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Recent trends in vegetation dynamics in the African Sahel and their relationship to climate

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Abstract

Contrary to assertions of widespread irreversible desertification in the African Sahel, a recent increase in seasonal greenness over large areas of the Sahel has been observed, which has been interpreted as a recovery from the great Sahelian droughts. This research investigates temporal and spatial patterns of vegetation greenness and rainfall variability in the African Sahel and their interrelationships based on analyses of Normalized Difference Vegetation Index (NDVI) time series for the period 1982–2003 and gridded satellite rainfall estimates. While rainfall emerges as the dominant causative factor for the increase in vegetation greenness, there is evidence of another causative factor, hypothetically a human-induced change superimposed on the climate trend.
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1. Introduction

The African Sahel, a semi-arid grass- and shrubland region bordering the Sahara desert to the south, is a dynamic ecosystem that responds to fluctuations in climate and anthropogenic land use patterns. Contrary to largely anecdotal assertions of widespread irreversible 'desertification' in the Sahel (e.g. Lamprey, 1975, reprinted in 1988), recent findings based on analyses of satellite images report an increase in greenness over large areas of the Sahel since the mid-1980s, which, at a coarse scale, is well correlated with an overall increase in rainfall and has been interpreted as a recovery of the vegetation from the great Sahelian droughts in the 1970s and 1980s (Tucker and Nicholson, 1999; Eklundh and Olsson, 2003) However, the greening trend is not uniform, suggesting that factors other than rainfall may have contributed to a differential greening response, with greening taking place in some areas but not in others.

Although its actual meaning on the ground has not yet been firmly established, the observed greening trend has challenged notions of irreversible damage inflicted on the Sahelian ecosystem (Dregne, 1983; Middleton et al., 1997), revived debates about the concept of desertification, and triggered re-assessments of its nature, scale and extent, facilitated by progress in remote sensing technology as a tool for environmental monitoring and analysis. However, while studies based on long time series of satellite and ground data have confirmed the dynamic nature of the Sahelian ecosystem and its susceptibility to change, they have not resulted in a consensus on either the direction of changes or its underlying causes.

2. Background

The Sahel (Arabic for 'shore') is a transition zone between the arid Sahara in the north and the (sub-) humid tropical savannas in the south, and is marked by a steep north–south gradient in mean annual rainfall (Le Houerou, 1980). The rainfall gradient is expressed on the ground in a continuum of change in vegetation species and life forms from the Saharan biome with very sparse vegetation cover—thorny shrubs interspersed between annual and perennial grasses—to the Sudanian and Guinean biomes, characterized by a higher amount of ground cover, taller vegetation and a greater proportion of woody species (White, 1983). Species thin out and eventually disappear or appear gradually, but 'at no moment would you have the impression of crossing a biological frontier' (Monod, 1985, p. 204).

The climate of the Sahel is characterized by a marked seasonality with a long dry season and a short humid season in the northern hemispheric summer, which is explained by the position of the region relative to major global and regional circulation features and the seasonal variation of tropical weather patterns (Nicholson, 1995). Climatic constraints, i.e. not only scarcity but also variability and unpredictability of rainfall, which increase from south to north, are the most important controlling factors of the Sahelian ecosystem. The vegetation cycle

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closely responds to the seasonality in rainfall, with virtually all biomass production taking place in the humid summer months. The sharp seasonal contrasts are overlain by considerable fluctuations in rainfall at inter-annual and -decadal time scales, which make the Sahelian region the most dramatic example of climate variability that has been directly measured (Hulme, 2001). Causes for long-term rainfall fluctuations are complex and can be found in changing configurations of forcings and feedback mechanisms, which can be induced by atmospheric and ocean circulation dynamics with global-scale effects, such as the El Nino southern oscillation (ENSO) cycles (Nicholson, 2001; Nicholson and Grist, 2001), non-ENSO-related variations in sea surface temperatures (Giannini et al., 2003; Brooks, 2004), and large-scale changes in land cover and land–atmosphere interactions (Charney et al., 1975; Hulme and Kelly, 1993; Nicholson, 2000; Hulme et al., 2001; Zeng et al., 1999). Furthermore, a number of modeling studies point to possible links between Sahelian rainfall variability and anthropogenic global warming (e.g. Eltahir and Gong, 1995; Giannini et al., 2003).

