1996-97 TECHNICAL REPORT
for the project
PE-4: Land Use Studies: Reconciling the Dynamics of Agriculture with the Environment

Report of Highlights for CIAT B.O.T.
LAND USE STUDIES

Centro Internacional de Agricultura Tropical (CIAT)
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Project PE-4: Land Use Studies: Reconciling the Dynamics of Agriculture with the Environment

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Output 3: Determinants, dynamics, and impacts of land use in Latin America characterized and strategic options assessed

Output 4: Environmental policy and sustainable indicators defined and reported

Project PE-4: Land Use Studies: Reconciling the Dynamics of Agriculture with the Environment

Project Overview

Objective: To improve policy and decision making for sustainable land and environmental management in Latin America through the scientific analysis of land and environmental patterns, anticipated dynamics, and policy indicators.

Outputs: Environmental opportunities and constraints identified and assessed. Land use patterns and their spatial distribution classified, and correlated with environmental and socioeconomic data. Determinants, dynamics, and impacts of land use in Latin America characterized and strategic options assessed. Environmental policy and sustainability indicators defined and reported.

Gains: Detailed georeferenced databases on land use, ecological, and socioeconomic factors. Environmental and sustainability indicators of land use, networking on the environment, land use, sustainable agriculture, and indicators. Verified scenario-assessment tools. A blend of theoretical, methodological, and field-based inquiry for decisions on sustainable agriculture and agroecosystem health.

Milestones:

1998	A framework for a conceptual land-use model applied and tested in the Pucallpa study area. A stochastic model of rainfall incorporated into a system for producing input to drive dynamic crop simulations. GIS coverages of administrative regions, climate, population, land use, and watershed data produced, documented, and made available for all continental Latin America. A continental network of users and developers of indicators of sustainability in Latin America.
1999	A stochastic land-use model developed for at least one of the study areas. Production of a CD-ROM Latin American data sampler, incorporating GIS coverages useful to policy makers. Sustainability indicator systems applied in Central America and within Colombia in the Orinoquia region. First regional report on environmental and sustainability indicators published.
2000	A published assessment of alternatives for the restoration of degraded lands in at least one study area. A publication on the use of land-use models in assessing land-use scenarios and policy options.

Collaborators*: ICRAF, CIP, ILRI, ECLAC, University of Guelph (Canada), IICA (Costa Rica), IILA (Italy), IIASA (Austria), WRI (USA), RIVM (the Netherlands), TCA-Amazonian Cooperation Treaty, the Earth Council (Costa Rica), the World Bank, NARS, GOs and NGOs in Latin America; DNP, IGAC, MinAmbiente, IDEAM, CARDER (Colombia); Ministry of the Environment, EMBRAPA (Brazil); IVITA, INIA (Peru); INIAP (Ecuador).

* See Acronym list at end of Report.

CGIAR system linkages: Protecting the Environment (60%); Policies (20%); Breeding (10%); Biodiversity (10%). Contribute to the Tropical America Ecoregional Program.

CIAT project linkages: GIS studies assist SB-1, SB-2, IP-1, and PE-2; model development with PE-3, PE-5, and BP-1.

Project PE-4: Land Use Studies: Reconciling the Dynamics of Agriculture with the Environment

Project objective

To improve policy and decision making for sustainable land and environmental management in Latin America through the scientific analysis of land and environmental patterns, anticipated dynamics, and policy indicators.

Output 1: Environmental opportunities and constraints identified and assessed	Output 2: Land use patterns and their spatial distribution classified, and correlated with environmental and socioeconomic data	Output 3: Determinants, dynamics, and impacts of land use in Latin America characterized and strategic options assessed	Output 4: Environmental policy and sustainability indicators defined and reported
1.1 Diagnosis of agroecosystem health in priority areas.	2.1 Characterization and mapping of land use patterns in hillsides, forest margins, and savannas.	3.1 Development of holistic framework for understanding land dynamics in Latin America.	4.1 Promote a network of regional and national institutions that develop or demand indicators.
1.2 Perform field characterization of study sites.	2.2 Implementation of digital maps of land use, environmental degradation, and poverty for Latin America.	3.2 Analyze historical land use changes.	4.2 Development of conceptual framework in consultation with the network.
1.3 Preparation of digital ecological maps at different scales (local to regional).	2.3 Perform quantitative analysis of potential sustainable land use for the ecoregion.	3.3 Identification of major ecological and socioeconomic determinants of land use and farmers' decision making. Assessment of ecological impacts of land use.	4.3 Definition of sets of environmental and sustainability indicators at different scales.
1.4 Assessment of alternatives for restoration of degraded land.	2.4 Identification of critical situations and major opportunities for sustainable land use	3.4 Development of explanatory simulation models of land-use dynamics.	4.4 Development of a digital map of environmental and socioeconomic indicators at field level.
		3.5 Identification and assessment of strategic and policy options for sustainable agroecosystem management.	4.5 Testing of selected agroecosystem indicators at field level.
			4.6 Biannual report produced.

Introduction

The Land Use Studies Project has seen some substantial changes during 1996-97. Gilberto Gallopín has left the Project Manager's postition to move on to a prestigious postition with the Stockholm Institute in Sweden. We all wish him well and envy his new found opportunities for skiing. Manuel Winograd and Glenn Hyman have been taken onto core funding. Peter Jones has assumed the task of Project Manager.

Special project funding, although not all confirmed, is looking healthy. We have received US$11 000 from the Rockefeller Foundation for the work on Markov models and US$14 695 from the World Resources Institute (WRI) for the population mapping data. Further funding is expected from the United Nations Environment Program (UNEP) for the watersheds study. For the sustainability indicators work, US$ 260 000 is probably forthcoming from the World Bank, and a project for US$250 000 is under review with the Infodev initiative of the World Bank.

Milestones for 1998

1. A framework for a conceptual land-use model applied and tested in the Pucallpa study area

   We have made considerable progress towards this milestone. A complete picture of the structure of land-use dynamics is now available (see Figure 12). We are using this to implement the model . See section 3.4.

2. A stochastic model of rainfall incorporated into a system for producing input to drive dynamic crop simulation

   We have passed a crucial point in estimating model parameters and envisage making a beta release CD-ROM available for testing in early 1998. See section 2.3.

3. GIS coverages of administrative regions, climate, population, land use, and watershed data produced, documented, and made available for all continental Latin America

   Administrative areas have been completed and delivered, climate maps are complete at a pixel size of 10 minutes. For developments in land cover, population, and watersheds, see section 2.2.

4. A continental network of users and developers of indicators of sustainability in Latin America

   See section 4.1 for developments in the network.

Output 1: Environmental opportunities and constraints identified and assessed

1.2 Perform field characterization of study sites

Activity: Forests in a savanna landscape - the Yucao watershed

- ✓ *Floristic and structural characterization made of riparian forest types*
- ✓ *Distribution of forests and spatial relations with other ecosystems documented*
- ✓ *Digital elevation model created*

The Colombian savanna landscape has traditionally been used to raise cattle. As demand for land increases, the *Llanos* are considered a region of great potential agricultural importance. Improved access and new technology (improved grass-legume pastures, better-adapted crops) will help intensify land use considerably in the coming decades. At this time, addressing the question of sustainability is important. Some indicators suggest that the new technologies improve land quality such as organic matter content and soil macrofauna. However, agriculture often has significant impacts beyond the field that is actually managed. Our research in the *Llanos* is aimed at describing what other ecosystems exist and how they relate to those parts of the savanna that are expected to be converted to intensively managed grassland.

The savanna is often portrayed as a flat landscape covered with native grassland. In reality, forests and streams form an important part of the landscape whose relatively small altitude differences cause important ecological differentiation. Satellite views show the dense network of streams, each bank bounded with a strip of riparian forest. In the watershed of the Yucao river, forests cover some 16% of the land. The terrestrial and aquatic ecosystems of the floodplains provide valuable resources and perform important ecological functions. Inhabitants of the savanna extract timber, wood for fuel, game, and fish (Cadavid and Smith, 1995, unpublished survey results). The floodplain is essential as a dry-season source of forage and water for cattle. All water, sediment, and nutrient fluxes from the savanna run through the forest that regulates them. The stream ecosystem, with a diverse fauna including many marketable ornamental fish species, greatly depends on the forest because it is largely heterotrophic. Not only do the streams have forest on either side, but for several months of the year the streams actually overflow **through** the forest.

In the second half of 1996, we started a project on the distribution, composition, structure, and functions of the riparian forests. We chose the watershed of the Rio Yucao (about 2500 km^2), a typical *Altillanura* watershed where land use is being intensified and accessibility improved. Physiographically, the watershed represents the flat and undulated subtype of the well-drained savanna. CIAT has been working on socioeconomic characterization and on-farm research in improved pastures. The focus on forests in this project is important because of the goods and services it provides, some of which are undocumented and underinvestigated. Also, the threat to this ecosystem is likely to become severe when agricultural intensification proceeds as expected.

A digital elevation model (DEM) was created by interpolation from contour lines and altitudinal points that were digitized from 1:25 000 scale maps. The digitized rivers were used to force flow in the appropriate direction to eliminate spurious sink holes. From this DEM of 25-m grid size, we calculated the flow direction and accumulation for each cell. We calculated the drainage area contributing to river flow for each of the 29 transects used to sample the riparian forest, for the location of the flow measuring station (225 900 km^2), and for the entire watershed (227 000 km^2).

