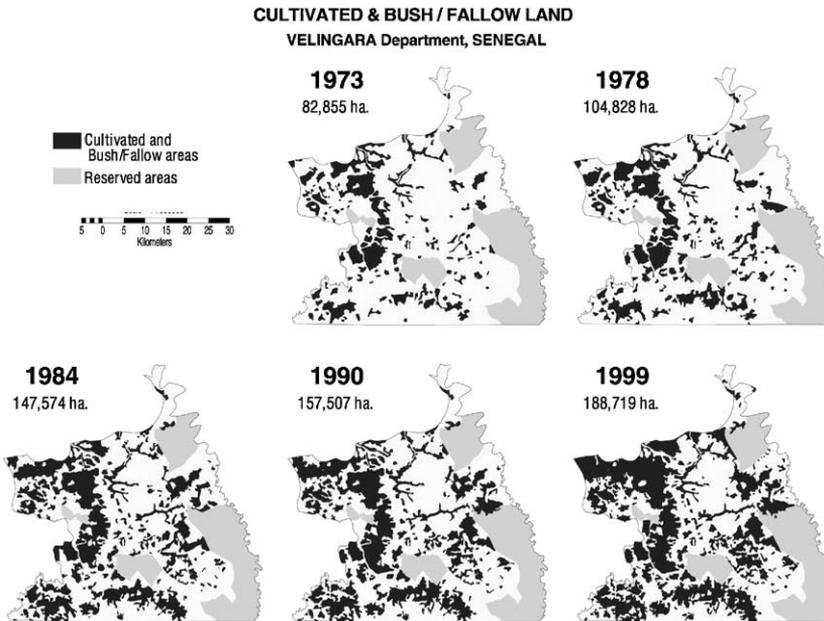


Fig. 4. The expansion of agriculture in the Department of Velingara from 1973 to 1999.

Table 3

Land removed from agriculture expressed as change in numbers of pixels (1600 m²)

Date into agriculture	Number of pixels in agriculture	Dates out of agriculture	Change in # of pixels	Percent change
1973	129,412	1978–99	59,894	42.28
1978	161,528	1984–99	76,896	47.61
1984	187,170	1990–99	65,569	35.05

(each pixel represents 1600 m²) were in agriculture in 1973, but were subsequently removed at some point between 1973 and 1999 (see Table 3), equivalent to a decline of 46.3%. These changes result from both a systematic placement of agricultural land into a fallow cycle and the less-common practice of shifting agriculture.

6. Discussion/conclusions

Many of the key drivers for land use and land cover change in this study are specific to the Department of Velingara (e.g. the Anambe Basin Project). Other drivers are similar to those encountered throughout Senegal or even

throughout West Africa. Eight categories of drivers are considered in the sections that follow.

- Sustainable intensification of agriculture
- Climate
- Population pressure
- Development projects
- Commodity production
- Forestry practices
- Fallow cycles
- Land tenure

6.1. Sustainable intensification of agriculture

Kelly et al. (1996) suggest that in order to obtain sustainable intensification of agriculture in Senegal, agricultural policies must address these urgent issues: (1) the quality and quantity of peanut seed available to farmers; (2) restoring soil fertility; (3) renewing animal traction stocks; (4) land tenure legislation; (5) increasing rural cash income to improve food security and input access.

Indicative of these issues is the dramatic decline during the 1980s in the use of fertilizers for restoring soil fertility. This can be best shown by comparing the amounts applied to specific crops and total distribution for the entire country in 1976 and again in 1990. Fertilizer use for peanuts and cowpeas fell from 38,360 tons in 1976 to 2966 tons in 1990. Similarly millet/sorghum/maize fell from 30,950 tons to 3119 tons and rainfed rice from 2290 tons to 127 tons. Overall, 116,320 tons were applied in 1976, and only 24,051 tons in 1990. During that period, however, levels of fertilization for cotton and irrigated rice remained the same, with only periodic deviations (USAID/Senegal, 1991).

