Human Ecology, Vol. 31, No. 2, June 2003 (© 2003)

Methodological Reflections on the Use of Remote Sensing and Geographic Information Science in Human Ecological Research

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Environmental analysts increasingly utilize remote sensing (RS) and geographic information science (GIS) techniques to study the relationship between human societies and their biophysical environment. This paper considers the influence these techniques have had on environmental research. Using the case of the Sahel, the paper first relates contemporary applications of RS/GIS to the history of the environmental scientific practice in the region. While facilitating an expansion of spatiotemporal scales, applications of these new techniques continue the methodological failings of the past by relying on visual measures of environmental change and problematic indicators of human land-use pressures. The human ecology fields (human, cultural, and political ecologies), by emphasizing the causal connections between local management and environmental change, can address the problems inherent with the spatial analytical turn in environmental science. Using the author's experience with the use of GIS in a political ecology study of grazing management in western Niger, ways of more closely integrating RS/GIS techniques into human ecological research are discussed.

KEY WORDS: environmental monitoring; land-use change; political ecology; Sahel; West Africa.

INTRODUCTION

There has been long-standing concern about changing environmental conditions in the West African Sahel among outside observers (Gritzner,

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1988; Grove, 1994; Ribot, 1999; Swift, 1996). The Sahel has proven to be a fertile testing ground for theories relating land cover and climatic change (Grove, 1994; Hulme, 1989; Thomas, 1993); social consequences of global environmental change (Homer-Dixon *et al.*, 1993; Kaplan, 1994; Ribot *et al.*, 1995; Watts, 1983), as well as a progression of behavioral, demographic, and institutional explanations of anthropogenic environmental change (Ribot, 1999; Taylor, 1992; Watts, 1983). The Sahel is commonly used as a global benchmark of excessive resource poverty and environmental degradation to which other vulnerable areas are compared (Middleton and Thomas, 1997) and, as such, the "Sahelian case" contributed to the forging of poverty-degradation links in global sustainability discourses (Adams, 1990; Broad, 1994; Buttel and Taylor, 1994; Lélé, 1991).

The political, cultural, and human ecology literatures have exposed the simplified narratives, which inform (Bassett and Zuéli, 2000; Cline-Cole, 1998; Fairhead and Leach, 1996; Leach and Mearns, 1996; Mortimore, 1989; Turner, 1999b; van Beusekom, 1999) and the underlying political economic struggles that permeate (Neumann, 1995; Peluso, 1993; Ribot, 1990; Schroeder, 1999) these environmental diagnoses and the conservation and development programs that they support. The interplay of environmental scientific practice with these environmental and development imperatives has been less developed (Agrawal, 1995; Bassett and Zuéli, 2000, Demeritt, 1998; Latour, 1999). Discarding of environmental scientific practice as a neutral mediator of reality, critically inclined social scientists have tended to portray it as either a straightforward mediator of political economic interests or an overly blunt purveyor of bias and ignorance of local situations.

This paper seeks to portray the more complex relationships among environmental scientific practice, on-the-ground realities, technology, and technique, and political economic interests. I briefly review the ways in which the bundle of technologies and techniques that constitute remote sensing (RS) and geographic information science (GIS) have affected environmental scientific practice in the Sahel. The increased availability of these technologies has strongly affected but not determined environmental scientific approaches. Their uneven adoption has allowed their adopters to use them as effective resources to bolster their scientific claims and shelter their methods from scrutiny. Interestingly, the incorporation of these technologies, while having substantial positive effects, has not led to a revolution in Sahelian environmental science. Instead, I argue that their most prevalent uses have reinforced earlier forms of scientific inquiry—forms of inquiry and causal reasoning that had been seriously questioned since the mid-1980s by physical and social scientists alike.

Commonplace uses of RS to monitor environmental change rely heavily on visual patterns in vegetative cover to infer ecological change.

Commonplace uses of GIS to understand socioenvironmental causality rely heavily on spatial correlations between readily available social and ecological data across broad areas. These methodological inclinations contrast strongly with those shared by human, cultural, and political ecologists, who generally follow field-oriented research traditions focused on understanding the multistranded complexity of people–environment relationships. The task is to finds ways to utilize the power of these techniques and technologies without losing the dynamic, structured, multilayered, and subjective natures of socioecological interaction as conceptualized by these different types of human ecologists. These "views from above" can be successfully integrated with the "views from below" provided by human ecological fieldwork. Such integrations are far from automatic, epistemologically hazardous, and time-consuming—thus requiring a vigilant reflexivity on the part of the human ecologist.

In this paper I briefly describe the environmental scientific tradition in the Sahel. Revisionist critiques of this tradition have become increasingly common during the 1990s. I show how RS and GIS have played a role as a scientific resource in these debates to the favor of environmental scientific tradition. Despite these conventional uses, I argue that GIS holds significant potential for human, cultural, and political ecological research. I present the case of how GIS analysis was used to study such linkages in the Sahel and in so doing, illustrate the strengths and limitations of GIS for the human ecologies (human, cultural, and political ecologies).

ENVIRONMENTAL SCIENTIFIC TRADITIONS IN THE SAHEL

The Sahel is defined here as the strip of land lying south of the Sahara desert that receives 100–600 mm of rainfall on average per year. Vegetative structure grades from steppe to dry savanna from north to south. Herbaceous vegetation is dominated by annual grasses and forbs. The productivity and species composition of herbaceous vegetation varies tremendously across space and time, determined in large part by the timing and amount of rainfall. Productivity is limited by both sparse rainfall and low soil fertility. Patches of higher productivity result from the confluence of higher soil fertility (resulting largely from transfers of nutrients by livestock, humans, and termites) and rainfall.