Because of the network of streams, the average distance from any point in the savanna to a stream is short. The last 20-200 m of that drainage pathway runs through forest, which therefore has a potentially important buffering function for surface fluxes of water, sediments, and nutrients. The flatness of the terrain, the dense vegetation, and the high infiltration capacity of the soil contribute to that function. On the other hand, widths of streams increase considerably because of flooding in the rainy season, thus reducing the effective pathway through the forest. Maintaining the present forest cover is therefore crucial. An increased load of sediments and nutrients would severely alter the ecology of the streams and negatively affect their species richness.

Forests have a much greater biomass than grassland ecosystems. Preliminary estimates of carbon stored in the vegetation and soil suggest that forests store 1.5-2 times more carbon per ha than does savanna. Although forests make up a relatively small part of the landscape, the carbon they store represents 25% of the total for the landscape. At landscape level, this amount is similar to the increase in carbon that might be obtained by replacing all native savanna with improved pastures (Fisher et al., 1994). Destruction of forests is a real risk if more intensive land use is stimulated, their conservation should therefore be an integral part of a sustainable development scenario for the savanna landscape.

If little was known about the amount and distribution of forests in the savanna landscape, even less is known about their composition and structure. During the 1996-1997 dry season we described species composition, vegetation structure, soil, and other environmental characteristics in 80 plots within the Yucao watershed. On an accumulated area of 3.2 ha, we found 148 species of trees with a minimum diameter of 5 cm at breast height. Many of these species are typical for this unique environment. Here the plant families with most species are Rubiaceae, Arecaceae (Palmae), Leguminosae, Moraceae, Myrtaceae, and Clusiaceae. The forest also contains valuable non-woody species, like the wild *Ananas ananasoides*.

Cluster analysis based on species composition indicated that the forests can be classified into five main types (Table 1). These different types reflect the ecological gradients between savanna grassland and streams, and the differential effect of small compared to larger streams. Compared to most forests of the moist lowland tropics, the riparian forests have low stature and biomass, and high tree density. These properties are probably related to low soil fertility and high levels of natural disturbance (inundation, erosion and deposition of sediments, and wind).

Forest type I is the *Mauritia*-dominated species—poor palm forest at the origin of streams where forests are narrow. They grow on the most fertile but waterlogged soils. The other forests are seasonally wet; type III (dry forest) does not experience inundation, types II, IV, and V do so with increasing water heights and presumably duration. Type II is transitional in the sense that it is far from the river, does not experience much inundation, but remains wet even in the dry season. The soils are relatively high in organic matter (OM) and nutrients. Types IV and V are mainly found along larger streams and rivers where they are flooded during the rainy season but the soils dry out considerably in the dry season. Despite these extremes, these are the forests with the largest basal area (excluding the palm forest) and the greatest stature. Almost half of the forests of type IV showed evidence of low-intensity, selective logging

Table 1. Riparian forest types and their characteristics[a].

Characteristics	Forest type[b]				
	I	II	III	IV	V
Distance to savanna (m)	10.00	72.00	17.00	52.00	43.00
Distance to river (m)	12.00	101.00	37.00	40.00	37.00
Area drained by river (ha)	2.00	44.00	687.00	1049.00	1649.00
Inundation level (m)	0.00	0.42	0.10	1.59	2.21
Soil water content (g cm^{-3})	0.88	0.43	0.14	0.14	0.13
Organic matter content (%)	9.10	10.10	3.70	3.50	3.30
Bulk density (g cm^{-3})	0.35	0.49	0.96	0.83	0.80
PH	4.40	4.10	4.00	4.00	4.10
C:N ratio	8.40	10.20	12.90	11.50	10.30
Mean no. species per plot	2.50	21.70	20.00	21.40	15.70
Basal area (m^2 ha^{-1})	51.00	30.00	25.00	31.00	46.00
Tree density (no. ha^{-1})	971.00	819.00	791.00	744.00	1050.00
Mean tree height (m)	9.30	9.00	9.40	10.60	10.00
Understory cover (%)	42.00	50.00	30.00	39.00	8.00
Evidence selective logging (%)	0.00	8.00	12.00	44.00	11.00

a. Data on trees refer to individuals with diameter > 10 cm at breast height. Soil data are for depths of 0-15 cm.

b. Most abundant species in forest types: I "morichal" = *Mauritia flexuosa*; II "transición" = *Vismia cayennensis, Dendropanax* sp., *Clidemia* sp., *Caraipa llanorum, Guarea* sp.; III "seco" = *Himatanthus articulatus, Alibertia* sp., *Phenakospermum guianensis, Xylopia aromatica, Caraipa llanorum*; IV "inundable" = *Hirtela* sp., *Zygia* sp., *Caraipa llanorum, Xylopia ligustrifolium*; and V "rebalse" = *Lonchocarpus* sp., sp. *indeterm., Tachigali cavipes, Calathola* sp., *Lindakeria* sp., and *Eschweilera* sp.

The different forest types show the wide range of ecologically different environments. The species that grow here resist many different types of stress and disturbance, including low fertility, drought, and inundation. The trees should not be expected to show rapid growth, but we can expect several species will be useful for rehabilitating degraded land. Forest regrowth in enclosures protected from fire and grazing has been documented in the savanna close to Carimagua (Torrijos, 1996).

Our data show that the riparian forests of the *Llanos* are unique ecosystems, different from other ecosystems of the savanna and different from nearby forests outside the savanna biome. They contain many plant and animal species, several of which are being extracted. The spatial distribution contributes to their value but also makes them vulnerable: the forest is everywhere, but in small quantities. Increased human pressure is likely to result in threatening levels of extraction of game and some tree species (those used for timber and poles). The population structure of a subset of tree species suggests sufficient natural regeneration exists within the forest, making sustainable selective exploitation possible. Heavy intervention or clear-felling will probably lead to the disappearance of forest because the conditions for re-establishment (strong water currents, sediment movement, distance of seed sources) are unfavorable.

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Activity: Pucallpa - the ecology of land-use dynamics

✓ *Ecological changes associated with land-use dynamics characterized*

The historical trend of land use in the Pucallpa region, like most other forest-margin regions, is to convert forest to agricultural lands that often end as pastures. The current landscape is a mosaic of agroecosystems without great immediate environmental problems. However, the sustainability of the different land uses is reason for concern. Timber extraction and hunting have impoverished the forests in species. Reducing the areal extension and fragmenting will cause further gradual loss of value. The Pucallpa region has many secondary forests, most being fallow lands of slash-and-burn agriculture. Although these fallows still seem to fulfil the role of restoring soil fertility, the normal fallow time-length of 3-5 years will almost certainly lead to degradation in the long term. The young fallows provide some of the services of older or primary forests, but their ecological and economic value will further decrease as fallow periods remain short and the distance to 'intact' forest relicts increases. Agricultural land with decreased productive capacity will either be abandoned or converted to pasture. The continued conversion of land to pasture as a desirable development is questionable. Monoculture pastures lead to degradation, and even the best technological alternatives (grass-legume associations) are not permanent. The use of land for pastures in this region leaves few if any options for other uses once the land is degraded; the land's ability to regenerate its productive capacity and a diverse plant community is probably lost for many years.

Our research addresses two main sets of questions. What are the changes that occur during conversion and degradation of lands under different uses, and what are the ecological properties of agroecosystems that determine their capacity to recover soil fertility and a diverse community?

Second, which are the important resources and services of primary and secondary forests, and how are they valued by the people in the region? (Reported under 3.3).

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Activity: Pucallpa – land-use strategies

✓ *Colonists' land use strategies identified and described in Pucallpa, Peru*
✓ *Tentative research needs identified by land user "group".*

We interviewed 151 farmer-settlers to understand current land-use dynamics. Preliminary informal surveys determined how respondents were stratified according to broad differences. Settlers included: farmers practicing slash-and-burn agriculture in upper forested areas, slash-and-burn farmers living along rivers, small-scale cattle ranchers with lands located largely along the road connecting Pucallpa to Lima, and a subset of forest slash-and-burn farmers who established oil palm as a cash crop. Fujisaka (1997a) describes land-use patterns and differences among these groups, and considers some of the problems and opportunities faced by each group.

Overall, Pucallpa farmers relied on rice as a major crop both for sale and consumption. Research to help solve upland rice disease problems, and those of soil nutrient depletion and increases of weeds, would benefit many farmers in the area. Working with farmers on improved fallows would also help because a high proportion of their lands is in fallow or secondary regrowth.

Upper-area farmers, who had earned income from coca production, were seeking new alternatives. Efforts to develop and promote new crops (e.g., camu camu *Myciaria dubia*) and agroindustries (e.g., palm oil) would appear reasonable. Research is needed to carefully determine *ex ante* demand for new alternatives.

Riverine slash-and-burn farmers were most concerned about diseases affecting their banana plantations (and upland rice). Research to address the problem is needed.

Cattle ranchers may have little interest in more productive forage systems as long as current pasture resources are more than sufficient, given the area's reduced herd size. Targeted work to increase systems productivity and sustainability with the few ranchers maintaining more animals per area may be appropriate.

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Activity: Effects of forest conversion, Brazil

✓ *Effects of forest conversion in terms of carbon stocks and plant biodiversity estimated*

The municipality of Theobroma (Rondonia, Brazil) covers 2165 km^2, of which 43% was deforested by 1993. Between 1973 and 1993, the national government continued to improve the highway, BR364, connecting the area to Brazil's central-southern region and established a colony in Theobroma. During this period, 98% of the deforestation occurred.

Fujisaka et al. (1997b) use data on carbon stocks gathered by the International Centre for Research in Agroforestry (ICRAF), the Tropical Soils Biology and Fertility Program (TSBF), and the Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA)-Rondonia; data on land use obtained by CIAT; and data and analysis of plant community change relative to land uses obtained by CIAT.

