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Assessing Natural Resource Management Challenges in Senegal Using Data from Participatory Rural Appraisals and Remote Sensing

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Summary. — This study demonstrates that there is a relationship between socioeconomic problems in parts of West Africa and remote-sensing-derived environmental information about the region (normalized difference vegetation index (NDVI), net primary production (NPP), and gridded rainfall data). Further, it finds that using both remotely sensed data and site-specific information from participatory rural appraisal (PRA) reports enables an improved understanding of natural resource management problems in the region. The study uses 100 PRA reports as sources of data on socioeconomic and natural resource management problems in Senegal and The Gambia. Utilizing a binary variable to extract semi-quantitative information from the reports, the study examines 10 PRA tools for their usefulness.
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Key words — participatory rural appraisal, PRA, RRA, Senegal, The Gambia, West Africa, natural resource management, Sahel, remote sensing, environmental variability

1. INTRODUCTION

Over the past two decades, the notion of community participation has become an important theme of development practice (Brown, Howes, Hussein, Longley, & Swindell, 2002). Consequently, many governmental and non-governmental organizations (NGOs) have adopted methodologies that incorporate the active participation of the targets of development (Chambers, 1994b).

In this context, participatory rural appraisal (PRA) was initially taken to mean an activity in which the research process was owned and initiated by the community itself, rather than by an outside organization (Pretty, 1994). Currently, however, nearly all rapid appraisal activities are referred to as PRA, which in practice includes such a wide range of activities and a diversity of objectives that the original meaning of the term has been lost (Maxwell, 1998).

Participatory and rapid appraisal methods came together in the 1980s and were termed *rapid rural appraisal* (RRA)—defined collectively as a set of methods for community studies on a variety of topics, but usually oriented to problem identification and community empowerment toward change (McCracken, Pretty, & Conway, 1988). While the reports used in this study are each termed PRA, it could be argued that the formulaic and extractive approach that was taken by the specific appraisal teams in Senegal is more akin to RRA than to truly participative approaches. Many of the documents used here are labeled according to the current definition and do not reflect the original definition of PRA, but they hold value as sources of

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information about communities and their problems.

PRA utilizes specific tools and techniques to gather information about and learn from rural people (Chambers, 1990, 1994a). PRA involves a short (3- to 10-day) visit to a community by a multidisciplinary team of trained facilitators who conduct the appraisal. At the end of this time, a meeting of the participants and the PRA team serves to report the results of the assessment to the community. A written report is then created and submitted to the sponsoring organization. One hundred such PRA reports have been used in this study in an effort to correlate the socioeconomic and natural resource management problems experienced by communities in Senegal with environmental factors measured by satellite remote sensing. This relationship adds a new dimension of understanding to spatially continuous and widely available biophysical data in data-poor West Africa.

Research has been done comparing the results of PRA to more formal farm and household surveys using conventional quantitative social research methods, and no significant differences in outcome between the two approaches have been found (Collinson, 1981; Franzel & Crawford, 1987; Rocheleau, Wachira, Malaret, & Wanjohi, 1989). PRA, however, is not without its critics. Gladwin, Peterson, and Mwale (2002) point to an overwhelming reliance on untested ethnographic observations that are made over brief periods of time. They assert that the conclusions reached using participatory methods frequently ignore individual variation in participant behaviors in order to focus on the similarities among them. Heterogeneous behavior is swept aside in the effort to generalize from too small a sample size.

Richards, Davies, and Cavendish (1999) assert that the ability of the tools used in PRA to provide accurate information is dependent on the degree of variation in the underlying data. Where variation is low (such as in studies of agricultural labor in the peasant farmer community, for example), participatory methods alone can provide information of value comparable to more traditional methods. Where variation is high (such as in suburban or urban zones with much more complex livelihood strategies), more conventional approaches may be needed to comprehend the variability and ensure that it is reflected in the research data (Richards *et al.*, 1999).

This study uses data from 100 PRA reports gathered by a variety of institutions and organizations active during the 1990s in Senegal and The Gambia, West Africa. Its objective is to evaluate the potential of the site-specific participatory data in these PRA reports, when they are used as secondary source documents, to augment remotely gathered ecological information about the natural resource management problems experienced by communities throughout Senegal and The Gambia. In other regions of the world where PRA is not practiced as systematically, this type of comprehensive study may not be possible. It is proposed that when integrated and considered together, information from these data-collection methods may provide a better understanding of many challenges faced by communities in West Africa.

In this study, data from the PRA reports about natural resource management in Senegal are coded and compared with satellite-derived information regarding the ecological situation there during the past two decades (Gueye, 1994). Information from 100 PRA exercises is used to assess community problems. The comparability of the PRA studies and the resulting reports is assessed. Also assessed are which PRA tools may be most useful when utilized in conjunction with remote sensing information. This type of analysis provides an opportunity for the research community to reap additional benefits from projects using PRA techniques that were conducted by numerous development agencies and organizations during the past two decades. Ideas for policy makers and practitioners of PRA on improving the usefulness of their reports are also presented.

(a) *PRA in Senegal*

Although PRA in Senegal has a strongly extractive orientation, where participation has remained a means rather than an end for the implementer (Rachel, 1997), it has been used as a planning and mobilization tool for development projects. During the 1990s, the use of this tool was supported by the US Agency for International Development through large investments in training programs integrated into technical schools, resulting in a substantial core group of facilitators (Rachel, 1997). Regardless of the stated objective of conducting an individual PRA (health care, organizational management, adult education, etc.), nearly every PRA in this study reported a similar suite of information on the natural resources available to the participants and the problems associated with these resources.

In Senegal, as in many other countries, PRA has been used in conjunction with both projects and development agendas. When NGOs are training communities in participatory methods at the same time that they are providing them with valued goods and services, it is unlikely that the information generated by the PRA will be entirely free from distortion and manipulation (Brown, 1998). This transactional environment is in place during establishment of the important priorities of the village, and the participating villagers are using the PRA exercise to communicate their priorities for goods and services in the hope of gaining the financial and technical assistance of the sponsoring organization.

It is possible that any one community's professed priorities and problems, as recorded in PRA reports, have been influenced by what these communities believed were the priorities of the implementing agency, instead of their actual issues. To minimize such effects, this study uses 100 PRA reports from 10 organizations with a variety of priorities, policies, and objectives, both stated and unstated. By using data from several diverse organizations, as well as a presence–absence methodology to examine the contents of the reports, the effect of any one organization's bias on the results is minimized.

2. DATA

The study uses information garnered from 100 reports documenting a PRA visit to a village or town in Senegal or in The Gambia, West Africa. The data from the PRA documents are analyzed in conjunction with information about the environmental situation during the past two decades, derived from remote sensing. The following sections describe these datasets.