Since early in the colonial period, variation in environmental conditions in the West African Sahel has attracted attention and concern among environmental scientists and conservationists (Gritzner, 1988; Grove, 1994; Ribot, 1999; Swift, 1996). These concerns, coupled with limited technical, conceptual, or financial resources to monitor change, contributed to conservation and agricultural development programs that worked to transform what seemed to the European mind chaotic and irrational practices of pastoralists and agriculturalists in the area (Baker, 1984). Throughout the colonial period, environmental science in the West African Sahel has been practiced largely by agronomists, range ecologists, geographers, and climatologists. Agronomists generally focused their work on trials of introduced cropping systems at the scale of the cropped field. Other scientists were concerned with monitoring environmental change over broader areas and relating these changes to human activities. The practices of these scientists were influenced by their adherence to the equilibrium models of ecology;[2] the spatiotemporal complexity of environmental change in the region; the political-economic programs of their scientific/development institutions; views of Africans and their agricultural practices; and the financial, technology, and transportation limits placed on their research.

Reflecting these influences, the environmental monitoring tradition in the Sahel has had three common features. First, environmental observations have been spatially and temporally biased. Observations were made largely during the dry season when travel was most feasible with some bias toward locations near roads within a day's travel radius around major towns (Hubert, 1920).[3] This, in combination with limited availability of broad-scaled land cover information, led to a proclivity to generalize from field observations at one locality and time (season and year) to the broader region and time. Early claims of desert expansion were based on regional generalizations of highly localized observation (Stamp, 1940; Stebbing, 1935; Swift, 1996).

Second, the monitoring tradition has relied on one-time, visual descriptions of the landscape (particularly vegetative cover) to evaluate environmental condition. Given that vegetative cover and species composition is

[2]This adherence was most evident among range management experts, whether they worked within North American range science, systems ecology, or French phytosociological traditions (Boudet, 1975; Braun-Blanquet, 1932; Breman and de Ridder, 1991; Pratt and Gwynne, 1977; Stoddart *et al.*, 1975). Since the range system was seen as naturally prone to evolve toward an internally regulated equilibrium or "climax" type, the goal of management was simply to identify the deviations from the desired community type (may differ from the climax) and recommend changes in stocking rate that would move the system in the desired "direction." The beauty of this framework was its seemingly facile application to different socioenvironmental situations–management prescriptions could be made without performing controlled studies on grazing impact nor with an understanding of the existing livestock management. As a result, only a handful of controlled/semicontrolled grazing studies have been performed in the region (e.g., Grouzis, 1988; Hiernaux, 1998; Hiernaux *et al.*, 1999; Penning de Vries and Djitèye, 1982; Turner, 1999c) and the relevance of stocking rate prescriptions to mobile livestock production systems have not, until recently, been scrutinized (Bartels *et al.*, 1993; de Leeuw and Tothill, 1993; Turner, 1993).

[3]The spatial bias of the observations made by environmental scientists was much less severe than that of colonial administrators. A number of early botanists made concerted efforts to sample a wide area (e.g., Aubreville, 1936; Chevalier, 1932) but were constrained by the network of village-to-village paths in often sparsely populated areas.

strongly affected by the interaction among the magnitude and distribution of seasonal rainfall, edaphic condition, and human land uses, short-term descriptive approaches alone provide very little insight into the causes behind changes in vegetative parameters nor into the persistence of these changes. The focus on visual description—notations of cover and species composition—not only reflects the limited experimental tradition in the French phytosociology school, but also the daunting variability and complexity facing researchers with limited time and resources (Adam, 1956; Boudet, 1975; Braun-Blanquet 1932).

Third, ecological observations have been made with surprisingly little understanding of or even reference to how the observed patch has been influenced by rural production systems. Especially in the case of grazing research, there has been a heavy reliance on spatial correlations between patterns of vegetative parameters and signs of human land-use to infer anthropogenic environmental change. Such analyses have a high potential for circular argument—human signs and signs of environmental change are often one and the same. For example, patchiness in vegetative cover (at 1–10-m scales) is often seen as the sign of human use and of environmental degradation (Wezel and Boecker, 1998), when in fact bare patches can develop "naturally" under certain combinations of soil texture, slope, and rainfall regime (Hiernaux and Gerard, 1999; Thiéry *et al.*, 1995).

The heavy reliance of visual description of pattern has not only increased the malleability of scientific observation and interpretation to the political–economic aims of the state but has produced a body of scientific work that contributes surprisingly little to the processual understanding of environmental change in the region. The stagnation of the desertification literature around definitions of environmental degradation and arguments for and against climatic or human causes of environmental degradation are symptomatic of this scientific tradition in dryland Africa (Dodd, 1994; Little, 1994; Swift, 1996; Turner, 1998a). This tradition has come under attack in the 1990s (Behnke *et al.*, 1993, Ellis and Swift, 1988; Laycock, 1991; Middleton and Thomas, 1997; Thomas, 1993; Westoby *et al.*, 1989), with critics arguing for process-oriented research informed by the spatial and historical contexts of climate and human land uses.

During the period of mounting criticism of the environmental scientific tradition in dryland Africa (mid-1980s to the present), the use of RS and GIS technologies by resource monitors and managers increased dramatically. In the next section, I review how remotely-sensed data have contributed to our understanding of environmental and land-use change in the Sahel. This will be followed by a section that evaluates the much smaller body of GIS-related work that attempts to combine remotely-sensed and other data to investigate the relationship between the social and environmental change.