Some 1800 settler families continue to convert forest into pasture in a system based on slash-and-burn agriculture and dual-purpose (dairy and beef) cattle production. Carbon stocks declined from about 200 t ha^{-1} in forest to 28 t ha^{-1} in pasture; and of 326 plant species encountered in forest, only 20 remained in pastures (along with 66 species not found in forest). The impacts of converting more than 93 000 ha of forest into other uses over 20 years include approximate losses of 14 million tons of carbon to the atmosphere and substantial losses of plant species. Land-use alternatives that would store more carbon include agroforestry and—given the strong incentives for settlers to convert lands into pasture—improved pasture management or developing silvopastoral systems. Plant species conservation may be improved with proposed ways to add private value to the forest.

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1.3 Preparation of digital ecological maps at different scales (local to regional)

Activity: Compiling watershed coverages for Latin America

✓ *Continental catchment maps digitized*

This is a joint project of the United Nations Educational, Scientific, and Cultural Organization (UNESCO), CIAT, and UNEP. Over the years, UNESCO has coordinated hydrological studies of the major catchments in each country throughout Latin America. The purpose of the studies is to quantify surface water resources and establish their distribution in time and space in each country's watersheds.

The basic data were obtained through projects undertaken in each country and systematically updated every 5 years. A methodological guide enables all studies and reports to follow the same criteria. UNESCO's Regional Hydrologist coordinates these activities at the regional level.

Participating institutions included hydrology, hydraulic, and water resource centers, and national hydrological and meteorological services. The project's outputs are an evaluation of water resources, surplus or deficit, through thematic maps on: drainage networks, distribution of precipitation, evapotranspiration, and river discharge plus complementary information on parameters of the hydrological cycle.

National project maps were digitized, either manually or by scanning and vectorization of the resultant image. In certain cases (i.e., Colombia and Chile) the data were provided in digital form. We re-projected the map to geographic coordinates and plotted them to check data quality.

The maps arrived in many different scales and projections so we used the Digital Chart of the World (DCW) at a nominal scale of 1:1 000 000 as a common base map. Although problems of data quality are known with DCW, it is the only continental standard base map available. We used it to correct for projection inconsistencies at country boundaries* and at coastlines.

Because the UNESCO studies are made country by country, there is no consistency of catchment scale or delineation across country boundaries. To account for this we have had to make decisions to produce consistent catchments. Where a country boundary follows a river (as commonly occurs) we have created a new catchment owned jointly by the two countries. Problems of scale were more difficult. We have not changed the catchment scale within a country by subdividing or lumping catchments. However, when a number of small catchments flow into a larger one we have had to extend the catchment boundaries downstream. Examples of this can be seen at the Paraguay/Bolivia and Peru/Brazil frontiers.

The complete adjusted coverage will be available shortly on the CIAT www home page and ftp. Tape or CD-ROM copies can be made available on request.

The CIAT climate database was used to create interpolated climate surfaces on a grid size of 10 minutes (about 18 km)(Jones et al., 1997). The method used was inverse square distance weighting from the closest five stations. Temperatures were corrected for elevation using a standard lapse rate model (Riehl, 1979). Evapotranspiration was estimated using the method of Linacre (1977).

Mean monthly images of rainfall, maximum and minimum temperature, and evapotranspiration (48 images) were produced on Idrisi (Eastman, 1990). These are now available on ftp site:
sig.ciat.cgiar.org/outgoing/unesco/

* Any country boundary shown in this study is that taken from the DCW and does not imply any endorsement of the legal status of the boundary by CIAT, UNESCO, or UNEP.

Other files to be found in this site are: "Luz.map" and "read.me". "Luz.map" is an Imagine "map" file of a poster prepared to describe the study; "read.me" as usual contains documentation of the files currently available.

In future, CIAT will produce coverages of climate information at a precision of 30 seconds or about 1 km. These will be made available to the project as they are produced.

We have not had the chance to consult with the countries on our interpretation of cross-boundary catchments. The dataset will be maintained by CIAT staff. Any suggestions and corrections will be welcome.

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Output 2: Land use patterns and their spatial distribution classified, and correlated with environmental and socioeconomic data

2.1 Characterization and mapping of land-use patterns in hillsides, forest margins, and savannas

Activity: CIAT–CIP–INEI collaboration on the census for agricultural research

✓ *Areas mapped of land not cultivated by farmers in Peru*
✓ *Farmers reasoning for not cultivating studied*

In November 1996, the directors general of CIAT and the Instituto Nacional de Estadística e Informática (INEI) of Peru signed a letter of agreement for inter-institutional collaboration. The first phase of the agreement was completed in 1997. Crop mapping, data sharing, and project development were among the activities of the project. The two institutions have decided to continue collaborating informally with the Centro Internacional de la Papa (CIP) until a more formal plan is developed.

Research on land-use dynamics was initiated as a part of this collaboration. For the 1750 districts in Peru we mapped the areas where farmers did not cultivate arable lands because of some kind of problem (Figure 1). Because arable farming land that is **not used** is part of the land-use dynamics of a region, this information is potentially powerful for understanding farmer decision making and agricultural sector dynamics. The map has generated several hypotheses and questions about land use in Peru. Because the data is from 1993, the agricultural regions affected by terrorism must have changed. Areas affected by drought conditions are almost exclusively found on the Pacific slopes and those where farmers cited a lack of credit are clustered in several parts of the country. We are studying the causes behind the problems farmers reported. Areas of soil degradation also show some clusters on the map and will be investigated. An interesting aspect of these data is the proportion of lands not cultivated according to reasons farmers cited

(Figure 2). The proportions suggest that soil degradation is less important than might have been expected. Credit, water availability, and rural to urban migration appear to be important factors in agricultural sector dynamics. Putting these arable lands into production could boost farmer income and reduce problems of poverty in Peru.

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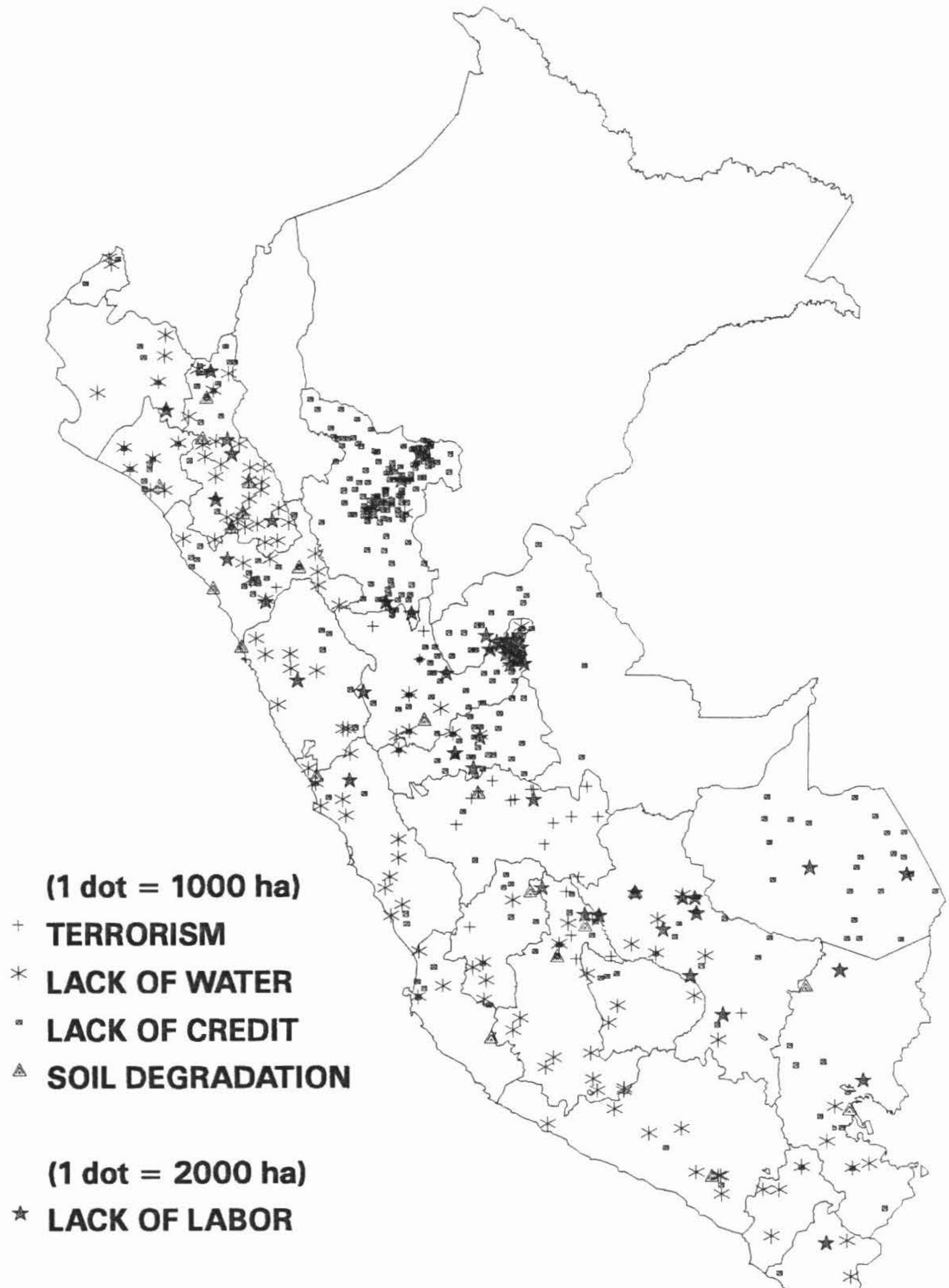

Source: Instituto Nacional de Estadistica y Informatica - Lima,

Figure 1. Arable lands not cultivated in Peru according to reasons cited by farmers.