Land in Velingara devoted to specific crops since 1976 have varied as well, as shown by the following statistics from the Ministry of Agriculture (République du Sénégal, 1999). The quantity of land in subsistence crops (maize, millet, and sorghum) was quite similar in 1976 (24,968 ha) and 1999 (27,698 ha), although it peaked at 42,537 ha in 1990. The cash crops showed similar fluctuations. The amount of land in rice was 2517 ha in 1976, nearly 3700 ha in 1999, with a high of 8105 ha in 1990. Cotton has remained stable with 12,748 ha in 1976 and 13,112 ha in 1999. The amount of land dedicated to oil peanuts has grown from 10,914 ha in 1976 to its peak at 16,039 ha in 1992, fallen off to 8585 ha in 1996 and back up to 15,580 in 1999. It is clear from these data that there have not been predictable increases in the amount of land dedicated to key crops as would be indicated by the trends in population growth. Nonetheless, the total amount of land actually in cultivation in Velingara for these specific crops has grown from 50,677 ha in 1976 to 72,176 ha in 1999 (with a peak of 95,923 ha in 1990–1991).

As discussed earlier, Reardon et al. (1997) state that investments in the increased use of farm capital, which is required to move from extensification or low-input capital-deficient intensification to a sustainable capital-led intensification, will take

place only if key criteria have been addressed. The ability of farmers in Velingara to meet the four criteria given earlier for capital-led intensification is described below.

Criterion 1. Agriculture is commercializing, input and output markets are accessible, and investment in intensification is profitable because returns are high and stable.

- Access to large coastal markets (e.g. Dakar, Kaolack, St. Louis) is difficult due primarily to distances from Velingara.
- Cotton production is supported in the Department, with supply of inputs through credit programs and marketing infrastructure.
- Commercial (mechanized) rice production is occurring as a result of the Anambe Basin project.
- Availability of affordable inputs is limited, due largely to failure of the private sector to fill the void left by the withdrawal of government subsidies and distribution (Kelly et al., 1996).
- Returns are variable for export cash crops (groundnuts and cotton). Even with an increase in groundnut prices following the 1994 devaluation of Senegal's currency, the CFA, the application of commercial fertilizer was still not cost effective.
- Mechanisms for domestic marketing of cereal crops (millet, sorghum) are not well developed in Velingara. These crops are largely grown for personal use (subsistence).

Criterion 2. Population pressure is high.

- Population density in the Department of Velingara is typical, compared to the national average for rural departments, but low, compared to that of the more-densely populated departments in the north-western portion of the country.
- Turner II et al. (1993), in their collection of case studies of intensification in sub-Saharan Africa, used a rural population density of greater than 150–200 persons km⁻² to define “high-density” areas. The assumption was that, in order for the types of transition to intensification of agriculture theorized by Boserup (1965) and others to take place, these population densities must first be reached. With a density of only 20–30 persons km⁻², Velingara falls well below these levels.

Criterion 3. Labor (family and/or hired) is available to undertake the labor-intensive tasks (e.g. construction of soil conservation capital, collection and distribution of manure).

- Although labor shortages in Velingara are not nearly as severe as in some parts of Senegal (e.g. the northern Peanut Basin), where urban or international emigration of the young has become a major household coping strategy, there is still insufficient labor. With low population density, much of the farm work is limited to family labor.
- Similarly, with limited returns on agricultural products, labor allocation to acquiring non-farm income is increasing because of the continuing need to diversify and avert risk, and get a better return for that input.

Criterion 4. Farmers have cash to buy inputs.

- Field visits indicate that farmers do not have the cash to buy inputs. Fertilizer use is primarily that subsidized for cotton or commercial rice, and limited amounts are withheld for application to other crops. Farm equipment is in need of repair or replacement.
- Considerable literature addressing agriculture in Senegal also indicates that farmers have not been able to purchase inputs over the past decade (Kelly et al., 1996; Reardon et al., 1997).