REMOTELY-SENSED DATA

Remotely-sensed data are recordings of the reflectance of visual and nonvisual wavelengths of energy from the land to an airborne camera or digital wave band sensor. Aerial photographs first began to be used in French West Africa for mapping of urban areas in the 1920s (Commandant de Martonne, 1923; Hubert, 1919) and only became available for general mapping work with the full 1:50,000 aerial coverages acquired by the French Institut Géographique National (IGN) in the early 1950s—coverages that were used to produce 1:100,000 topographic maps of the colonial territory. Satellite imagery data became generally available since the mid-1980s (LANDSAT MSS and TM, SPOT-XS, NOAA-AVHRR).

The availability of these data dramatically increased analysts' abilities to monitor changes in the pattern and extent of cultivated areas (aerial photos in particular) and vegetative cover over broader areas and time frames than in the past. This contribution is especially important in arid regions such as the Sahel where population is sparse, land use is extensive, and vegetative cover is spatiotemporally variable. The increased use of remotely sensed data has thus worked to address the problems of spatial and temporal bias and inappropriate generalizations that have plagued the environmental monitoring tradition. For example, these data were used effectively to counter claims of the marching desert—claims that were generated from site specific studies along an ill-defined desert edge (Hellden, 1991; Tucker *et al.*, 1991).

In the 1990s, environmental analysts increasingly relied on remotely-sensed data for the monitoring of environmental change in dryland areas such as the Sahel. These data proved to be attractive to donors and analysts alike because of the spatial breadth they provide compared to field measures; the temporal depth provided through repeat coverages; their lower cost compared to fieldwork; and their connection to what was seen as unbiased measures of land cover. Moreover, the greater coverage of these data contributed to the growth of the global environmental change community, who in turn rely heavily on these data (Buttel and Taylor, 1994). This reliance has political dimensions since these data have proven to be an important scientific resource to garner funding and to lend scientific legitimacy to the globalist claims about the nature and causes of environmental change.

Despite the real advances they offer and popularity of the use of remotely sensed data for the monitoring of land-cover change, a number of problems are revealed in their use in the Sahel:

1. Persistent promotional statements that, given their wider spectral breadth, satellite sensors can "see" more than the untrained human eye have not been born out in the Sahel. For example, early claims

of abilities of facile estimation of above-ground biomass, crop yield, soil moisture, and species composition of vegetation have not been supported by actual work.[4] This failure is due in part to the limited infrastructure and financial resources in the Sahel. More importantly however, is the considerable spectral heterogeneity that results from the combination of sparse vegetation cover and variable soil background, surface humidity, and senescent vegetation (Beck *et al.*, 1990; Huete and Tucker, 1991; Leprieur *et al.*, 1996). The power of remotely-sensed data rests largely in its form—spatially broad, uniform, repeatable quantitative measures of reflectance within a spatial grid, a form that is much more analytically useful than visual descriptions of an on-the-ground observer (Bastin *et al.*, 1993).

2. The relative ease of the acquisition of remotely-sensed data (for those with financial means) contrasts strongly with the difficulty of collecting on-the-ground data necessary for training sites and accuracy assessment. This has contributed to a surprisingly large number of published studies with not only insufficient accuracy assessments but with very limited on-the-ground observations. In the development and conservation fields, rigorous ground-truthing and introspection about land-cover categorization are very rare. This coupled with the limited on-the-ground experience of analysts suggests that interpretations may likely diverge from existing land-cover conditions.
3. Similar to the environmental scientific tradition in the Sahel, understandings of environmental change supplied by remotely-sensed data are visually descriptive rather than processual (Milich and Weiss, 2000b). Therefore, there is a tendency for environmental change to

[4]The use of satellite imagery to map agricultural land-use has had mixed results, even for higher resolution imagery such as Landsat TM and SPOT-XS, because of small field size and the similar spectral signatures of cropped and recent fallows (Falloux, 1989; Marsh *et al.*, 1992; Reenberg, 1994; Turner and Congalton, 1998). The use of RS for harvest forecasting has therefore relied on relating regional greeness measures (most commonly the Normalized Difference Vegetation Index or NDVI) across all land uses with district-level harvest estimates (Rasmussen, 1999) very analogous to the relationships found between rainfall and NDVI (Milich and Weiss, 2000a). Satellite image processing to discriminate between lignaceous and herbaceous vegetation production has achieved only limited success (Fuller and Prince, 1997; Moleele *et al.*, 2001). Various cumulative NDVI indexes (summed across growing season) have been found to estimate total or herbaceous standing biomass over wide biomass ranges (200–3000 kg/ha) with coefficients of determination ranging from 0.25 to 0.8 (Diallo *et al.*, 1991; Hiernaux and Justice, 1986; Prince, 1991; Wylie *et al.*, 1992). These relationships are useful for mapping regional variation in biomass production, but provide limited discriminatory ability at the spatial scale of an administrative district, given the wide confidence intervals relative to average biomass levels (Diallo, *et al.*, 1991). Therefore, conventional analyses of satellite data have not provided information at spatial and biomass density resolutions necessary for human ecological work.

be described as changes in land-use or vegetative cover, with little attempt to link this to underlying causes of these changes nor to how they affect the productive capacity of the land.