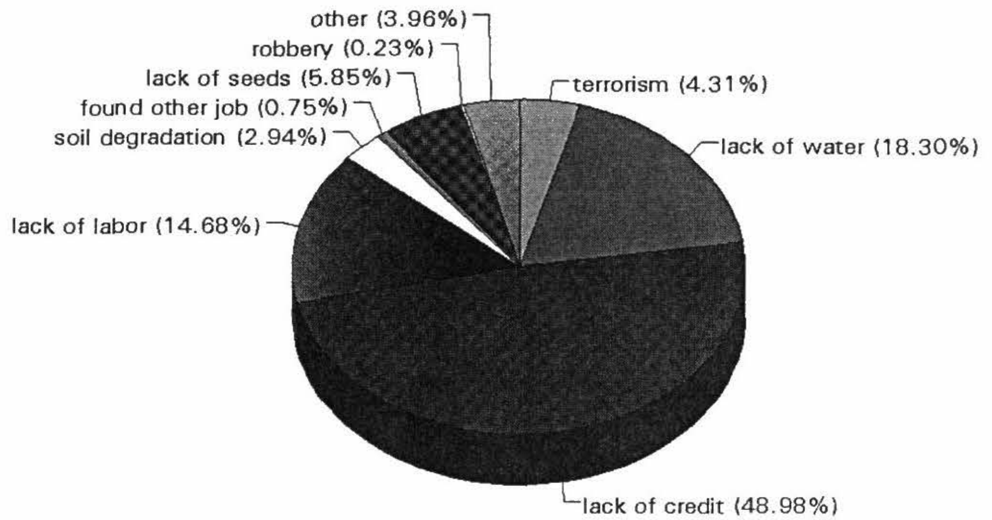

Figure 2. Reasons farmers cited for not cultivating arable lands.

Activity: Deforestation along highway BR364, Brazil

✓ *Deforestation along highway/colony swath in Brazilian Amazon analyzed*

A mosaic of 31 Japanese Synthetic Aperture Radar Satellite (JERS)-1 radar images from October 1995 was constructed to examine deforestation in the swath along the highway, BR364, and from the city of Río Branco and the colony of Pedro Peixoto in Acre, through the city of Porto Velho in Rondonia, and to the colony of Theobroma and the town of Jaru in Rondonia. Deforested areas corresponding to government-sponsored colonies, cattle ranches, and spontaneous settlements were distinguished and classified by pattern and shape.

The most deforestation was encountered in the Theobroma area, followed by Pedro Peixoto, and the cities of Río Branco and Porto Velho. The mosaic shows that much of the area between the two colonies remains forested.

The mosaic covered 117 222 km^2, of which 7885 km^2 (6.7% of the total) were classified as non-forest. Large cattle ranches accounted for 1923 km^2 (1.6% of the total and 24% of the non-forest area).

Buffers were established around the highway from Río Branco/Pedro Peixoto to Jaru/Theobroma at 0-5 km (BFR1) and 5-20 km (BFR2). The buffers covered 7168 km^2 (BFR1) and 21 824 km^2 (BFR2), of which 21.7% (BFR1) and 12.4% (BFR2) was deforested, and 5.0% (BFR1) and 2.4% (BFR2) represented clearing by large holdings (Figures 3 and 4).

Clearly, deforestation was heaviest closer to the highway, in and around the colonies, and in the cattle-ranching area northeast of Theobroma. Away from the city of Porto Velho and the colonies, deforestation along the highway was substantially less. Prior to highway construction, settlement in the region was largely along the rivers. Our analysis shows that clearing along the area's rivers was relatively minimal.

Deforestation was heaviest where highway and colony combined. Where there was highway but no colony, clearing was much less—although deforestation did take place along the highway. Of the deforestation in the mosaic, 54% took place within the two buffers (i.e., within 20 km of the highway).

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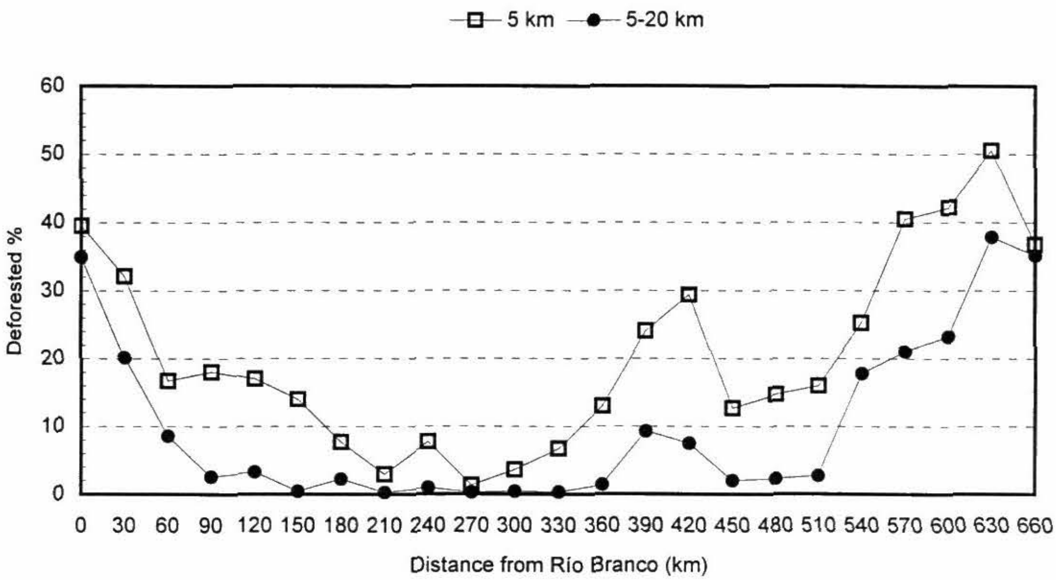

Figure 3. Percentage of deforestation along BR364 from Rio Branco/Pedro Peixoto to Jaru/Theobroma, Brazil, along 0-5 km and 5-20 km buffers.

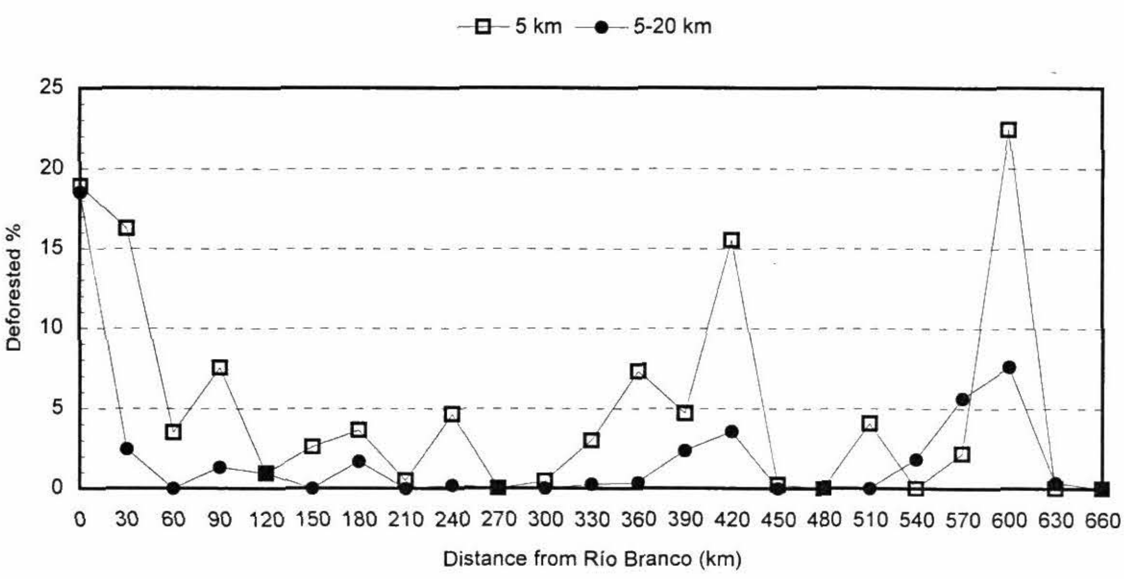

Figure 4. Percentage deforestation by large-scale cattle ranches along BR 364 from Rio Branco/Pedro Peixoto to Jaru/Theobroma, Brazil, along 0-5 km and 5-20 km buffers.

2.2 Implementation of digital maps of land use, environmental degradation, and poverty for Latin America

Activity: Crop distribution mapping for Latin America

✓ *Database of crop production developed for Latin America*

Maps for crop distributions are critical for commodity studies, agroecological modeling, and numerous environmental applications. The most basic need is to know how many hectares have been cultivated, where cultivation has occurred, and how much food has been harvested. As part of the project's goal of analyzing land-use patterns and dynamics, we have developed a database of crop production for Latin America. The database has numerous uses for agricultural research. For scientists of the Consultative Group on International Agricultural Research (CGIAR) and our National Agricultural Research Systems (NARS) partners, crop distribution mapping can help guide our crop improvement programs by helping breeders understand the relationships between crops and the environmental constraints in which they are grown.