The assumptions laid out by Reardon et al. (1997) are only being partially met in Velingara. The same would be true in most of rural Senegal with perhaps the exceptions of the Niayes and the Senegal River valley. For the near future, intensification in Velingara will occur either in the form of labor-driven intensification, or not at all. Our field visits indicate that both situations are occurring. Most of the small-scale intensification is labor-driven but, in much of the Department, the coping strategy is still one of extensification of agriculture. Intensification is occurring in a few areas, such as the Anambe Basin, due to commercialization of rice production; in those households with capital to invest in fruit trees or agricultural post processing; or for those with market access for garden products, typically within proximity to the few major towns.

6.2. Climate

Climate impacts, primarily in the form of periodic drought and generally declining precipitation, have resulted in reduced rice cultivation in the fossil river valleys and other low areas. This has increased the significance of the irrigated rice project in the Anambe Basin. Decreased precipitation has also played a role in the increased severity of bushfires. On the whole, however, climate is not considered to be a major factor in land use and land cover change in Velingara.

6.3. Population pressure

Senegal is expected to reach a population of 16 million by 2020, which despite a continued rural to urban influx (urban population grew from 35% to 42% in 1995–96 alone), will lead to severely increased pressure for access to arable land. Presently 58% of Senegalese families are cultivators, 88% of which live in rural areas (Ly et al., 1998). This percentage is even higher in the Department of Velingara.

The population growth in Velingara was 33.2% between 1976 and 1988. It can be attributed to several factors: (1) migration of farmers from the north, leaving areas that are presently experiencing pressures from overpopulation, declining soil fertility, and decreased precipitation; (2) migration to the Anambe Basin by rice farmers from Lower Casamance; (3) periodic migrations from the countries of Guinea Bissau or Guinea Conakry due, in the past, to war and general political instability and, more recently, to demographic pressures and economic opportunity, with a similar

movement across the border from the densely populated Gambia to the north; (4) influence of the rapidly growing religious center, Medina Gounass, and commercial center, Velingara City. There is also influence from the growth of the larger population centers of Tambacounda and Kolda in adjacent departments.

6.4. Development projects

The Anambe River Valley Development Project (Fig. 2) has become a major change driver within the area surrounding the Anambe Basin, creating an overall increase in agriculture, and a limited shift from traditional crops to fruit trees and other intensive crops. The infrastructure of the project is intended to make irrigation and in some cases, land, available to farmers. Phase II of the Anambe Basin project has resulted in the recent damming of the Kayanga River and the newly created reservoir (Figs. 2 and 5).

6.5. Commodity production

Cotton was introduced as a cash crop in Velingara in the early 1970s by the parastatal organization SODEFITEX. Production at the farm level is maintained through extension, marketing, and credit supports. In an effort to increase cotton production in Velingara, new or improved roads are being built in areas not previously cultivated for cotton (or cultivated at all). These roads, necessary for expansion and timely marketing of mature cotton, are driving forces for a variety of changes, including increased conversion of land into other forms of agriculture, better access to Niokola Koba National Park (possibly resulting in poaching and agriculture intrusion), and better access to forests for charcoal producers.

Production of Senegal's other two key cash crops, peanuts and rice, is significant in Velingara. Rice is now largely produced in the irrigated lands of the Anambe Basin, and presently impacted only marginally by farmer's decisions to pursue crop diversification. Peanut production, the typical alternative to cotton, has been impacted in recent years by insufficient access to sources of quality seed (Kelly et al., 1996; Reardon et al., 1999).