(a) *PRA documents as data sources*

Figure 1 shows the locations of the communities in Senegal where the PRAs were conducted, with the administrative units and agricultural systems that predominate in the region. Table 1

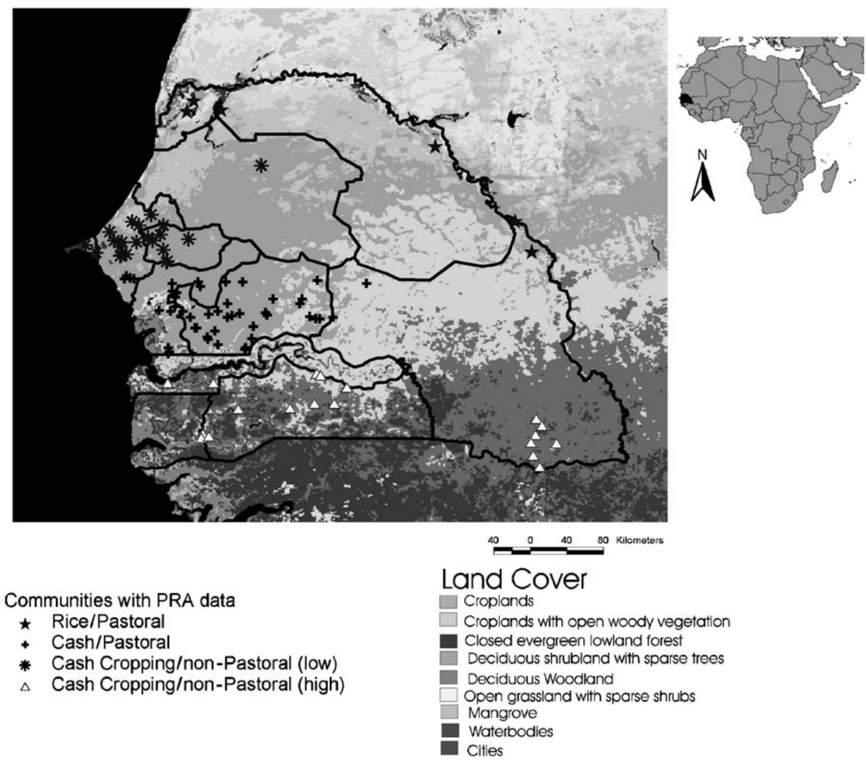

Figure 1. *Map of village locations where reports of PRA were conducted. The community categories are derived from the FAO Food Insecurity and Vulnerability Information and Mapping System (FIVIMS) (AGRYMET, 2000).*

Table 1. *Sponsoring organizations and number of reports in study, with regions where reports were conducted*

# PRAs	Sponsoring organization	Subsistence/rice-pastoral (%)	Cash cropping/ pastoral (%)	Cash cropping/ non-pastoral (low) (%)	Cash cropping/ non-pastoral (high) (%)
26	Africare—Senegal	0	96	0	4
21	USAID Natural Resources project (PGCRN)	10	24	0	67
20	Projet D'Appui/USU—ACDI—USAID projects	5	45	50	0
8	Development Assistance for NGOs (CONGAD)	0	25	75	0
6	Land Tenure Center, University of Wisconsin	17	0	67	17
6	Rodale Institute, Senegal	33	50	17	0
5	World Vision International, Senegal	0	60	20	20
4	International Institute for Environment and Development (IIED)	0	100	0	0
2	Village reforestation in the north-west groundnut basin project (PREVINOBA)	0	0	100	0
2	Action Aide The Gambia	0	0	0	100

shows the sponsoring organization that conducted or commissioned the reports. Of these organizations, 67% had as their goal a review of the current state of the natural resource management of the villages. Of the 100 PRAs documented, 27 were training exercises, supervised by expert facilitators but directly conducted by people inexperienced with PRA tools. Their reports, however, were written by expert facilitators and are thus comprehensive and similar in content to the other reports in the sample. This similarity was evaluated using PRAs that had two reports, both for CONGAD, one done as a training exercise and one as an official report. Although the official data for these communities were used for this study, the amount of overlap in the reports was very high in the context of the problem analysis being conducted here.

To assess the similarity of the training and experience of the PRA teams, their use of traditional PRA tools was determined (Brown *et al.*, 2002; Chambers, 1990). All the PRA teams used semi-structured interviews (SSI), so these were not evaluated for consistency. Twelve tools were evaluated: village maps, transects of the village, Venn diagrams, village histories, work calendars, decision trees, socioeconomic ranking, problem matrices, flux diagrams, prioritization matrices or pyramids, matrices of revenue sources, and matrices of the use of forest products. Of the 100 PRA documents, three had no lists or examples of the tools used in the PRA exercise within the report and did not contain sufficient information on the problems of the village; therefore, these three were not used in the analysis.

Figure 2 details statistics about the PRAs.

(b) *Satellite data on vegetation*

In the Sahel, vegetation gradually changes from a sparse bushland in the north to annual grasses and scattered bush steppes in the Central Sahel, gradually merging into Sudanian savannas, where perennial grasses are mixed with trees, bushes, and extensive rain-fed cultivation. This vegetation is described here to reflect two states: the overall productivity of a village site and the degree of variability from year to year.

Mean annual net primary production (NPP) has been used to determine different levels of agroecological potential across Senegal (Prince & Goward, 1995). The NPP fields used here, obtained from the University of Maryland at College Park, were produced by the Glo-PEM biophysical model and were at 8 km resolution (Goetz, Prince, Small, & Gleason, 2000; Prince & Goward, 1995). Annual NPP is defined as the net difference between annual carbon uptake (grams CO_2/m^2/year) from the atmosphere