We initiated a program to improve our contacts with crop data providers, update our previous crop distribution maps, map new crops, and automate the process for future updates. This year, our focus has been on database development and automated mapping of crop distributions. We have obtained the most recent crop distribution data at the best available geographic resolution for the 21 mainland Latin American countries (Table 2). All the information must be carefully studied to assess its comparability from one country to the next. Various difficulties have to be overcome, for example, different types, dates, and details of data. We are investigating data quality problems in our efforts to reduce errors and provide metadata. We have linked over 75% of the tabular crop data to the third-level administrative division maps (Jones and Bell, 1997). So far, our efforts have focused on the principal crops of the region and those of particular interest to the CGIAR system. However, this project has looked at the broad range of crops to take a more comprehensive view of the agricultural sector in Latin America. We have gone far beyond our previous focus on CGIAR core crops.

Table 2. The CIAT crop distribution database.

Country	Administrative level	Year of accession	Number of crops	Collection method
Central America:				
Belize	Department	1994	42	Census
Costa Rica	Country	1993-95	14	Sample
El Salvador	Region	1994	7	Sample
Guatemala	Department	1989-95	6	Sample
Honduras	Municipality	1993	63	Census
Mexico	Municipality	1991	78	Census
Nicaragua	Department	1995	9	Sample
Panama	Municipality	1990-91	17	Census
South America:				
Argentina	Department	1991	6	Census
Bolivia	Municipality	1987-95	20	Sample
Brazil	Municipality	1993	62	Census
Chile	Department	1979-94	40	Sample
Colombia	Department	1993	26	Sample
Ecuador	Region	1991-93	93	Sample
French Guyana	District	1994	9	Census
Guyana	Commune	1993-94	19	Census
Paraguay	Department	1995	35	Sample
Peru	District	1993	229	Census
Surinam	Municipality	1990-91	44	Census
Uruguay	Department	1993	61	Sample
Venezuela	Federal District	1984-85	25	Sample

Contributors:
Glen Hyman
German Lema

Activity: Raster modeling for geographic analysis and improving crop distributions within administrative units

- ✓ *Intercenter collaboration – ecoregional services*
- ✓ *Developing methods of automating distribution mapping*

The choropleth data structure of the CIAT crop database is optimum for handling large amounts of crop data but is deficient for many other purposes. It can store information for the administrative unit but cannot display the distribution of crops within the unit. Formerly, our methods to locate distribution within administrative units have relied on the subjective interpretation of the map technician, who uses own knowledge of the crop environments and map interpretation skills to produce vector point data. The method is useful and will produce accurate maps for the scale of the project. However, this manual method suffers from two important limitations. First, the subjectivity of the work may limit the data for purposes of comparison, especially if different technicians work on the same map or if using time series maps. Second, the technique is time-consuming and therefore limited by the human resources that can be assigned to do the work.

An even more critical limitation of the choropleth format is its insufficiency for modeling purposes. Perhaps as much as 90% of spatial analysis and modeling is carried out using raster data structures. We have thus recognized the importance of redistributing the vector data to a raster format. We carried out some preliminary work on this last year and have now developed the first modeling results. This type of conversion has not been attempted for agricultural crops. However, Uwe Deichmann (1996) has developed vector-to-raster redistribution models for population data as part of the UNEP/CGIAR initiative on the Use of Geographical Information System (GIS) in Agricultural Research. We are using a similar approach, tailoring the work to crops instead of population.

Our first efforts to improve crop distribution information within administrative units have focused on using a continental-scale, land-cover map and an accessibility map (Figures 5A and 5B). The United States Geological Survey (USGS), together with the UNEP-Global Resource Inventory Database (GRID) project, developed the continental land-cover map. The source data are from advanced very high resolution radiometer (AVHRR) satellite imagery at 1-km spatial resolution—appropriate to continental-scale analysis. In 1996, CIAT provided some of our crop and land-cover datasets for USGS to verify. We continue to work with USGS in their efforts to improve the quality of these data.

To better estimate the distribution of crops within an administrative unit, we used accessibility information on the assumption that crops are more likely to be cultivated in conjunction with the road networks that allow transport to storage facilities and markets. This basic assumption has a rich history in the geographic literature (Chisholm, 1979) and we employ it here as a first approximation expecting to refine our methods in the future. Eade (1997) developed the accessibility map using a cost-distance approach. The map uses the DCW road network and map of populated places (Defense Mapping Agency, 1994). Towns with a human population of 10 000 or more are assumed to have maximum accessibility and are represented by individual grid cells on the digital map. For all roads and trails a travel velocity is assumed. The roads are organized in a hierarchy so that highways and paved roads are assigned higher velocities than dirt roads or trails. Areas far from populated places are less accessible than areas near to towns. For each grid cell, the time that it takes to reach a town is calculated using distance and cost functions. These tools are widely available in standard GIS software packages (e.g., Idrisi, GRID-Arc/Info). The resulting map gives us an index of accessibility for the study area.

The vector to raster conversion of the crop data is carried through in two phases. First, all areas in forest from the USGS land-cover map are assumed to have no cropland, effectively masking these areas out during future processing. Second, the total crop area is redistributed within the administrative unit based on the accessibility index, which is transformed into a municipality level potential surface by dividing the value at each grid cell by the sum of the indices within each municipality. This is a simple way of weighting areas according to their ease of access to urban areas. The weighted potential surface is then combined with the crop data to estimate the distribution within municipalities (Figures 5C and 5D). The method still falls short of the results obtained by the individual technician making subjective judgements about where crops are cultivated.

The processing described above has been automated and developed with a graphical interface that allows a user to select a country and a crop for mapping (Klass, 1997). The programs are then run, making a new point dataset for display and further analysis. Users can choose the thresholds for displaying the density of crop production. This interface effort is in its opening stages. Any of the crop data shown in Table 2 can now be processed to produce maps such as the one shown in Figure 6. The map of maize distribution, and a similar map of wheat distributions, are CIAT's first maize and wheat maps (Hyman, 1997). Maize experts in the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT) are evaluating the map and its associated data. They have high expectations of using this information for crop improvement and economic analyses of their core crops.

The crop and livestock mapping efforts are slated to become key datasets for several collaborative projects already underway. The crop production dataset will be used as a variable in the CIAT-UNEP indicators project. The International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) has contacted us about developing a project on the agroecology of chickpeas in Latin America. They are interested in these data for their other core crops also. The International Livestock Research Institute (ILRI) is interested in livestock information for their projects in Latin America. We will use the data for a study of crop distributions of Latin America, an investigation along the lines of some of the classical agricultural regionalization work carried out for North America.

A most important aspect of our crop and livestock database efforts is institutionalization of the work. We will be able to analyze agricultural land use in a timely manner, at higher frequencies, and with an expanded view of the crops of Latin America. This implies continued core commitment. Datasets may be created by special projects, but their maintenance will not be funded by short-term donors.