6.6. Forestry practices

More than 80% of the population of Senegal use traditional sources of fuel, firewood and charcoal (Ly et al., 1998). Because of population increases in Velingara and throughout Senegal, the demand for woodfuels and forest products continues to increase as well. In Velingara, there is visual evidence of intensive charcoal production, especially along the main access roads. Forests are noticeably degraded and, in some cases, key charcoal species have been completely removed. Grazing has also impacted forests. Nonetheless, the borders of the forest reserves and other protected areas in Velingara have remained relatively intact (Fig. 5), unlike many similar reserves in other parts of the Casamance. Selective cutting of key species occurs in several forest reserves, but with the exception of the forests near Medina

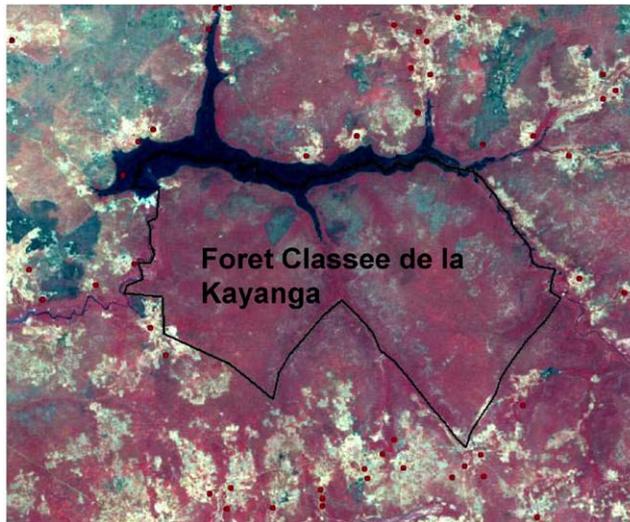


Fig. 5. Despite the increased pressure from settlement around the new Kayanga Reservoir (red dots represent villages), the *Forêt Classée de la Kayanga* boundaries remain relatively intact. Agriculture (light area), in addition to long-term settlements to the south, is continuing to expand around the northern side of the newly created reservoir. Long-term agriculture to the south of the reserve is relatively stable (Image: 2001 Landsat ETM+).

Gounass, we saw only limited evidence of agricultural incursion or outright deforestation. For most of the Department this appears to be the result of adequate alternative sources for forest products, although there is growing pressure on the forests for land for agricultural expansion.

Of particular importance in the maintenance of the forest reserve boundaries is the National Forest Code. The Forest Code is designed to give villagers more control over “their” forests (i.e. transfer some of the power of the State to the *Communauté Rurale*). To date, the protection offered the forest from these local governments has been limited and brings into question the optimism over the ability their government to save local resources (Fanchette, 1999).

Forested lands can be managed for retention of carbon stocks, both above and below ground. Results from Liu et al. (2004) suggest that primary carbon sequestration impacts in Velingara will be made in the forests. Those management approaches include multiple non-timber uses of the forest, sustainable charcoal production, reduction of slash and burn practices, reforestation of degraded and non-degraded sites (e.g. on marginal agricultural soils and lands subject to severe erosion), and retention of forest litter and debris after silvicultural activities (IPCC, 2000). Results from village-level models developed for Velingara by Sankhayan and Hofstad (2001) suggest that forest degradation could be best retarded through introduction of improved agricultural techniques, higher cotton prices, increased rural wages and reduced charcoal prices.

6.7. Fallow cycles

Based on interviews, and supported by interpretation of remotely sensed data, the fallow cycles in Velingara appear to be more intact than in many other parts of Senegal. Although slowly decreasing, an average of 6 years of fallow is not uncommon.

6.8. Land tenure

Kelly et al. (1996) suggested a need for land tenure reform that permits transactions in land to ensure better land allocation. Nonetheless, their research suggests titling of land with its inherent role as collateral for credit access does not have strong farmer support. Both forest and agricultural land is subjected to the public's response to tenure insecurity. By directive of the Law on the National Domain, the *Communauté Rurale* has responsibility for the allocation of all land, which belongs to the state. Although the law is aimed at providing more local control of land allocation and management, it varies greatly between the *Communautés Rurales* (Freudenberger and Freudenberger, 1993). Many of the *Communautés Rurales* suffer from the lack of a well-developed management plan (Freudenberger and Tappan, 1996). As a result, villagers are continually concerned about the concept of *mise en valeur* (which translates: if land is not being put to "productive use," it can be allocated to someone who will do so). Evidence of the law's impact in this regard includes forest clearing and other inappropriate land management techniques, practiced to maintain the appearance of *mise en valeur* (Freudenberger and Tappan, 1996; Wood, 2002). Until the mid-1980s, because uncultivated land was still generally available, there was not significant tenure conflict throughout the Department. However, with a steady increase in population, internal migration, and the impacts of recent land policies, this has been changing, especially between farmers and pastoralists (Fanchette, 1999).