4. Historic series of remotely-sensed data offer a chance to move toward more processual understandings of change. Like all archival information, such series are necessarily incomplete—snapshots of particular times. This incompleteness may produce narrative structures that may be misleading. Unlike other archival sources, these remotely-sensed data produce seemingly common narratives because of the strong correlation in the time slices sampled. For example, the incorporation of historic aerial photography is the major means to achieve any historical depth. In the Sahel, full aerial coverages were acquired in the early 1950s when population began to expand rapidly and the mid-1970s following the 1969–73 drought. Such sampling automatically produces a neo-Malthusian narrative structure which is seemingly reproduced across many studies.
5. Remotely-sensed data are socially sanitized pieces of information. Especially for data of poor spatial resolution (NOAA AVHRR, Landsat MSS), it is often difficult to identify uniquely human signatures on the dryland landscape. With data of higher resolution, the human signature is land cover change—therefore, human activities are seen as cropped areas and devegetated zones. Following environmental scientific tradition, there is a strong tendency to equate human activities with measures of environmental change. Such depictions, if not downright teleogical, facilitate very reduced forms of socioenvironmental analysis.

In sum, the analytical uses of remotely sensed data have greatly increased the temporal and spatial breadth of conventional environmental assessment in the Sahel. At the same time, the uses of remotely-sensed data show strong similarities with the environmental scientific tradition in the Sahel, a tradition that was being roundly critiqued during the same period that remotely sensed data was increasingly used. In both cases, visual descriptive analyses are produced with little connection to human context and ecological process. The continuation of this mode of analysis is not simply a legacy of the past. The nature of remotely sensed data has obviously played a role. In addition, it reflects new political struggles within international science over what is legitimate environmental science. The global environmental change community has adopted RS as tool and in so doing has linked a shift up in spatial scales with data-intensive empiricism and technically sophisticated science (Turner, 1999a). In contrast, both the social scientist talking to people and the field ecologist walking a transect are seen as quaintly old-fashioned and ineffective—any contributions from whom are seen as best realized by feeding on-the-ground data to the regional database constructed by the RS analyst.[5] In this context, the scientific goal of generalization has curiously been reworked from the classic focus on understanding process and rejection of description, to one based on spatial scaling criteria. In the applied environmental scientific context, studies that describe change and pattern over broad scales are often seen as being more general and scientific than local studies of social and ecological process.[6]

GEOGRAPHIC INFORMATION SCIENCE (GIS)

Remotely-sensed data alone provide little information as to causes of land-cover change beyond simply identifying cropped and devegetated zones. Attempts to use remotely-sensed data to better understand anthropogenic change have relied on causal inference from the spatial correspondence between social and environmental features. Much spatial inference has occurred outside a formal GIS framework ranging from simply observations of co-occurrence (de Wispelaere, 1980; Haywood, 1980; Jacobberger, 1988) to more quantitative gradient analyses (Bastin *et al.*, 1993; Hanan *et al.*, 1991a; Pickup and Chewings, 1988). GIS technologies provide a much more powerful framework to perform multidimensional and multifactor analyses. However, the application of GIS to resource management issues remains poorly developed in semiarid Africa. Its most widespread applications have been the production of visually attractive representations of spatial data for planning purposes (Haack and English, 1996; Jagtap and Amissah-Arthur, 1999). The use of GIS for causal inference has ranged from pattern description, overlay analysis, or simple gradient analyses[7] (Amissah-Arthur *et al.*, 2000; Hansen and Reenberg, 1998; Lambin, 1988; Reenberg and Lund, 1998;

[5]Shifts of development funding away from the area have also contributed to the upward shift in scales—monitoring research that covers a wider area is considered to provide more for the development/research dollar. RS analysts have been so successful in capturing funds available for environmental monitoring that ground-truth data have become scarce. For example, at least fourteen articles and monographs rely on the same set of on-the-ground ecological data produced by a monitoring program whose institutional support ended in 1999 due to a lack of funding (Benjaminsen, 1993, 1996; Franklin and Hiernaux, 1991; Frison *et al.*, 1998, 2000; Hanan *et al.*, 1991b; Hiernaux, 1988; Hiernaux and Justice, 1986; Justice and Hiernaux, 1986; Kammerud, 1993; Loudjani, 1993; Mougin *et al.*, 1995a, 1995b; Prince, 1991; Tounsi, 1995).

[6]The preoccupation with spatial breadth and pattern to the exclusion of ecological process has affected the natural sciences as well. Much work in landscape ecology has become increasingly concerned with pattern and scale, losing sense of process and causality (Allen, 1998).

[7]Overlay analysis can be used to compute the relative spatial overlap in the distributions of different parameters. Simple gradient analyses have been used to look for various measures of proximity to point features such as human settlements as explanatory variables for land cover variation.

Ringrose *et al.*, 1996) to more sophisticated two-dimensional and multivariate spatial modeling approaches that have more commonly been used to evaluate deforestation in the humid tropics (Lambin, 1997; Mertens and Lambin, 2000).

Human, cultural, and political ecological approaches, despite differences, share an attention to rural people's land-use practices and the multiplicity of social factors that shape their land use strategies. From this perspective, common GIS applications to study the relationship between rural societies and their environment have some major analytical problems. The first is the heavily reliance on data sets that are highly aggregated and incorporate a reduced number of social and ecological variables. Most analytic applications of GIS in Sudano–Sahelian West Africa have largely been conducted at spatial scales ranging from the subnational to the regional. There are few social and ecological data available at such spatial scales (Rindfuss and Stern, 1998). Variable choice is driven more on its form and availability (spatially registered quantitative data across broad areas) than on a variable's relevance to those social and ecological processes that have been identified by theory or previous empirical work as important to the studied society-environment relationship.