<u>Contributors:</u>
Glen Hyman
Peter Jones
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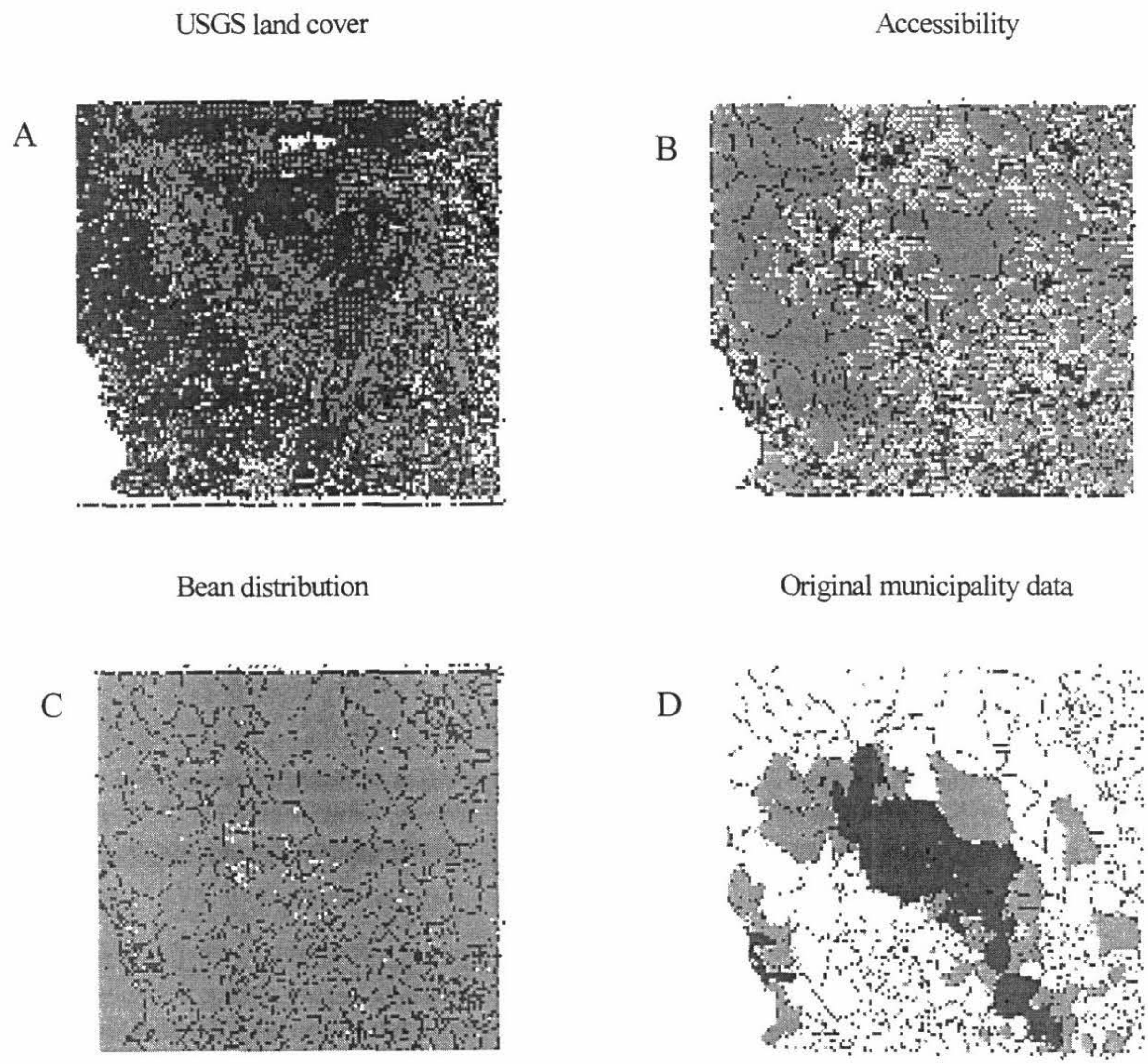
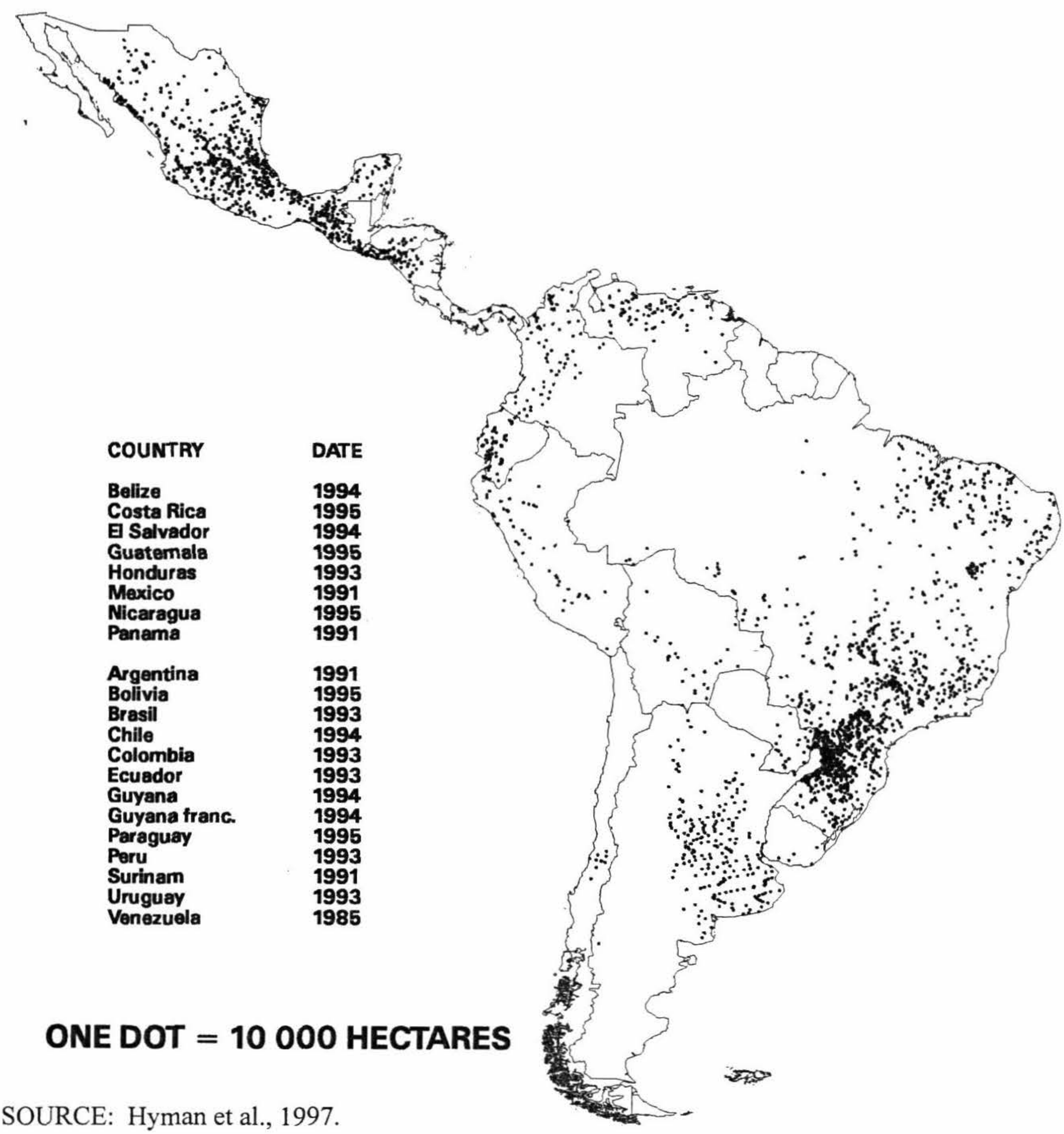


Figure 5. Land-cover and accessibility information used to redistribute crop production data within municipal units.



SOURCE: Hyman et al., 1997.

Figure 6. Maize in Latin America.

Activity: PE4-Whitefly collaborative project

✓ *Map of distribution of bean golden mosaic virus in Central America produced*

We have mapped the distribution of beans in relation to the known occurrence of bean golden mosaic virus (BGMV). This is a simple application with potentially huge benefits. Researchers working on BGMV can now define critical areas of bean production that the virus is affecting, and those areas that should be protected from future infestation. Once the production and virus data are related to the physical and human geography of bean growing regions, whitefly researchers can better understand the behavior of the virus, especially with respect to its spatial diffusion.

Contributors:
Glen Hyman
Justine Klass

Activity: The CIAT population database for Latin America

✓ *Population map for mainland Latin America produced*
✓ *Types of population mapping compared*
✓ *Cost-distance model developed*

In 1997, we completed most of the database and carried out vector to raster modeling of population. The principle data for the population project are the geographic boundaries of Latin American municipalities and the population figures. The municipal boundary file was digitized from maps from each individual country (Jones and Bell, 1997). We collected the population data from a variety of sources, including census documents, unpublished data obtained from government institutions, and information downloaded from the Internet (Hyman and Jones 1997, unpublished data).

Figure 7 shows the first population map we produced for mainland Latin America. This map displays points proportional to the population of the municipal administrative unit. The population database holds figures for over 10 000 administrative units in Latin America. On this map we only displayed points for municipalities with over 10 000 people. The points are drawn using an exponential scale to better represent the distribution across municipalities. So far, we have only found minor errors. In some cases, to correct these we will have to visit the national information agencies that provide the data. The major consideration for updating the database will focus on incorporating changes in administrative boundaries. Additional funding will be needed to obtain the population data for the Caribbean region.

Interest in the social and demographic aspects of environmental change and agricultural transformation has been growing steadily. At the same time, many demographers and population geographers have embraced GIS. This has led to some studies and initiatives at various scales that focus on population modeling in a spatial context (Goodchild et al., 1993; Flowerdew et al., 1991; Langford et al., 1994; Moxey and Allanson, 1994; Tobler, 1979). In many countries, demographic and socioeconomic data are often only available at fairly aggregate levels. These polygonal units vary greatly in areal and population size, and contain considerable variation from national means. Clearly, this level of available detail, or geographic scale, is often insufficient for modeling purposes (Deichmann, 1996). Where the main purpose of a population density map is to convey an accurate impression of density distribution, the conventional choropleth representation is not always the best choice. It encompasses many problems including: incompatible spatial resolution of the reported data, arbitrary units with false discontinuities, and difficulties in selecting and representing classes (Langford et al., 1994).

Approaches to the problem of estimating population distributions within administrative units can be divided into two categories, boundary-changing and boundary-removing transformations. For example, in cases where political boundaries have changed over time, or where population can be redistributed within each administrative unit by including ancillary data (e.g., classified land-use imagery) boundary-changing transformations are required. Boundary-removing interpolations are applicable where the distribution within the unit is modeled explicitly by creating a more-or-less continuous surface, usually involving some mathematical models or assumptions that are represented by a high-resolution raster grid.