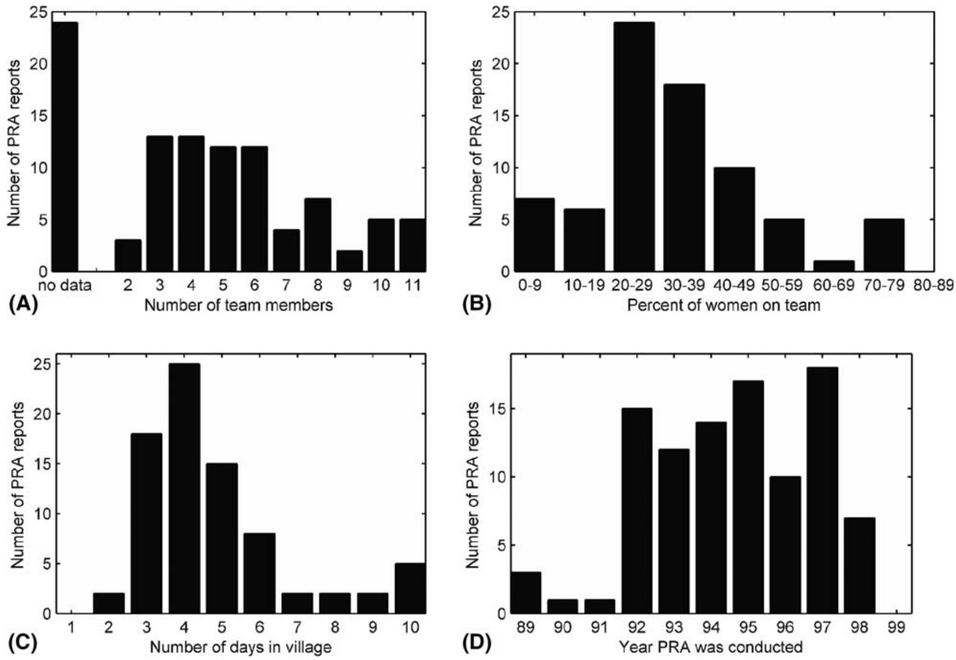

Figure 2. *Statistics on PRA reports: (A) the number of people on each PRA team, (B) percent of women on the PRA team, (C) the number of days the PRA team stayed in a village, and (D) the number of PRA reports per year.*

through photosynthesis by the land vegetation and that lost back to the atmosphere through autotrophic or maintenance respiration. NPP is also related to the net ecosystem exchange (NEE) of carbon accumulated or lost from the surface by its vegetation and soils. NPP is strongly related to the interannual variability of agricultural yields and is, therefore, an adequate surrogate for agricultural production statistics that are lacking in Senegal (Fuller, 1998; Hicke, Lobell, & Asner, 2004; Li, Lewis, Rowland, Tappan, & Tieszen, 2004; Prince, Haskett, Steininger, Strand, & Wright, 2001; Rasmussen, 1998a, 1998b; Tucker, Justice, & Prince, 1986).

In order to describe the average productivity of the region, the average NPP used here was calculated from the mean of growing season monthly values from 1989 to 1999. Senegalese NPP ranges from 0 in the north to approximately 1000 grams CO_2/m^2/year in the south (Figure 3A). The linear feature seen in Figure 3A is related to the coarse resolution of one of the primary production model inputs. This feature does not affect the results of this analysis because the NPP shows the relative differences in agricultural productivity across the country, a relationship that is not significantly affected by the spatial discontinuity of less than 100 g/m^2/year.

To estimate the degree of variability of the vegetation, normalized difference vegetation index (NDVI) data from the National Oceanic and Atmospheric Administration's (NOAA) Advanced Very High Resolution Radiometer (AVHRR) sensor was used (Holben, 1986; Myneni, Hall, Sellers, & Marshak, 1995; Tucker, 1979). This data have long been used to study vegetation dynamics in the Sahel and elsewhere globally (Justice, Dugdale, Townshend, Narracott, & Kumar, 1991; Lotsch, Friedl, Anderson, & Tucker, 2003; Prince, Justice, & Los, 1990; Townshend, 1994; Tucker, Dregne, & Newcomb, 1991). The variability of AVHRR NDVI data during the period 1981–99 was measured using the coefficient of variation to determine the level of environmental variability in the region, affecting the amount of rangeland available for livestock and the success of rain-fed agriculture (Figure 3B). Because vegetation becomes more varied as it becomes less abundant, the coefficient of variation is negatively correlated with the overall productivity of the site. Figure 4 shows how rainfall, net primary productivity, coefficient of variation of NDVI, and coefficient of variation of rainfall are related. These variables describe how productivity relates to variability at a variety of scales.

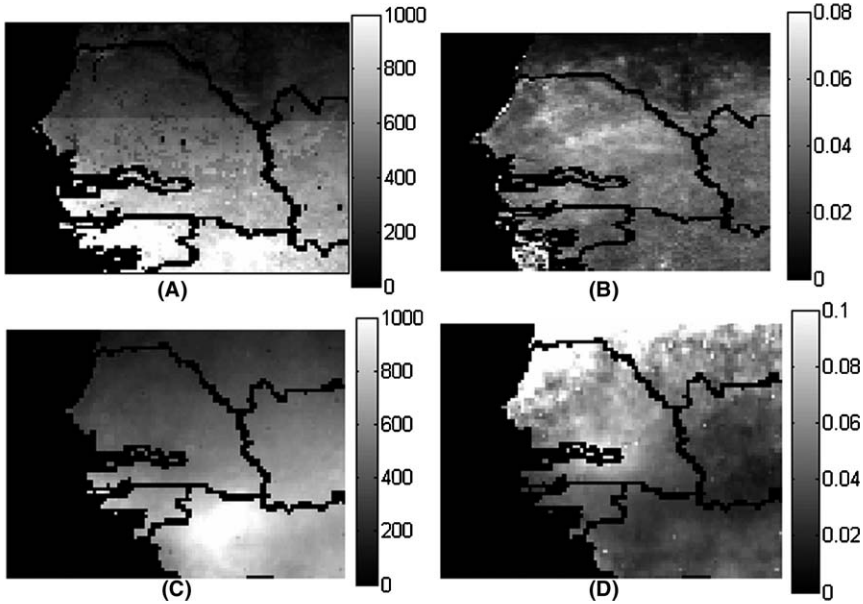

Figure 3. *Images of environmental variables used in the study: (A) mean annual NPP in g/m²/year, (B) coefficient of deviation (standard deviation/mean) of the interannual NDVI anomaly in NDVI units, (C) average annual rainfall in millimeters per year, and (D) coefficient of variation of annual rainfall measured in millimeters.*

(c) *Rainfall data*

The NOAA Climate Prediction Center's Africa Rainfall Estimate (RFE) product is used to describe rainfall patterns during the 1990s (Laws, Janowiak, & G, 2003; Xie & Arkin, 1996). At 0.1° resolution, this dataset provides an adequate resolution to characterize rainfall in a country with a steep moisture gradient from north to south (Figure 3C). The average annual rainfall is complemented with the coefficient of variation of the annual rainfall totals, providing information on the overall interannual variation during the decade (Figure 3D). By using both the longer-term annual rainfall variation fields and the shorter-term monthly vegetation variability fields, we can learn much about the environmental situation of the 100 communities in question, including those in regions that have adequate rainfall levels but poor rainfall distribution during the rainy season (high NDVI variability), and those that suffer from overall deficiencies of rainfall every other year (high rainfall variability) (Figure 4).