Arguments to ignore social and ecological variables for which data are unavailable are not convincing from a human ecological perspective. The choice of data will very much influence causal inference. Choosing to use land cover (e.g., vegetation condition) as a measure of land use (grazing, NTFP collection, etc.) in a GIS analysis is just as likely to lead to the same teleological arguments generated by the descriptive studies of the past—despite more sophisticated quantitative analysis (Hoeschele, 2000). This problem is compounded by the common reliance on spatial correlations between human presence or activities and visually apparent indicators of land degradation to infer anthropogenic change. Causal inference from spatial correlations among a reduced set of variables (e.g., population density and land-cover) is hazardous given the high autocorrelation of human ecological data sets. Those studies which have worked to move beyond spatial determinism have relied on incorporating econometric techniques (Geoghegan *et al.*, 1998) into the spatial analysis (translating distances into cost functions). The implicit assumptions of welfare maximization and market efficiency in such approaches deviate from the findings of much human ecological work in the region.

In summary, GIS technologies provide expanded abilities to analyze spatially registered multivariate data across two to three spatial dimensions. Their use for causal analysis of society–environment relations has not however provided significant human ecological insights. GIS applications to date are consistent with environmental analytical traditions in their reliance on the spatiotemporal correspondence of human presence to visually apparent environmental change over broad spatial scales. These applications diverge strongly from the human ecological focus on explicitly tying human land-use practices to environmental change through more local studies (Guyer and Lambin, 1993). The perceived strengths of RS/GIS in environmental monitoring and analysis has worked to privilege environmental scientific methodologies that not only deviate from those followed by different human ecologies but have led to the persistence of older, highly questioned, forms of environmental analysis.

GIS AS A TOOL FOR HUMAN ECOLOGICAL ANALYSIS?

In the proceeding sections I have argued that the increased use of remotely-sensed data and GIS techniques has not revolutionized the ways in which we analyze people-environment relations in the Sahel but actually further entrenched traditional modes of analysis. These modes of analysis rely heavily on visual descriptions of land cover as measures of environmental change and evaluate causes of environmental change through spatial correlation with little understanding of local context. Interestingly, it is these forms of environmental analysis that new understandings of dryland ecology have seriously questioned.

An important question raised by this discussion is the degree to which these failings result from features of these tools or how these tools have been used. These tools are far from neutral in their effect on environmental scientific practice, facilitating certain forms of analysis while integrating less well with others. Still, I will argue that the widespread failure of the application of these technologies to human ecological issues rests largely with theories and methodologies within which these technologies have been integrated. While the applications of these technologies have contributed to the scaling-up and decontextualization of environmental analyses, they do hold promise for the more process-oriented human ecological work (human, cultural, and political ecologies). One way in which RS and GIS can be used in human ecological work is to provide a broader spatial context or verification of relationships and changes observed by more localized fieldwork (Guyer and Lambin, 1993). Such research pairings are fruitful. The broad spatial analysis of remotely sensed data is informed by the local human ecological research which in turn benefits from the more regional analysis provided by GIS/RS.

While such paired approaches are useful, greater integration of the applications of these technologies within a human ecological framework can provide a much better understanding of both the social and ecological dimensions of the spatiotemporal dynamics of land use. Such understandings are particularly needed to further develop the human, cultural, or political ecologies of agropastoralism in dryland areas such as the Sahel. These regions are typified by high spatiotemporal variability in rainfall, resources, residential patterns, and production strategies. The changing mosaic of cropped areas and grazed zones, as mediated by various social institutions, significantly affects dryland ecologies and the economic security of rural peoples. In this way, socioenvironmental relationships are strongly mediated by changing spatial patterns of resource availability and the social relationships that surround these resources. The historic inability of outside observers to conceptualize and depict these changing spatial relationships has very much limited their abilities to specifically tie human land uses to environmental change. Making such ties is a goal shared by human, cultural, and political ecology.

If we reconsider GIS as a potential tool for human ecological research, an increase in the spatial resolution is necessary in order to depict a more socialized landscape (pieces of land are tied to specific users, managers, and owners, etc.). At such spatial scales, could GIS be a useful tool for the multiscaled, spatially explicit and intertemporal analysis required to link social and ecological change in such a variable environment? In the next section, I briefly present my own experience with such an attempt. In so doing, I will highlight the strengths and limitations of such approaches and argue that success requires constant reflection and vigilance on part of the human ecologist.

CASE: THE POLITICAL ECOLOGY OF GRAZING MANAGEMENT IN WESTERN NIGER

The research that I describe here was part of a larger study of nutrient cycling and management across a 500 km^2 agropastoral landscape in the Sahelian country of Niger (Fig. 1). This research was conducted by an International Livestock Research Institute research team that included myself, a range ecologist, two animal nutritionists, and an economist. My contribution to this research was to investigate how social change, broadly defined, influenced the grazing management of livestock and the resulting spatial distributions of livestock activities (grazing and resting) across the study area. Combined with data generated by the range ecology and animal nutrition work, spatial distributions of livestock activities are used to generate estimates of livestock-mediated nutrient flows across the agropastoral landscape. In this way, the study provides much needed empirical information to the long-standing debates about soil fertility maintenance in agropastoral