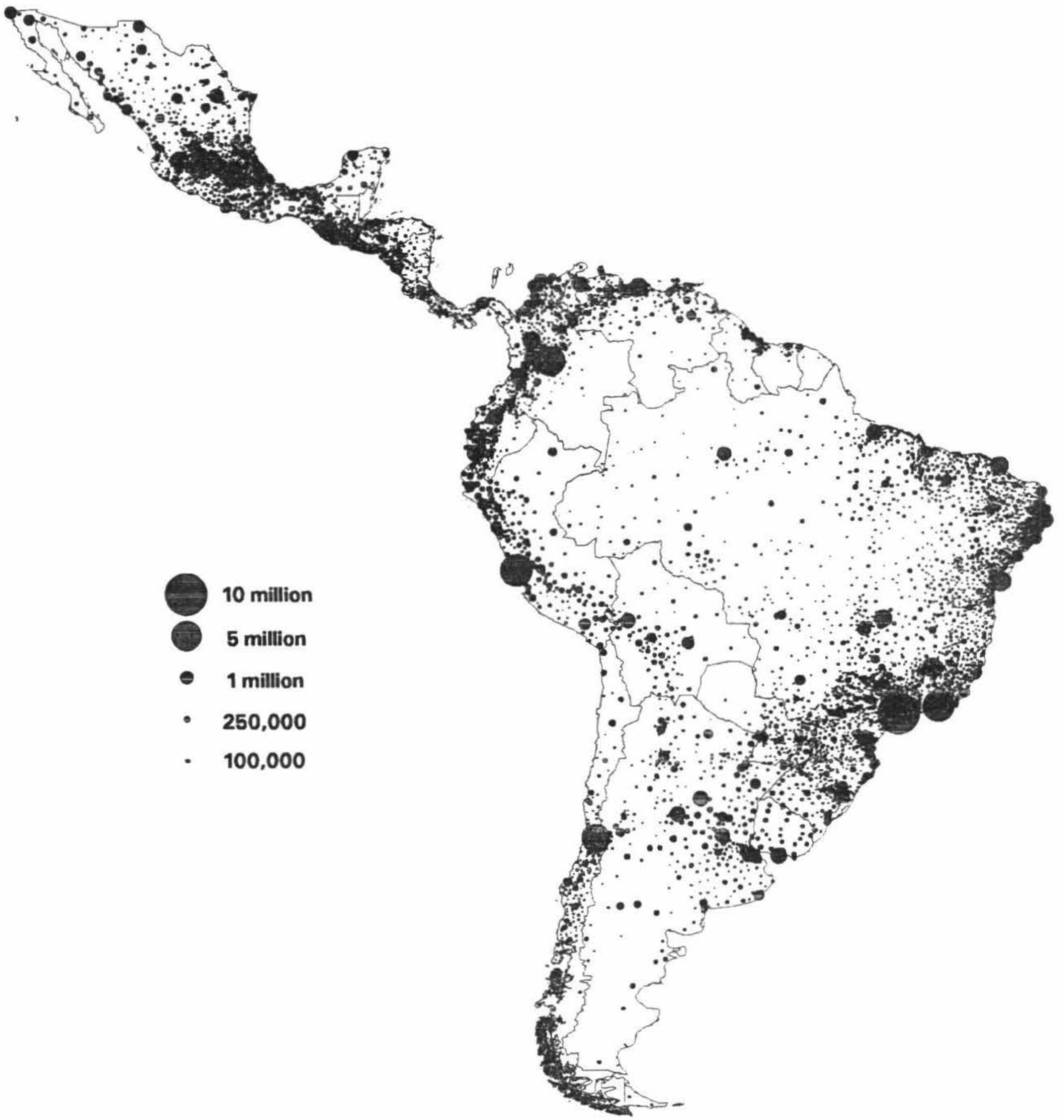


Figure 7. Population of Latin America.

As part of the CIAT population project we have attempted to clarify and review some procedures to prepare alternative population density models at two geographic scales—continent-wide municipal (third administrative) level, and countrywide township (fourth administrative) level.

We compared traditional mapping methods against those using ancillary data, and against those using statistical assumptions about the population distribution. We then evaluated the methods and the suitability and limitations of each technique. Finally, we have considered some further modifications of these models that would again improve the accuracy of the population distribution.

Table 3 shows a classification of the various modeling and visualization techniques that we have applied to population data. The methods here discussed are the last two in the table. We obtained ancillary data for the project from well-known datasets commonly available, the transportation network from the DCW (Defense Mapping Agency, 1994), and the night-time imagery from the National Oceanic and Atmospheric Administration (NOAA) (Elvidge et al., 1997).

Table 3. Selected methods for modeling population density.

Method	Input data	Data type	Complexity	Ancillary data
Choropleth map	Polygon cover	Municipal: areal	Simple	None
Proportional circle	Point cover	Township: points	Simple	None
Pycnophylactic interpolation	Polygon cover	Smooth surface	Moderate	Smoothing algorithm
Urban areas defined by:				
night-time imagery	Point cover	Surface	Complex	Night images and city-size estimate equation
cost-distance model	Point cover	Surface	Complex	Transport cover and model

The simplest empirical relationship between a city's population and its surface area can be expressed as:

$$ln\,A = ln\,a + b\,ln\,P$$

Where A is the area of the city, P is its population, and a and b are unknown constants. By using night-time imagery to define urban areas and hence estimate their size, we can perform a regression analysis to extrapolate rural town area given a population figure. The next stage is to assume a population density model within the city area. This is typically a negative exponential function of the form:

$$D = Ae^{-br}$$

Where D is the population density, r is the distance from the city center, and a and b are unknown constants. In this case we have assumed a normal (Gaussian) distribution for population within urban areas, and a normal distribution about a point for rural areas.

The assumptions we make here are: only urban areas (defined as those having electricity for lighting) are visible in night-time imagery; and population settlements have a normal distribution about their center.

A simple way to improve population distributions within municipal boundaries is to assume that population is directly related to accessibility. We would expect that more people live in areas where road networks are dense and fewer people live where there is little development.

Therefore, if we have information on road networks in relation to urban areas we can use these data to estimate populations within a municipality. We applied this assumption to the Latin America population data by using an accessibility surface to redistribute municipal populations within their administrative unit.

The methodology requires the use of an accessibility surface, a map of populated places, and the population data. The accessibility surface was based on towns with over 10 000 people and the road network from the DCW (Eade, 1997). The surface is modeled by assuming **expected** travel times over roads and all areas that are not roads. Movement is faster over paved roads compared to gravel roads or trails. This method is common and algorithms for cost-distance analysis exist in many software packages.

To redistribute the population for each administrative district we used the following equation:

$$\Sigma (A_{ij} / A_k) \times P_k$$

Where A_{ij} is the accessibility for each cell ij, A_k is the sum of accessibility inside the administrative unit k and P_k is the population within the administrative unit k.

We summed the accessibility values for the raster cells of each municipality. Next, we divided each cell by the total for the municipality to give an accessibility potential throughout the municipality. The potential surface is then multiplied by the population surface to produce the accessibility map.

The methods used in this project incorporate ancillary data and statistical models to characterize the population. Each method presents advantages and disadvantages depending on: scale or geographic resolution of the data, ancillary data available, and distinct factors of location.

Each of the types of maps has its own advantage or disadvantage for communicating information about population and for use in a geographic model. The thematic map shows the data in their simplest format, but does not indicate population distribution within administrative units. This format is less suitable to geographic modeling. The cost-distance model improves the population distribution based on the transportation network. Clearly this method improves upon the thematic representation, although verifying its quality is difficult without a detailed case study. The Gaussian model made with night-time imagery appears to give a better representation of urban areas. This representation is much more intuitively appealing from a visual point of view.

There are two serious difficulties related to transformations of these datasets in a GIS. First, GIS transformations produce effects that have direct implications on the data quality. For example, the sum of all values in a raster surface may be different from the source data from which it was derived. Second, GIS literature and software documentation lacks in-depth discussion of transformation effects, nor does adequate information exist on controlling the transformations.

Many processes alter the statistical and geometric properties of the digital map. Often users must make important decisions regarding the selection of an algorithm or transformation. These choices affect the data quality and precision. Rarely does the analyst have sufficient information about the consequences of the choices. In all cases we need to evaluate the models to determine if the data satisfy the requirements of a given application.

Contributors:
Glen Hyman
Peter Jones

2.3 Perform quantitative analysis of potential sustainable land use for the ecoregion

Activity: Stochastic rainfall modeling

✓ *Way to interpolate parameters found*

We noted (Jones and Thornton, 1993) that the simple Markov processes used for the temperate regions were inadequate for the tropics. It turns out that the third order Markov model that we produced can cover both types of climate. A Markov rainfall simulator can be used to provide simulated data for running dynamic crop models and, most importantly, estimate climate risk.

A drawback to using a stochastic simulator is that it requires a long run (usually 20 years or more) of historic daily data to calibrate the model. If we have these data then we can use them directly. Why go through the procedure of fitting the model? The crucial point therefore is to be able to derive the model coefficients for any point even when historic data are not available.

Our model requires an impressive list of coefficients. These include 12-monthly probit baseline parameters, which we denote β; and 12-monthly standard errors on a 12 x 12 correlation matrix for the annual resampling, which brings annual rainfall variance up to the expected value. We need 12-monthly shape parameters (*p*) and 12-monthly means for the gamma distribution of rainstorm size (*av*). The other parameters are the probit lag parameters (*d*) to include the effects of the preceding days.

Although daunting, the list can be calculated from relatively simple, spatially interpolated data. Research into the hidden structures within the parameter set has paid off handsomely. Jones and Thornton (1997) show some of the spatial and temporal relationships within the model parameters. We showed the advantage of being able to make time plots of critical model parameters. The information revealed was much more than from simple plots of precipitation.

However, the most important result was that similar climates, no matter where they were in the world, showed similar patterns of parameters.

$$12\,\beta + 12\,av + 12\,p + 121\ covariance + 12\,se + 3\,d = 183\ parameters$$

The model does, however, contain some really useful, deep-structured redundancies. This year we found one of them. Based on work done in 1983, we have found a way of eliminating 12 parameters and forcing the model to reproduce the original rainfall totals from the site being estimated.

To understand this we need to go into the workings of the model, which works in two parts: one decides whether today will be a rain day, the other decides how much rain should fall. There is a hidden link between the two parts. A triad is a binary form of three digits denoting rain on each of 3 days. Thus 101 means it rained yesterday, it did not rain the day before yesterday, but it did rain 3 days ago.

Within the model, there are two classes of probability. One shows the probability of rain today. The other shows the probability of today being in a certain triad state.

$\Phi^{-1}(\beta + d_1 + d_2 + d_3)$ gives the probability of rain today (the model coefficients are all calculated in probit space, - Φ^{-1} is the function that retransforms them to ordinary probabilities).

We can write a transition matrix that governs the relationship between these two types of probability.