7. Summary

There is little evidence of sustainable agricultural intensification in most of Velingara, with extensification occurring largely at the cost of reduced upland woodlands and to a limited extent, gallery forest. In Velingara agricultural extensification accounts for greater forest conversion than charcoal production or other general cutting, although present modes of charcoal production will lead to severe degradation of the forests and have greater impacts on overall carbon stocks (Liu et al., 2004).

The statistics derived from the remotely sensed data for change in the Department also support these conclusions. There are two key observations from these activities: (1) land devoted to agriculture, either in active cultivation or in short-term fallow, is increasing, and (2) the spatial and temporal distribution of land in agriculture

implies that land is being actively moved into and out of agricultural land use (i.e. semi-permanent cultivation, which is a form of extensification).

Land constraints are only beginning to be significant in most parts of the Department. Labor, though not in serious short supply, is limited and makes labor-demanding strategies (e.g. capital-deficient intensification) less attractive than land-demanding strategies (e.g. extensification).

The specific impacts of national resource policies on landscape change in Velingara are not as clear. Field visits indicate that agricultural extensification in Velingara is reinforced by recent and current agricultural policies, which severely limit access to farm inputs and credit. The effects of recent in forestry and tenure policy are still quite limited, but there are indications that they could offer significant potential for local control of resources and, in some cases, enable villagers to resist what had previously been uncontrollable outside influences. Successful strengthening and implementation of these policies are, therefore, vital for providing an environment in which Senegalese farmers will be able to intensify agriculture, reduce deforestation or forest degradation. As a result, not only will there be an increase in the rate poverty reduction, but also increase the overall sequestration of carbon with all of its global climate change implications.

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References

- Adams, W., Mortimore, M., 1997. Agricultural Intensification and Flexibility in the Nigerian Sahel. *Geography Journal* 163 (2), 150–160.
- Boserup, E., 1965. *The Conditions of Agricultural Growth: the economics of agrarian change under population pressure*. Aldine Press, Chicago.
- Chase, R., 1982. *Soils and Water Management in the OHV. FSRE Project—USAID, Dakar, Senegal*.
- Clay, D., Reardon, T., Kangasniemi, J., 1998. Sustainable intensification in the highland tropics: Rwandan farmers investments in land conservation and soil fertility. *Economic Development and Cultural Change* 46 (2), 351–378.
- Cleaver, K., Schreiber, G., 1994. *Reversing the Spiral: The Population, Agriculture, and Environment Nexus in Sub-Saharan Africa*. The World Bank, Washington, DC.
- Darkoh, M.B.K., 2003. Regional perspectives on agriculture and biodiversity in the drylands of Africa. *Journal of Arid Environments* 54, 261–279.
- de Koning, G., Verburg, P., Veldkamp, A., Fresco, L., 1999. Multi-scale modeling of land use change dynamics in Ecuador. *Agricultural Systems* 61, 77–93.
- Fanchette, S., 1999. Densité de population et intensification agro-pastorale en Haute-Casamance. *Espaces, Populations, Sociétés* 1, 67–81.
- Freudenberger, K., Freudenberger, M., 1993. *Fields, Fallow, and Flexibility: Natural Resource Management in Ndam Mor Fademba, Senegal*. International Institute for Environment and Development, London.
- Freudenberger, K.S., Tappan, G., 1996. *Kandia: Threatened forest, threatened livelihood*. Report to USAID/Senegal, Dakar.