(d) *Agriculture system information*

Additional data on agricultural systems were obtained from the FAO's Food Insecurity and Vulnerability Information and Mapping Systems (FIVIMS). FIVIMS are networks of national information systems that assemble, analyze, and disseminate global data related to food insecurity and vulnerability. The FIVIMS West Africa maps on agricultural production systems were used to categorize the PRA villages into groups with similar agricultural activities and levels of self-sufficiency (AGRYMET, 2000; Li *et al.*, 2004). For study purposes, the subsistence recessional agriculture–pastoral group was intermixed with the rice–pastoral group because both were located along the Senegal River and its tributaries and both conducted mostly dry-season recession agricultural activities instead of rain-fed agriculture. The largest group, the cash-cropping/non-pastoral class, was divided into two: communities above 13.5° north (referred to as *low productivity*) and those below that latitude (referred to as *high productivity*) to aid in the analysis (Stanicoff, Staljanssens, & Tappan, 1986). This distinction also allows the division of the southern zone, which is usually self-sufficient in grain, from the northern zone, which imports food from abroad or from other regions in Senegal (Li *et al.*, 2004).

Pastoral and non-pastoral cash crops are predominantly rain-fed millet, peanut, and black-

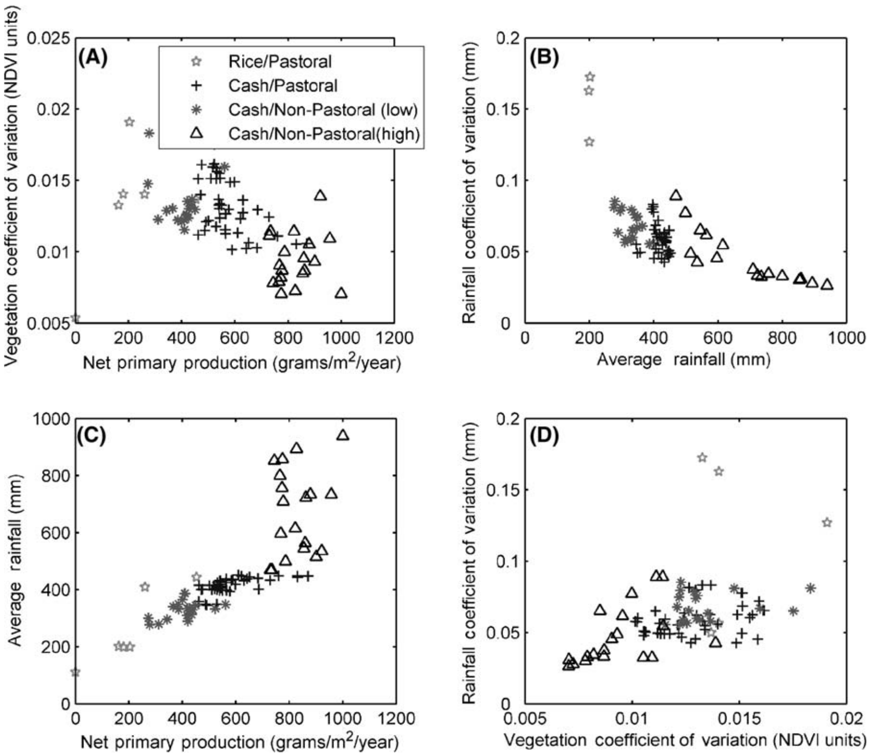

Figure 4. *Scatter diagram showing the relationship between the environmental variables in four agricultural zones denoted with different symbols: (A) NPP (g/m²/year²) plotted against coefficient of variation of monthly NDVI anomaly in NDVI units, (B) average annual rainfall (millimeters) versus coefficient of variation of annual rainfall (mm), (C) NPP (g/m²/year²) plotted against average annual rainfall (mm), and (D) coefficient of variation of monthly NDVI anomaly in NDVI units plotted against coefficient of variation of annual rainfall (mm).*

eyed pea, with sorghum in wetter areas. Market gardening is done throughout the country wherever water resources are available to accommodate it. Pastoral systems are defined by the movement of animals across the landscape in search of pasture. However, virtually all villages in this study kept livestock, which included cows, horses, sheep, goats, and chickens, and occasionally, in the southern regions, pigs. The location of the communities in these groups is presented in Figure 1 over a map of land use from the Global Land Cover 2000 data (Mayaux, Bartholome, Fritz, & Belward, 2004).

3. METHODOLOGY

To determine the similarity in training and use of techniques among facilitators, the study analyzes the PRA tools utilized by the various organizations. The percentage of PRAs that utilized a particular PRA tool is presented in Table 3, listed by organization.

Using a decomposition/scatter plot, the data on natural resource management problems obtained from the PRA documents are related to data gleaned from remote-sensing surveys. Each of the 100 PRA documents is examined for mention of problems that a community had identified. To extract the problems mentioned across diverse communities, reports, and assessment objectives, a binary variable is applied (Gonzalez, 2001). If a PRA report mentions any particular problem in a community, that problem is given a value of one for that community; otherwise, it is given a value of zero. This methodology has the advantage of removing the potential bias of different organizations' program priorities, because many communities prioritized their problems to be consistent with the sponsoring organizations' stated goals. By using a yes/no presence test, all problems mentioned in each PRA report may be recorded, creating a semi-quantitative variable from the information presented in the PRA reports.

It was apparent from the reports that, in order to assess the ability of a community to manage its natural resources in a sustainable way, both socioeconomic and natural resource problems must be considered. The problems mentioned in the PRA reports fall into both these categories and are described in Table 2. Rural Senegalese farmers measure their ability to make a living in terms of rainfall, soil productivity, and water resources for pastures,