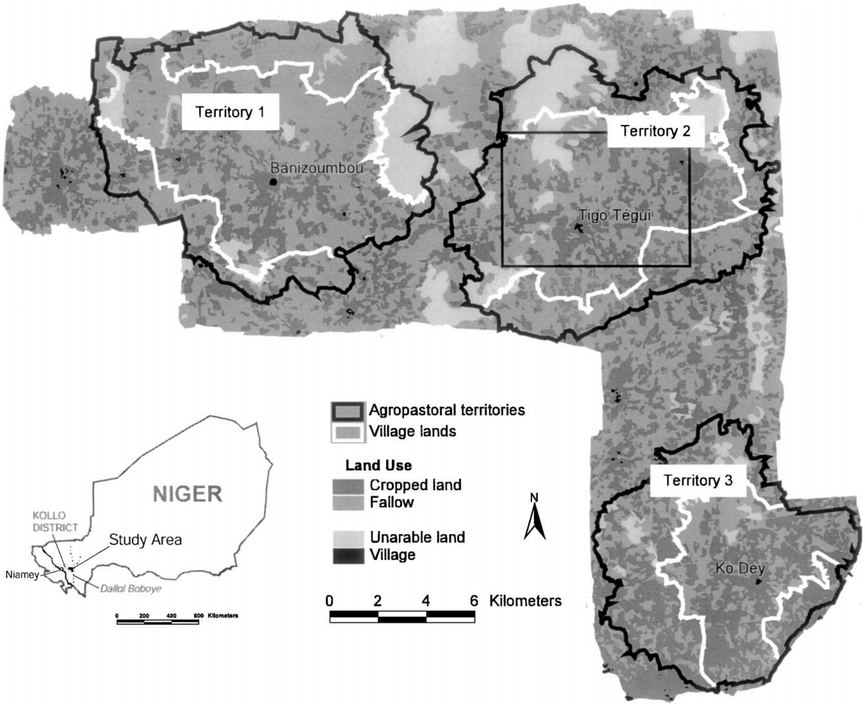

Fig. 1. The location of the 500 km^2 study area in western Niger showing the locations of the three agropastoral territories (black borders) and village agricultural lands (white borders) in relation to major land uses in 1992 (cropped, fallow, unarable, and village).

production systems of semiarid Africa (Hiernaux *et al.*, 1997; Powell *et al.*, 1995; van Keulen and Breman, 1990).

My research was framed as a political ecology study (Fig. 2). GIS analysis was incorporated into this broader framework with its use restricted to investigate how different grazing management modes affect the spatial distribution of livestock activities. The use of a GIS allowed us to delineate the spatiality of land-use ecology (grazing and farming) across socialized landscapes (1:5000)—e.g., agropastoral landscapes made up by land units and domestic livestock herds with identifiable owners, managers, and users. Herders were interviewed every 3 weeks over a 20-month study period about the grazing itineraries followed by their herds over the previous 24 hours (6500 itineraries in total). These data were processed to estimate the unit-level grazing densities produced by different grazing management modes within the study area (Turner and Hiernaux, 2002). Relationships between grazing management and features of household and community were

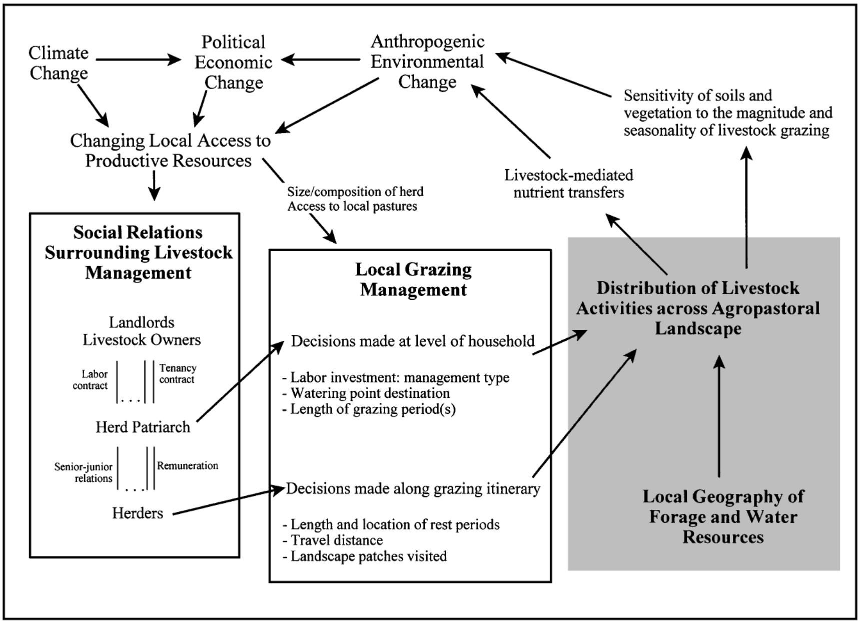

Fig. 2. Political ecological study of grazing management in western Niger. Local grazing management decisions are made either at the level of the household, primarily by the herd patriarch, or along the grazing itinerary by herders themselves. These decisions, along with the local geography of forage and water resources, influence the spatiotemporal distribution of the livestock activities that may affect the productive capacity of the agropastoral landscape through nutrient redistribution or changes in soil structure or species composition of pasture vegetation. Management decisions are shaped by multistranded social relations that surround livestock management in the area, which are in turn influenced by broader political economic, climatic, and environmental changes influencing local access to resources. Grey-shaded portion of the diagram represents those causal relationships that were analyzed in part through the use of a GIS.

evaluated through a combination of qualitative and quantitative analysis of information not incorporated into the GIS.