- Houghton, R., 1994. The worldwide extent of land use change. *BioScience* 44 (5), 305–313.
- International Geosphere Biosphere Program (IGBP), 1993. Relating land use and global land-cover change. IGBP Rpt. N. 24/HDP Report No. 5.
- International Geosphere Biosphere Program (IGBP), 1999. Land-use and land-cover change implementation strategy. IGBP Rpt. N. 48/HDP Report No. 10.
- International Panel on Climate Change (IPCC), 2000. Land Use, Land-Use Change, and Forestry. Cambridge University Press, Cambridge, UK.
- Kelly, V., Giagana, B., Reardon, T., Gaye, M., Crawford, E., 1996. Cash crops and foodgrain productivity in senegal: historical view, new survey evidence, and policy implications. MSU International Development Paper No. 20, Michigan State University, East Lansing.
- Kok, K., Farrow, A., Veldkamp, A., Verburg, P., 2001. A method and application of multi-scale validation in spatial land use models. *Agriculture Ecosystems and Environment* 85, 223–238.
- Lambin, E., 1994. Modeling deforestation processes: a review. TREES Series B. Research Report No. 1, European Commission, EUR 15744EN.
- Lele, U., Stone, S., 1989. Population Pressure, the Environment and Agricultural Intensification: Variations on the Boserup Hypothesis. The World Bank, Washington, DC.
- Lillesand, T., Kiefer, R., 2000. Remote Sensing and Image Interpretation. Wiley, New York.
- Liu, S., Loveland, T., Clement, R., 2003. Contemporary carbon dynamics in terrestrial ecosystems in the southeastern plains of the United States. *Environmental Management*, doi:10.1007-S00267-003-9152-2.
- Liu, S., Kaire, M., Wood, E., Diallo, O., Tieszen, L., 2004. Impacts of land use and climate change on carbon dynamics in south-central Senegal. *Journal of Arid Environments*, this issue.
- Ly, M., Kane, L., Ly, A., Mbaye, A., Seck, P., 1998. 2020 Vision Network for West Africa: Country Note for Senegal. International Food Policy Research Institute, Accra, Ghana.
- Péllissier, P., 1966. Les Paysans du Sénégal: Les civilisations agraires du Cayor à la Casamance. Imprimerie Fabrègue, Saint-Yrieix, France.
- Pingali, P., Binswanger, H., 1988. Population density and farming systems: the changing locus of innovations and technical change. In: Lee, R., Arthur, W., Kelley, A., Rodgers, G., Srinivasan, T. (Eds.), *Population, Food and Rural Development*. Clarendon Press, Oxford.
- Priess, J.A., de Koning, G.H., Veldcamp, A., 2001. Assessment of interactions between land use change and carbon and nutrient fluxes in Ecuador. *Agriculture, Ecosystems and Environment* 85, 269–279.
- Reardon, T., 1997. African agriculture: productivity and sustainability issues. In: Eicher, C., Staatz, J. (Eds.), *Agricultural Development in the Third World*. Johns Hopkins University Press, Baltimore.
- Reardon, T., Shaikh, A., 1995. Links Between Environment and Agriculture in Africa: Implications for Economic Growth and Policy. Policy Brief #2. Natural Resources Policy Consultative Group for Africa, USAID, Washington, DC.
- Reardon, T., Kelly, V., Crawford, E., Diagana, B., Dione, J., Savadogo, K., Boughton, D., 1997. Promoting sustainable intensification and productivity growth in Sahel agriculture after macro-economic policy reform. *Food Policy* 22 (4), 317–328.
- Reardon, T., Barrett, C., Kelly, V., Savadogo, K., 1999. Policy reforms and sustainable agricultural intensification in Africa. *Development Policy Review* 17 (4), 375–386.
- Reiners, W., Liu, S., Gerow, K., Keller, M., Schimel, D., 2002. Historical and future land use effects on trace gas emissions using an ensemble modeling approach: Costa Rica's Caribbean lowlands as an example. *Global Biogeochemical Cycles* 16, 223–240.
- République du Sénégal, 1988. Recensement Général de la Population et de l'Habitat, Mai–Juin 1988: Résultats Préliminaires. Ministère de l'Economie et des Finances, Direction de la Statistique, Dakar, Senegal.
- République du Sénégal, 1999. Recensement National de l'Agriculture. Ministère de l'Agriculture, Dakar, Senegal.
- Riebsame, W., Meyer, W., Turner II, B., 1994. Modeling land use and cover as part of environmental change. *Climate Change* 28, 45–64.
- Ruthenberg, H., 1976. *Farming Systems in the Tropics*. Clarendon Press, Oxford.
- Sankhayan, P.L., Hofstad, O., 2001. A village-level economic model of land clearing, grazing, and wood harvesting for sub-Saharan Africa: with a case study in southern Senegal. *Ecological Economics* 38 (3), 423–440.