Table 2. *Description of problems documented in PRA reports*

Problem	Description
Groundwater	Lack of infrastructure to obtain groundwater (enough wells, functioning pump, etc.), lowered groundwater table that reduces the effectiveness of existing infrastructure, or increased salinity or brackishness that reduces water quality
Soil	Soil fertility reduced more significantly than remembered from the recent past. Erosion problems from water and wind, including gullying
Education	Inadequate or complete lack of formal education facilities, such as French language classrooms or Muslim religious schools. In addition, training for adults who cannot read or write, and management training needed to improve the efficiency of revenue-generating projects, are lacking
Precip	Reduced or increasingly variable rainfall a major problem for agriculture and other natural resource activities
Migration	Migration of young and other ablebodied villagers mentioned in the report. Income from migrants is sometimes a major source of revenue
Health	Lack of health facilities a significant problem in the village, reducing the ability of the population to work and uses women's time by forcing them to travel to health facilities in neighboring communities
Defor	Deforestation is mentioned as a significant problem. Investments in reforestation activities such as planting trees, protecting natural regeneration are mentioned. Technical assistance is often requested by the village
Labor	Reduced manpower due to migration is a significant issue in managing natural resources
Revenue	Inadequate revenue is generated or food grown throughout the year, causing villagers to spend significant amounts of time and effort to find additional sources of food or revenue during bad years or annually during the summer months (*soudure*)
Yields	Reduced yields due to soil infertility and reduced rainfall are mentioned as important contributions to reduced income for the entire community
Pests	Plant (striga), animal (rats, baboons, birds), bacterial, and fungal pests have significant impact on the yield obtained by the farmer
Plant/anSick	Plant or animal sickness causes increased mortality. Animal sickness is often caused by the inability to provide adequate food during the dry season
Firewood	Scarcity of wood near the village causes women to spend a significant amount of time searching for cow dung or walking long distances to find wood for household needs
Land	Increased population and reduced yields have increased land requirements above that which are available to the village. This has led to land scarcity, which significantly reduces the ability of the population to meet its needs by farming
Credit	A lack of credit to purchase farm implements, seeds, and fertilizer is mentioned as a significant factor in reduced revenue-generating activity
Roads	Poor roads or bad transport infrastructure is a serious problem for the village in its efforts to bring goods to the market or to reach health facilities in a timely manner
Fire	Wild fires, forest fires, and bush fires are mentioned as a natural resource management problem and a threat to village infrastructure
Vet	Lack of veterinary medicines and facilities is mentioned as a significant problem leading to increased animal mortality and/or productivity
GrainStor	Lack of impermeable grain storage facility contributes to reduced grain stocks and reduced income/increased hunger

cattle watering, and horticultural purposes, as well as in terms of education for their children and for themselves, for example. Farmers consider the inability to produce as primary and the resulting lack of salable or tradable products or commodities as secondary results of resource management failure (Healy & Stancioff, 2001). Thus, all factors impinging on production, both socioeconomic and biophysical, are included in this study.

To analyze the overall meaning of the environmental data in relationship to the problems extracted from the PRA reports, two methods have been used: multiple correspondence analysis (MCA) and averaging of the environmental variables. The MCA is used to determine the relationship between the four environmental variables and the 19 problem variables. The mean of the environmental variables for all communities with each identified problem is used to provide a measurement of the ecological conditions found near these communities. The averaged variables then provide a means for comparing other locations in West Africa that are not included in the study with the results presented here.

MCA has been used to assess the relationships between the identified problems and the four remotely sensed environmental variables (Greenacre, 1984). MCA is a technique for displaying associations among a set of categorical variables in a scatter plot or map that allows a visual display of the patterns within the data (Everitt & Dunn, 2001). The analysis indicates whether certain levels of one trait are associated with some levels of another. Conducting a geometric analysis on the resulting two-way contingency table summarizes the observed association of the two traits. The implementation of correspondence analysis uses the singular value decomposition of the matrix, whose elements are based on the chi-squared statistic. Details of this implementation can be found in Everitt and Dunn (2001). The MCA map can be interpreted by comparing the distances between the row points and the distances between the column points in order to show association between the variables. Two variables that are close together on the MCA map are more closely associated with one another than with those that are farther away (Everitt & Dunn, 2001; Greenacre, 1984).

MCA has been applied to an indicator matrix (Greenacre, 1984) created by counting the number of communities with low variability and three NPP, or mean rainfall, levels (levels 1–3) and the number of communities with high variability and two NPP, or mean rainfall, levels (1 and 2). The resulting matrix, with elements consisting of 19 problems by five environmental levels, was decomposed using singular value decomposition in order to ascertain the primary relationships between the variables, as described in Everitt and Dunn (2001) and Greenacre (1984).

The second method averages the environmental characteristics of all communities with a specific problem. For example, the mean annual NPP of each of the communities with "brush fire" as a significant problem was averaged and then plotted against the mean monthly vegetation variability in those communities, in order to gauge an overall environmental situation for the communities with that problem. An analysis of the relationship between the problems and the average environmental situation is presented.

4. RESULTS

(a) *PRA tools*

The PRA tools that proved most useful for this study were the village transect, the decision tree, the problem–solution matrix, and the prioritization pyramid (Table 3). The village transect exercise provided an opportunity for many significant environmental, agricultural, and resource management problems to be observed, discussed, and noted in the report text. The transect material provided data on problems that may have been outside the scope of the sponsoring organization in question but which were present and noted in the report and could thus be utilized in this study.

The decision tree, the problem–solution matrix, and the prioritization pyramid diagrams were of key importance in this study, as they tended to integrate the local community's situation with the environmental, social, and economic milieu, highlighting either a community's response to the natural resource management problems or the consequences of the problem for the community. These three PRA tools also had a high level of similarity with regard to the types of information they recorded, and each elicited useful and pertinent discussion of issues in the text of the document. Each of these tools was simple and standardized and had similar functions in the PRA activity, and nearly all of the PRA reports (94%) utilized at least one of these tools.

Table 3. *Percent of PRAs using appraisal tools*

	Number					
	97 All (%)	26 Africare (%)	21 PGCRN (%)	20 USAID (%)	8 CONGAD (%)	⩾6 Others (%)
Village map	94	96	86	100	75	100
Venn diagram	90	92	95	100	75	77
Village history	78	88	76	85	63	75
Village transect	75	54	86	95	75	78
Problem–solution matrix	69	62	76	85	50	58
Work calendar	68	96	48	45	75	74
Prioritization pyramid	56	96	38	35	25	56
Revenue matrix	45	81	24	20	38	47
Forest matrix	45	58	29	60	38	40
Decision tree	36	96	38	10	0	3
Flux diagram	31	4	62	30	25	29
Social ranking	26	54	5	0	25	43

The number of PRAs in each percentage is listed in the row at the top. The "Others" column lists the average of the statistics from organizations with six or fewer PRAs in the study (see Table 1).

The PRA tools that were least useful to this study were those that lacked adequate definition or standardization within Senegal and The Gambia. The forest matrix, for example, frequently reported local names for trees that were inadequately defined, and thus the results could not be compared across communities with different local languages and traditions. The information contained in the flux and Venn diagrams provided only marginal utility in this analysis, as these tools explored relationships among people and organizations whose effects on the management of natural resources were not sufficiently specified. In addition, the rendering of these diagrams was very inconsistent and typically sufficiently illegible as to be unintelligible to the outside reader.

(b) *Problems identified in the PRA documents*

The percentage of communities to identify each of the problems described in Table 2 is shown in Table 4. The most frequently cited problem is groundwater, with 92% of the PRA reports identifying this as a problem for the community. Soil infertility is the second most prevalent, at 90%. Lack of education and reduced precipitation are the third and fourth most common community problems identified. Reductions in precipitation in this semi-arid region have led to falling water tables, and this situation requires continual investment in deeper, traditional, hand-dug wells and in modern, pump-driven, borehole wells in order to provide adequate drinking water for the community. In addition, a growing population has further increased the need for water-extraction infrastructure. Access to abundant, high-quality water can provide many opportunities for income-generating activities such as market gardening and animal raising, which are precisely the kinds of projects that many of the PRA-sponsoring organizations wish to fund.