While grazing, livestock in the study area are managed in three general ways. Livestock can be accompanied by a herder throughout the grazing period (herded). Livestock can be led from the settlement and then left to graze on their own (herd-release). Finally, livestock can be allowed to graze completely on their own (free). These three management modes vary significantly in their labor requirements. Therefore, how a herd is managed depends on the effective supply of labor to the managing family (family size, labor investments into agriculture, available wealth to hire a herder, labor emigration) and the incentives for investing this labor into herding (herd size, access to agricultural land, self-ownership of herd). Changes in the access to

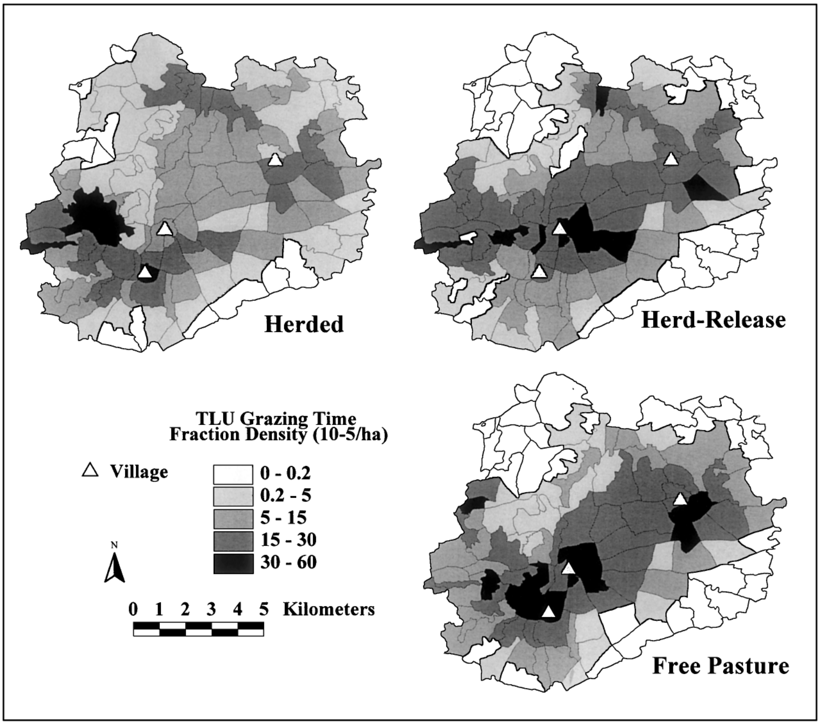

Fig. 3. The distribution of the fraction of TLU (tropical livestock unit) grazing time under three management modes (herded, herd-release, and free pasture) within agropastoral Territory 2 (see Fig. 1). Different shadings of land units within the territory correspond to the fraction of the total grazing time under each particular management mode that occurred within the land unit divided by its area (in hectares). The locations of villages in the territory are also designated by white triangles.

resources (land, livestock, and labor) at the level of the household will affect how the herd is managed as it grazes across the agropastoral landscape.

GIS analysis shows that grazing densities vary significantly across the agropastoral landscape and differ markedly among the three grazing modes (Fig. 3).[8] These findings demonstrate the ecological importance of *how*

[8]Unit-level grazing (animals actively grazing) and nongrazing livestock densities vary by two and three orders of magnitude, respectively, within the study area (Turner and Hiernaux, 2002). Spatial analytical approaches for estimating grazing pressure in the Sahel have either relied on district level mean livestock densities or assumed that livestock presence declines with distance from villages or water points (de Boer and Prins, 1989; de Leeuw and Tothill, 1993; Hanan *et al.*, 1991a; Michel *et al.*, 1999; Turner, 1998b; Valentin, 1985; Valenza, 1981). This GIS application shows that both grazing and nongrazing livestock densities are not spatially correlated with villages or water points (Turner and Hiernaux, 2002).

land-use practices are performed (a research emphasis of human ecology) and question the relevance of common measures of environmental stress used by spatial analysts, such as district-level stocking rates or proximity to settlements and water points. By providing more accurate estimates of livestock-related environmental stresses, this GIS application not only exposes problems with the assumptions behind prior spatial analyses of livestock grazing but establishes a strong base from which the relationship of independently measured grazing pressures to the vegetated landscape can be investigated.

The GIS analysis used in this study was chosen to perform a specific, well-defined task within a broader political ecological framework. Its use to specifically tie herd management decisions to the spatiotemporal distribution of grazing pressure was seen as appropriate for this study. The high spatial variability of herd movements in semiarid Africa has historically limited the ability of researchers to link herd management decisions to spatiotemporal patterns of grazing (Bassett, 1986; Benoit, 1979; Bonfiglioli, 1982; Dupire, 1970; Dyson-Hudson and Dyson-Hudson, 1980; Fratkin *et al.*, 1994; Galaty and Bonte, 1991; Gallais, 1975; Hopen, 1958, Stenning, 1960). GIS represents an important tool for addressing this methodological problem. Its broader use to understand the factors contributing to the variation in herd management was not seen as appropriate for this study. The information used was a mix of qualitative and quantitative social data, which are not tied to specific locations on the agropastoral landscape. To incorporate this analysis within the scope of the GIS would have been difficult and would have necessarily led to a reduction in the causal connections considered.