- Stancioff, A., Staljanssens, M., Tappan, G., 1986. Mapping and remote sensing of the resources of the republic of Senegal: a study of the geology, hydrology, soils, vegetation and land use potential. SDSU, Remote Sensing Institute, SDSU-RSI-86-01.
- Tappan, G., Wood, E., 1995. Framework for long-term monitoring of natural resources in Senegal. Proceedings of the National Colloquium on Natural Resource Management in Senegal, Dakar, Senegal, April 6–7.
- Tappan, G., Hadj, A., Wood, E., Sall, M., 2000a. Use of argon, corona, and landsat imagery to assess 30 years of land resource changes in west-central Senegal. *Photogrammetric Engineering and Remote Sensing* 66 (6), 727–735.
- Tappan, G., Wood, E., Hadj, A., Lietzow, R., 2000b. Monitoring climate and human impacts on the vegetation resources of Senegal: drought, agricultural expansion, and natural resource management. USGS/EROS Data Center, USAID/Senegal Project Report PASA No. 685-P-00-00005-00.
- Tappan, G., Sall, M., Wood, E., Cushing, M., 2004. Ecoregions and land-cover trends in Senegal. *Journal of Arid Environments*, this issue.
- Tiessen, H., Feller, C., Sampaio, E.V.S.B., Garin, P., 1998. Carbon sequestration and turnover in semiarid savannas and dry forest. *Climate Change* 40, 105–117.
- Trochain, J., 1957. Accord interafricain sur la définition des types de végétation de l'Afrique tropicale, *Bulletin de l'Institut des Etudes Centrafricaines* 13–14, 55–93.
- Turner II, B., Hyden, G., Kates, R. (Eds.), 1993. *Population Growth and Agricultural Change in Africa*. Carter Lecture Series. Centre for African Studies, University of Florida. University Press of Florida, Gainesville.
- USAID/Senegal, 1991. Senegal agricultural sector analysis: statistical annex. ADO Report. Dakar, Senegal.
- Wood, E., 2002. modeling and characterizing agricultural expansion: a case study in Senegal. Ph.D. Dissertation, University of Wisconsin, Madison.
- Wood, E., Tappan, G., Lietzow, R., Albright, T., 1998. The impact of agricultural production systems on land use/land cover change: Senegal, West Africa. *Raytheon Center for Global Change* 5 (2), 2–16.
- Wood, E., Tappan, G., Lietzow, R., 2000. Monitoring the impact of agriculture on land cover change in southern Senegal: a case study in the Department of Velingara. USGS/EROS Data Center, USAID/Senegal Project Report PASA No. 685-P-00-00005-00.
- Woomer, P.L., 1993. The impact of cultivation on carbon fluxes in woody savannas of southern Africa. *Water and Soil Pollution* 70, 403–412.
- Woomer, P.L., Palm, C.A., Qureshi, J.N., Kotto-Same, J., 1997. Carbon sequestration and organic resources management in African smallholder agriculture. In: Lal, et al. (Eds.), *Management of Carbon Sequestration in Soil*. CRS Press, Boca Raton, FL.