A high percentage of the PRAs report problems with lack of education facilities, migration of community members out of the village, and lack of health facilities. These socioeconomic problems have an impact on the ability of farming communities to maintain their livelihood. Poverty-mapping studies show that the location of schools, health facilities, and markets are important indicators of poverty (Healy, Stancioff, & Ballo, 2003). In addition, there is a strong correlation regionally among rainfall patterns, soil degradation, and the incidence of poverty (Healy & Stancioff, 2001). That these problems are among the most frequently cited is not unexpected, given Senegal's national economic situation (Delgado & Jammeh, 1991; Engberg-Pedersen, Gibbon, Raikes, & Udshold, 1996; USAID, 2002).

The varied agricultural systems and locations of the appraised communities also have effects on the frequency and severity of problems noted. For example, 100% of the rice/pastoral communities and 91% of the cash-cropping/pastoral communities cite deforestation as a problem, along with a frequent mention of firewood scarcity. In addition, 86% of the commu-

Table 4. *Percent of PRAs reporting natural resource management problems by agricultural region, sorted by frequency*

	Number				
	100 All	6 Subsistence/ rice-pastoral	24 Cash cropping/ pastoral	51 Cash cropping/ non-pastoral (low)	19 Cash cropping/ non-pastoral (high)
Groundwater	92	83*	91*	92*	95*
Soil	90	83*	100*	90*	79*
Education	73	83*	68	76*	68*
Precip	71	83*	82*	72*	53
Migration	66	67	91*	70	26
Health	65	33	55	72*	68*
Defor	65	100*	91*	58	42
Labor	63	17	59	78*	42
Revenue	62	50	86*	70	16
Yields	52	67	59	58	21
Pests	48	17	41	44	79*
Plant/anSick	43	50	55	46	21
Firewood	41	83*	64	38	11
Land	38	33	50	46	5
Credit	33	33	18	30	58
Roads	27	0	32	24	37
Fire	23	0	5	12	79*
Vet	20	0	14	8	63
GrainStor	18	0	9	24	16

A "*" denotes the top six problems in each region.

nities in the cash cropping/pastoral and 70% of the cash-cropping/non-pastoral, low-productivity zones mentioned a lack of sufficient revenue for basic needs as a significant problem. These two regions have higher population densities than the communities farther north. There, the concerns about health facilities, insufficient labor, and pests raiding the crops are less severe than in communities to the south that use cash-cropping agricultural systems. Ranking the problems according to agricultural systems is useful in demonstrating that, in general, similar problems of infrastructure, reduced rainfall, and declining groundwater recharge have affected communities in a wide range of circumstances from the north to the south. This is due in part to the recent overall geopolitical and economic situation in Senegal (USAID, 2000).

(c) *Correspondence analysis of variables*

The MCA technique is used here to determine how variability, productivity, and rainfall affect the problems that a given community reports in a PRA. Figure 5A and B shows the relationships between natural resource management problems and the environmental situation. The closer the two variables are to one another in these plots, the more closely related they are.

In both panels of Figure 5, it can be seen that the overall pattern is similar, with bush fires, credit problems, and lack of veterinary services being associated with both high rainfall and highly productive/low variability environments. On the left side of the figure, the most highly variable, low-productivity, and high-rainfall (hi NPP 1 and hi Rain 1) regions are at the top, near deforestation and firewood. The problems of pests and lack of credit and groundwater fall between the high productivity/low variability and the moderate productivity/low variability locations, indicating that these problems are more common in areas with more agriculture and fewer trees, one possible interpretation of the difference in variability. Reduced precipitation, lack of revenue, and plant and animal sickness are problems most closely associated with low levels of primary productivity. The more direct problems of soil infertility, declining yields, increased migration, and diminishing groundwater are closest to the center of the mapping space, and they fall between medium and low NPP variables.