The human ecologist should not look to GIS as an integrating framework but as spatial analytical tool that can add to the broader human ecological analysis if its tasks are well defined and appropriate to its strengths. This simple but important mantra is often difficult to follow, especially when the research is being performed by group of people—people with different understandings of GIS and with different disciplinary backgrounds. In such research environments, pressures develop that work to expand the influence of GIS beyond what is appropriate to answer the research questions. From my experience, these include

1. The data and time demands for a GIS often grow during the course of a project with less time spent on research unrelated to the GIS. Not only are time and data requirements often underestimated, but seeming integrativeness of a GIS may work to make any new data gaps within the GIS less acceptable. There is often a strong pull to "fill" the GIS—missing data creates a sense of incompleteness, even if the incompleteness does not jeopardize research goals.

2. As a tool for the spatial analysis of georeferenced data, GIS is more useful for analyzing socioenvironmental data that are best categorized as behavioral—data that measure actions, laws, events through space. Such data alone do not capture the features of human society and ecology that help shape their interaction.
3. Especially for those that do not have a background in some form of human ecological analysis, GIS can easily be seen as a general framework through which social and ecological systems could be integrated spatially. Such visions are very analogous to the power accorded to systems analysis during the 1960s, leading to closed, homeostatic models of the society-environment interaction.
4. The GIS may demand a social and spatial fixity that the ambiguity of social and ecological reality may not easily supply. For example, the GIS requirement of arcs and polygons with fixed boundaries runs counter to more diffuse, unbounded conceptions of some forms of use rights. Depicting the socialized landscape in a GIS may therefore contribute to the territorialization of resource access with significant social implications.

These tendencies are similar to those that developed within research teams embracing systems analysis in human ecological research during the 1960s (Taylor, 1992; Watts, 1983). Intellectual history should not be repetitive—these pressures are not insurmountable. GIS should be seen as a spatial analytical tool and not as a integrative framework. It should be used to answer well-defined questions that are informed by a broader conceptual framework. Even if conceptually bounded in this way, GIS can lead to an erosion of the broader research agenda if the researcher is not vigilant about protecting his/her broader conceptual framework and research time against the demands of GIS building and analysis. These demands can pull the researcher away from important work that lies outside of the GIS. The human ecologist must be vigilantly self-reflective to ensure that the promise and power of GIS does not result in unbalanced research.

CONCLUSIONS

Environmental monitoring and resource management programs in dryland Africa have been major users of RS/GIS technologies. The utilization of these techniques have improved environmental analyses by providing a means to expand their spatial and temporal scales. On the other hand, spatial analysts specializing in these techniques have promoted environmental research approaches that ignore previous human ecological research in the area and are prone to the same type of logical errors that plagued environmental science of the colonial period (reliance on visual indicators of degradation; spatial correlation to infer causation). The scientific appeal of these applications have worked to "scale up" environmental analysis in dryland regions leading to the curious situation in which local process-oriented studies are deemed not generalizable compared to spatially broad and quantitatively descriptive RS/GIS studies. There is a strong need for human, cultural, and political ecologists to not only critically engage these analyses but to look toward utilizing the strengths of these technologies by integrating them, where appropriate, within their own process-oriented work.

RS/GIS technologies have been used successfully to provide a broader spatiotemporal context to localized human ecological research. These applications generally couple work focused on the relationship between social, land-use, and ecological parameters with broader, RS/GIS spatial analytical work. Spatial analysis is thereby informed by the more complete understanding of causal connections uncovered by detailed field work. Human, cultural, or political ecological work that more fully integrates the RS/GIS within one of these research frameworks is less commonly performed. A key requirement for such work is a scaling down of the RS/GIS work to spatial scales at which the activities of land managers can be directly tied to particular areas of the GIS or of the remotely-sensed image. In other words, the GIS/RS landscape needs to socialized—differentiated by different people's activities, rights, and attached meanings.

I presented my experience using GIS in a political ecology study of grazing management in an agropastoral region of western Niger. The case demonstrates the strong potential of GIS to more clearly delineate the relationship between variations in herd management and spatial patterns of grazing pressure across the agropastoral landscape. Variation in grazing management could in turn be explained by managers' investment of labor into grazing management as influenced by broader political economic and climatic change. Thus, GIS analysis played a crucial but circumscribed role in the research (Fig. 2).

The development of a GIS is time consuming. The large time commitment to construct a GIS along with its systems-like attributes, contribute to the pressures to expand its use to incorporate more of the variables and causal connections considered in a study. This is especially true in multidisciplinary team research where there can be a naive reliance on the GIS to provide an interdisciplinary framework. Naive expansion of the analytical role of GIS in a human ecological study threatens to reshape a process-oriented study to a static spatial analysis of a reduced data set. It is important that the researcher, whether following a human, cultural, or political ecology framework, clearly delineate at the outset how the GIS will be used.

In this paper, I have criticized common uses of RS/GIS in environmental monitoring and management. These technologies represent important resources for improving people-environment research. Unfortunately, these technologies have largely been applied to people-environment topics by spatial analysts with little background in social or ecological research in their study areas. While repeating many of the analytical mistakes of past environmental research, their use of these sophisticated technologies has pulled attention and funding from more local process-oriented work in human, cultural, political, and field ecology. Rather than mounting broadside attacks on the reductionism of these approaches, ecologists of all stripes should critically engage with their prevalent uses in a constructive manner and break through the specialization that surrounds these technologies by incorporating them into their own work when appropriate. It is only through such self-reflective uses of these technologies by those familiar with local contexts that the full spatial analytical powers of these technologies can be fully realized in people-environment research.

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