Although variability in rainfall and the occurrence of droughts are seen as normal phenomena in arid and semi-arid climates (Glantz, 1987), rendering mean annual rainfall figures almost meaningless (Hulme, 2001), the droughts that affected the Sahelian region in the late 1960s through the 1980s following a series of favorable years were unprecedented in this century in their length and impact. Land degradation and famine conditions during these droughts, exacerbated by political instability and unrest, have triggered an upsurge in interest in the issues at work in the Sahel and appropriate countermeasures that might be taken, resulting in the United Nations Conference on Desertification (UNCOD) in 1977. The conference has prompted an ongoing and still unresolved debate about the causes and effects of drought, land degradation and desertification (Herrmann and Hutchinson, 2005). Two competing camps represent diametrically opposed positions in this debate: while adherents of the desertification hypothesis hold human activities responsible for a—hypothetically irreversible—decline in vegetation conditions in the Sahel, expressed as 'overuse of resources' and 'human mismanagement' (Mensching, 1990; Mainguet, 1991; Ibrahim, 1978), desertification skeptics interpret declines in vegetation condition and density as drought-induced and hence temporary phenomena, with humans playing only a minor role, if at all (Nicholson et al., 1998; Olsson et al., 2005). Mortimore and Adams (2001), Tiffen and Mortimore (2002) and Reij et al. (2005) report local-scale 'success stories' and stress the high potential of adaptation of the Sahelian population to rainfall variability in time and space. A growing archive of satellite observations has indeed shown a close coupling between vegetation greenness and rainfall variability. Tucker and Nicholson (1999) found the green vegetation boundary of the Sahel to fluctuate by up to 150 km from a wet year to a preceding dry year in response to rainfall. With such great natural fluctuations, the permanence of land degradation in the form of desertification can only be established by monitoring susceptible areas over a time scale of decades.

Ecosystem monitoring, in the Sahel and elsewhere, has been facilitated by progress in remote sensing technology and the availability of data sets at ever finer spatial, temporal and spectral resolutions. Remote sensing presents important advantages to the monitoring of vegetation dynamics and land degradation—such as the synoptic perspective it offers—however, there are limitations to this technology that also have to be taken into account. As a synergistic tool, remote sensing does not unfailingly distinguish between different vegetation types and, therefore, might hide changes in vegetation cover not associated with changes in overall greenness, such as shifts in vegetation composition. Other limitations arise from the technological and cost-induced trade-offs between different types of resolution, such that simultaneous increases of spatial, spectral and temporal resolutions, all of which can provide more precise information in different aspects of vegetation dynamics, in one system are inhibited (Cihlar, 2000).

7. Conclusions

This research adds to a series of coarse-resolution studies on the Sahel which refute claims of widespread human-induced land degradation at a regional scale, e.g., Prince et al. (1998), Tucker and Nicholson (1999); Hellden (1991) and Eklundh and Olsson (2003). Rather, a greening of the Sahel expressed in positive trends in NDVI indicates a net increase in biomass production during the period 1982–2003, which challenges the notion of irreversible desertification in the Sahel. Whether this greening trend is a return to pre-drought conditions or a transition to a new equilibrium state with a different vegetation composition, however, is unclear and can only be established with detailed field work at local scale and analysis of finer resolution spatial data from LANDSAT and MODIS.

Rainfall emerges as the dominant causative factor in the dynamics of vegetation greenness in the Sahel at an 8 km spatial resolution. However, the presence of spatially coherent and significant long-term trends in the residuals suggests that there might be another, weaker, causative factor. Since the Sahel is a 'cultural landscape' (Rasmussen et al., 2001), which is driven not only by climatic but also human factors, it is conceivable that the trends found in the residuals might be attributed to a 'human signal', as evidence from the literature suggests for particular regions (see Section 6.3). While short-term impacts such as pests can cause rainfall-independent deviations of the NDVI in individual years, long-term trends are more likely to be induced by human factors, such as changes in land use, exploitation of natural resources, production strategies and conservation efforts. Field studies in selected sites are required to confirm this hypothesis and to contribute to the understanding of processes and causes at work in particular local contexts.

Throughout most of the Sahel, there are no signs of large human-induced land degradation at this scale of observation—which does not mean that pockets of land degradation are not present at local scales. Only parts of northern Nigeria and Sudan show areas where human impact hypothetically inhibited a greening trend in the order of magnitude expected from the positive trend in rainfall conditions.