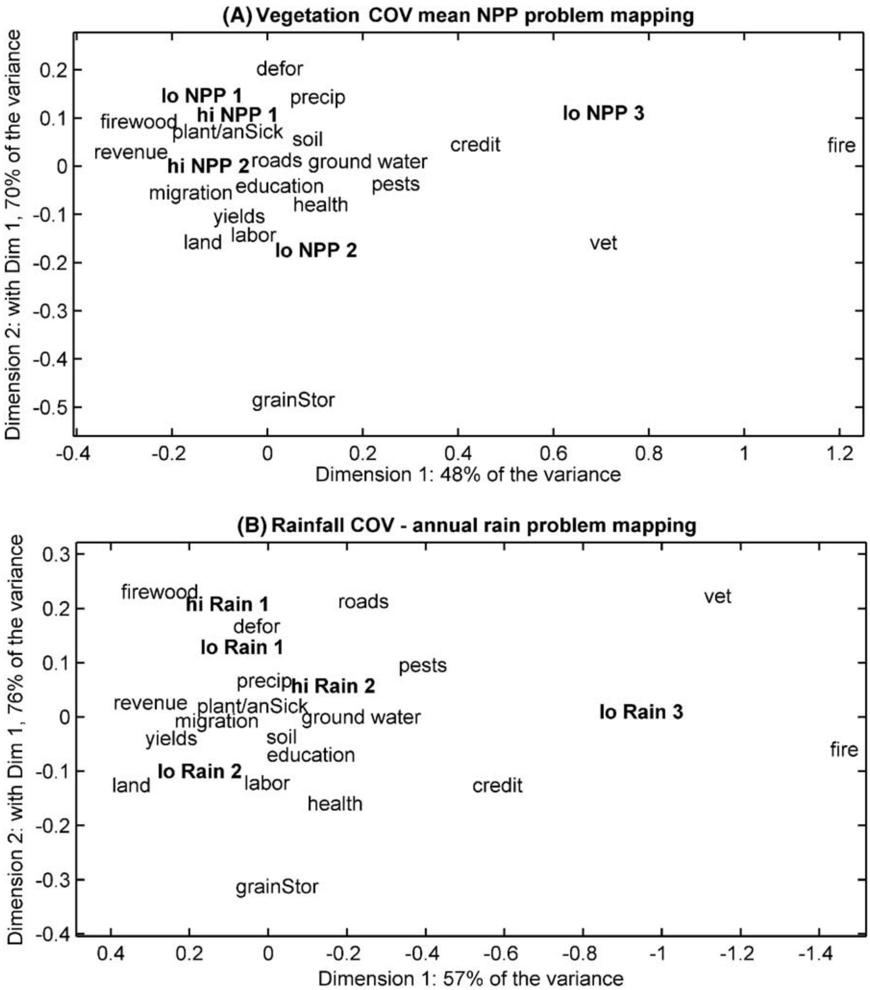

Figure 5. *Results from MCA of problems and environmental variables. (A) Problems mapped using three levels of NPP (1 from 0 to 400 g/m^{2}/year, 2 from 401 to 700 g/m^{2}/year and 3 above 701 g/m^{2}/year) and two levels of variability (lo from 0 to 14 g/m^{2}/year, 2 is high, above 14.1 g/m^{2}/year. There are no high variability and high NPP category (hi NPP 3). (B) Problems mapped using rainfall and two levels of the coefficient of variation for annual rainfall means. The levels are defined as 1 from 0 to 300 mm/year, 2 from 301 to 600 mm/year and 3 above 501 mm/year, and two levels of variability, lo from 0 to 0.25 mm/year, hi above 0.26 mm/year). There is no high variability and high rainfall category (hi Rain 3).*

A similar story can be told using the rainfall variable and vegetation variability MCA diagram presented in Figure 5B. The problems of education, labor, and land scarcity, migration, and yields, found at the bottom left of the diagram, are associated with low-variability/ moderate-rainfall zones. The problems of grain storage, insufficient labor, health, and bad roads found in the lower left part of the diagram are associated with medium levels of productivity and with both low and high levels of variability.

Moderate levels of rainfall are found in regions where agriculture has long been present. These areas, such as in the peanut basin capitals of Kaolack and Thies, are characterized by declining investment in soil fertility and agriculture infrastructure. Population pressure and severely reduced soil inputs have forced more labor inputs and larger geographic areas to be planted to produce enough food for the growing population. In the following analysis, the strong correspondence between these variables, seen with MCA, is exploited to provide a clearer interpretation of the environmental variables.

(d) *Averaging of environmental variables*

Using environmental data derived from satellite observations, we can define the underlying environmental conditions where the identified problems have been found. Figure 6 shows the 19 problems plotted using the average net primary productivity and the average environmental variability of the locations reporting the problem. As in the MCA analysis, bush fires, lack of veterinary services, lack of credit, and pests are all associated with each other and are found in wetter, less variable environments. On the other end of the spectrum, firewood, lack of revenue, and land scarcity are found in highly variable, low-productivity, and low-rainfall sites. Nearby we find deforestation, reduced crop yields, plant and animal parasites, and inadequate food.

As land degradation through overexploitation and reduced precipitation affects the functioning of ecosystems, there are many consequences (Fuller & Ottke, 2002; Gonzalez, 2001; Hare, 1984; Prince *et al.*, 1990). The problems found in the high variability/low

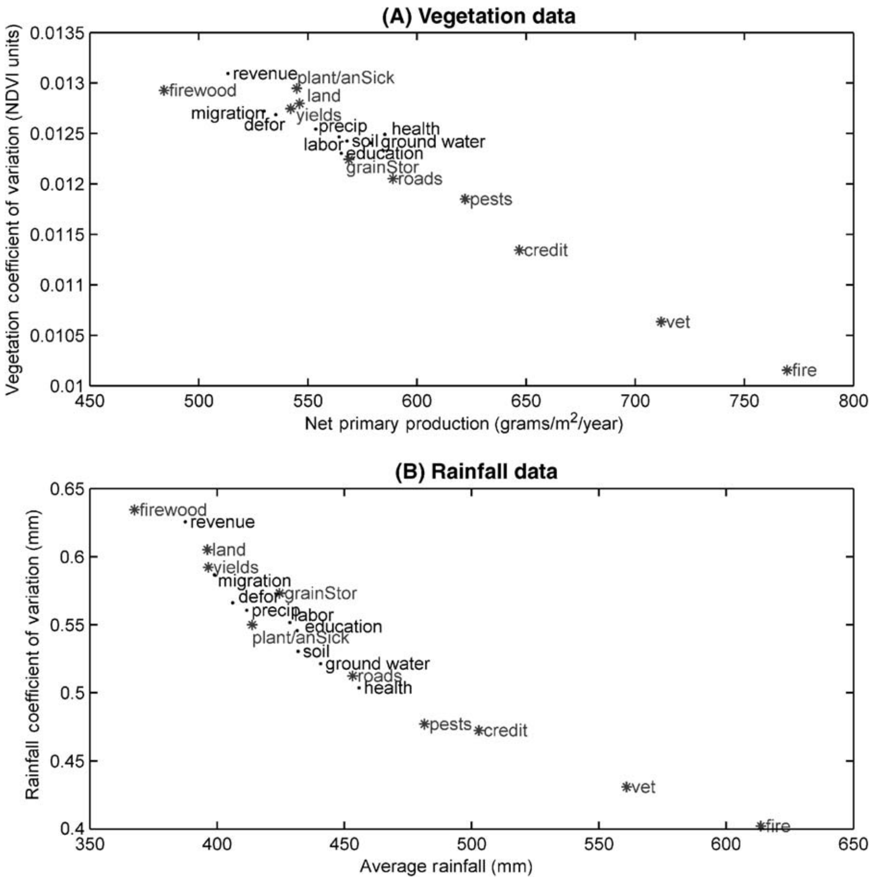

Figure 6. *Problems mapped using averaged environmental variables. The symbol "∗" represents problems found in more than 50% of the communities, symbol "·" is for those found in less than 50%. (A) (Top panel) Average NPP (g/m²/year) and the average normalized vegetation variability (NDVI units) of the communities with the 19 problems. (B) (Bottom panel) Problems according to average annual rainfall (mm) and rainfall variability (mm) normalized by the mean rainfall.*

NPP area of the graph are among those expected in regions experiencing environmental stress. These areas are experiencing the lowest levels of natural regeneration and the highest tree mortality, as well as significant reductions in the ability of farmers to conduct rain-fed cropping, and it was expected that these problems would be found there. Thus, from this analysis, it seems that the PRA reports have identified problems across Senegal that are in keeping with those seen using satellite data.

(e) *Problems by agroecological system*

Figure 7 shows eight natural resource management problems from the four agricultural system groupings. These plots demonstrate that the result of the correspondence analysis depends on how the environmental variables were averaged. The two classes of communities in the middle part of the country (cash cropping, both pastoral and non-pastoral) are mapped into tightly grouped points in both panels. These communities are located close together and have very similar sets of problems, given the latitudinal gradient of the rainfall, primary productivity, and variability. In these two groups, an interesting problem is one of bush fires. In the farther northern area of cash-cropping/pastoral communities, bush fires are a problem in only one community, which has a higher variability/lower vegetation profile than the average. In comparison, in the farther-south group of cash-cropping/non-pastoral

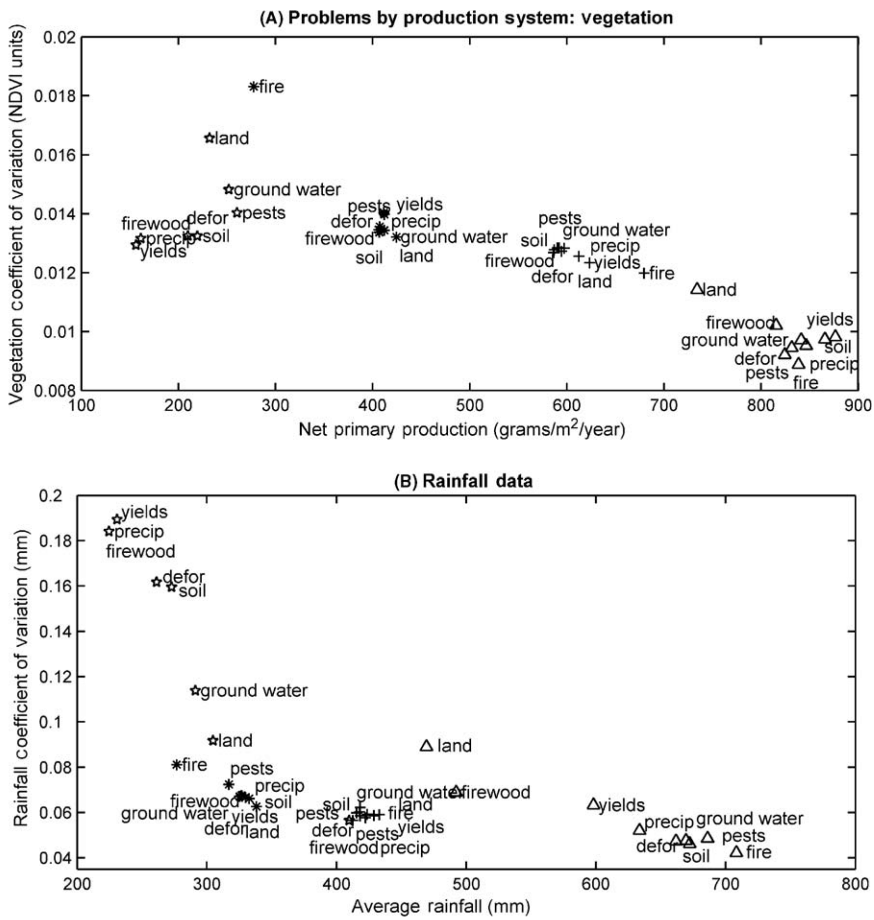

Figure 7. *Natural resource problems in four agricultural system zones, mapped by rainfall and vegetation. (A) The average NPP and the average vegetation variability of the communities with the 19 problems. (B) The problems according to average annual rainfall and rainfall variability.*

communities, bush fires are a problem in six communities, and the fire point is thus in wetter/less variable communities as was seen in the previous analysis, and as is expected. In the far south group of cash-cropping/non-pastoral systems, fire is again at the bottom of the cluster of points in the top panel, and land scarcity—a problem seen to be associated with dryer, less productive locations—is outside the cluster of points.

The northern rice-cropping/pastoral and southern cash-cropping/high-productivity classes show a different behavior from the other classes, because the relationship between variability and average rainfall is positive instead of negative in these regions (see Figure 4). When using the rainfall variables to compare the types of communities that experience land scarcity—the southernmost region compared with the northernmost region—it can be seen that land scarcity is associated with wetter, less variable areas in the north (where such land is more valuable and thus sought after) but is associated with dryer and more variable communities in the south (where more land is needed per capita to farm). Table 4 summarizes the percentage of communities reporting the various natural resource management problems by agricultural system type. The table reinforces the stated association of various natural resource problems with differences in environmental productivity and rainfall.

5. DISCUSSION AND CONCLUSION

Various international organizations have invested heavily in training personnel and using PRA methods in Senegal and in many other countries around the world. Despite this investment, many NGOs that utilize PRA methods do not make use of the reports once they are written, except as documentation for their development programs (Gladwin *et al.*, 2002). PRA documents can be a critical and persuasive source of information on both the strengths of communities and their vulnerability to environmental hazards, economic shocks, and global climate fluctuations. This study applies methodologies that enable PRA documents with varied origins and initial objectives to be used together as a data source that can explicate and elaborate on environmental data, such as that derived by remote sensing, and thus further the understanding of the problems of farmers and their communities in Senegal.

Using the PRA documents as a secondary source of data illustrates that, apart from the development objectives that prompted the sponsoring of the work, the more comprehensive and well written a document is, the more useful it is for this form of analysis. While there are various compositions of multidisciplinary teams with different ratios of gender representation, different numbers of days in the field, varying methods and tools used, and a wide variety of objectives motivating the creation of PRAs, despite these differences, natural resource management problems are so pervasive in these agricultural communities that they come through clearly in all the reports. As the community using participatory methods expands, and the definition of PRA changes, further investment in the education of PRA facilitators, with a focus on rigorous and standardized final PRA documents, will be necessary to ensure the continued usefulness of PRA reports in future analyses such as this one. Clear and comprehensive reports will also benefit the communities that are their subjects, as the funding organization will incorporate the needs and development priorities of each community into their plans more effectively, even if the local community does not adopt the participatory tools as their own (Brown, 1999).

Remote sensing has long been used in Africa to gather spatially and temporally continuous information about the environment in regions with a dearth of long-term records on agricultural production, rainfall, and temperature dynamics. Humanitarian organizations such as USAID's Famine Early Warning System Network (FEWS NET) have invested in collecting remotely sensed rainfall and vegetation data and have used it to provide information on drought and floods that affect food production (Hutchinson, 1998). Interpreting the meaning of these signals, however, has always been a challenge. Climate variations that appear severe to a meteorologist or remote-sensing specialist located in Washington DC may not be as important as high food prices or economic instability due to current social and economic realities in the region (FEWS, 1997).

Using both remote sensing and the results of participatory studies to investigate natural resource management problems, research will be more cost effective and meaningful. Remote sensing can inform the planning and focus of PRA by targeting regions that have experienced long-term reductions in rainfall during the past half-century, increases in year-to-year vegetation variability, and changes in the distribution of rainfall events. Improved targeting can enable development and research programs to be more effective in achieving their goals. Data and insights derived from PRAs can help transform remote-sensing statistics into information about causes, consequences, and possible solutions to natural resource management problems in the region. This study presents methods and analysis techniques that may provide the means to use already existing PRA documentation together with remote sensing information to conduct new analysis on environment-society coupled problems.

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