(state)

$$p = \left(\begin{array}{cccc:cccc|c}
000 & 001 & 010 & 011 & 100 & 101 & 110 & 111 & \\
1-\Phi^{-1}(\beta) & & & & 1-\Phi^{-1}(\beta+d_3) & & & & 000\\
\Phi^{-1}(\beta) & & 0 & & \Phi^{-1}(\beta+d_3) & & 0 & & 001\\
 & 1-\Phi^{-1}(\beta+d_1) & & & & 1-\Phi^{-1}(\beta+d_1+d_2) & & & 010\\
 & \Phi^{-1}(\beta+d_1) & & & & \Phi^{-1}(\beta+d_1+d_2) & & & 011\\
0 & & 1-\Phi^{-1}(\beta+d_2) & & & & 1-\Phi^{-1}(\beta+d_2+d_3) & & 100\\
 & & \Phi^{-1}(\beta+d_2) & & & & -\Phi^{-1}(\beta+d_2+d_3) & & 101\\
 & & & 1-\Phi^{-1}(\beta+d_1+d_2) & 0 & & & 1-\Phi^{-1}(\beta+d_1+d_2+d_3) & 110\\
 & & & \Phi^{-1}(\beta+d_1+d_2) & & & & \Phi^{-1}(\beta+d_1+d_2+d_3) & 111
\end{array}\right)$$

It looks as if we cannot do much with this matrix until we realize that we can apply some simple constraints to make it positive definite.

Thinking about the possible triad sequences produces the answer. We write s_{000} as the state of the system when no rain has fallen for 3 consecutive days. The frequency of $s_{110} = s_{011}$ and that of $s_{100} = s_{001}$. Prob (s) sums to 1 and prob (outcome) sums to 1. Adding alternative rows of the matrix eliminates four rows. We can therefore apply these restrictions by adding in four rows to the matrix. This then becomes positive definite and has a viable inverse. Thus we have a reliable algorithm to pass from state probabilities to rain-day probabilities. This is the breakthrough we needed.

Calculating the average storm size (*av*) now requires only the baseline probabilities and the lag parameters. The rain-day probabilities are found by summing s_{001}, s_{011}, s_{101}, and s_{111}. Eliminate 12 unwanted degrees of freedom and we can restrain the model to simulate reality.

How do we fit the model to global climates? We noticed long ago that the model parameters were specific to classical climate types. We looked at them in groupings formed by the Holdridge (Holdridge, 1947) and the Koppen (Koppen, 1918) classifications. There were signs of a pattern.

Over the years we have been collating data. At the start of the work, in 1981, data were only available for five stations, but they constituted the proving ground. From the structure we found in the data it was obvious that a clustering of global climates would help to identify the correct parameter values. Late in 1996, we processed data from about 1200 stations. The patterns were there. We have worked over the last year to get data from 6221 stations worldwide. Because our model applies to temperate regions as well as tropical (see above) we have been catholic in our approach to accepting data. We have even processed data from bases in Antarctica, but because this implies no extra cost why should we not attempt to push the limits of the model?

We cluster the data using a simple leader algorithm. The climatic distance measure is calculated by rigid rotation of the climate data (on the rainfall record) to eliminate the first phase angle of the 12-point Fourier coefficients represented as vectors for the six frequencies. Monthly mean temperature and diurnal temperature range are rotated through the same phase angle (Jones and Thornton, 1997). The data are standardized to zero mean and unit variance and a simple Euclidean distance measure is calculated.

The leader algorithm produces cluster seeds sequentially as observations fall outside existing cluster limits. A final pass reallocates observations to the nearest cluster seed. This is necessary because observations may have been attached to a seed before a closer seed was formed. In practice, about 10% to 20% of observations are reallocated.

We trimmed the cluster limits until we obtained a reasonable number of tight clusters. We chose a limit that gave 718 clusters. For each of these, we prepared a dataset including station name, latitude, longitude, elevation, and the monthly mean climate data along with the parameter values to be estimated. In many clusters, the parameter values were well approximated by the mean for the cluster. However, we put all cluster datasets through a stepwise regression procedure including the squared terms of the basic monthly data and the raw data.

In the main, the regression procedure proved to be highly efficient in estimating the model parameters. We need more data to cover regions in the tropics for which our calibration depends on distant stations.

We are almost there. In the next 2 months we will have a tentative release of the software and databases for Latin America and Africa. These will go out to colleagues who will evaluate the discrepancies and errors that are surely there. We hope that this initiative, started 16 years ago in

CIAT, can come to fruition with a feedback from the scientists in CGIAR centers and national programs throughout the world.

Contributors:
Peter Jones
Philip Thornton, International Livestock Research Institute (ILRI)
Humberto Becerra

2.4 Identification of critical situations and major opportunities for sustainable land use

Activity: Using radar imagery to assess the presence of improved pasture systems and to detect degradation in savannas

✓ *First images identifying degraded areas*

To improve the management of the Colombian lowland savannas, we must develop methodologies for monitoring this environment. The study area is located in the Colombian lowlands, Meta Department, and encompasses the *municipio* of Puerto Lopez, between the cities of Puerto Lopez and Puerto Gaitán. The Meta River limits the study area to the north. Acquiring clear optical imagery is difficult because of cloud cover and the haze produced by burning native pastures, a situation typical of the humid tropics. Even when a clear image can be acquired in the dry season, a single optical image is of limited use in drawing a complete picture of the type of pastures and their levels of degradation. Contrasts between improved and native pasture can diminish because of generalized water stress. The burning of native pastures can erase differences between degraded and healthy pastures. Combining images acquired during different parts of the year is desirable, but during the rainy season acquiring optical imagery is virtually impossible in the Colombian lowlands.

These problems decided us on exploring the possibility of using radar imagery to help distinguish between land uses in the study area. Radar sensors can acquire images through cloud cover, thus allowing multiseasonal studies. For this application, we chose to use images from the Canadian RADARSAT satellite, using C-band (with a wavelength of 5.6 cm). We wanted to study the possibility of using multiseasonal radar images from RADARSAT together with electro-optical imagery to distinguish native from improved pastures, and to identify areas of severe degradation within each of these two types of vegetation. Here we present the first results of the study of two RADARSAT images acquired near Puerto Lopez, on May 2nd and May 26th, 1997. This research constitutes CIAT's participation in the Colombian chapter of the Canadian GLOBESAR-II project, developed by the Canada Centre for Remote Sensing.

The RADARSAT images acquired in May are in the ascending S6 mode, covering most of the study area. The May 26th image was planned to be the only image to be acquired during May. Radarsat International, the company commercializing RADARSAT images, acquired the May 2nd image as a backup in case acquisition or processing of the later image should fail. Because a rainstorm occurred on the evening of May 26th, we decided to request the May 2nd image for comparison purposes. The Santa Cruz meteorological station (4° 09′ N, 73° 11′ W, 230 m) measured 63 mm of rain on May 26th, and no rain on May 1st and 2nd. As complementary information, we are using a Landsat-TM half-scene acquired in January 1996, which has a cloud cover of about 20% and is affected by haze. Although we are planning to purchase an additional TM image, this one allows us to make general observations on the possible combined use of electro-optical images for monitoring the area.

We synchronized field measurements with the acquisition of the May 26th image. Field recognition and measurements began on May 23rd and extended to June 20th. We chose to make detailed observations on a limited number of relatively homogenous plots and on relatively flat terrain. We studied 14 plots in the *serranía* and over 40 plots in the *altillanura* landscape. The corners of the plots have been measured with a 12-channel, hand-held global positioning system (GPS).

Observations taken for each plot include identification of land use, description of the dominant species, measurements of vegetation height, evaluation of ground cover by dead and live vegetation, qualitative evaluation of soil roughness, orientation of periodic features, and a qualitative evaluation of the soil's drainage capacity. For each field, we took five samples of vegetation biomass, each for a 1 m x 1 m area, from which we measured moist and dry biomass. For bare soils, we made a more quantitative evaluation of roughness. We measured maximum and average size of soil aggregates and maximum variation in height, and estimated the standard deviation of height. We also measured the distance between both ends of a fixed-length chain laid on the ground, to follow the soil's irregularities. The short distance is an indicator of roughness that can give a strong signal to the 5.6 cm radar. On the evening of acquiring the May 26th image, we took five samples of the first 5 cm of the soil surface in each of 14 plots, for which we calculated the volumetric and gravimetric soil moisture. For all studied plots, we complemented observations with numerous photographs.

We took ground control points to georeference the image to the local projection, using vectors of the stream network digitized from 1:25 000 scale maps. Instead of georeferencing the images, we projected the polygons of the plots onto the image geometry. This allowed image parameters to be extracted while avoiding the effect of resampling on image radiometry and variance. We calibrated the images using the gain values and the geometric parameters included in the image header files. The average and standard deviation of the backscattering power was calculated for each plot and for each image, and the averages then converted to decibels. For this stage of the analysis, the images were not radiometrically corrected for the effect of topography. We chose the plots in the flattest areas possible, but some have a slight inclination so a topographic correction would be necessary to develop more precise relationships between backscatter and vegetation parameters.

Most of the native savanna plots appear darker than the improved pasture, except the ones presenting high grass growth or invasion by shrubs. The darker tone of the native savanna is attributed to finer leaves and stems, and to lower biomass in many cases. Because most native savannas are burned each year (although a delay of 14 months is recommended to allow all species to flourish) we expect that acquiring a multitemporal radar image would allow us to distinguish native from improved pastures. In addition to tone, improved pasture plots in the flatter *altillanura* sector present smaller rectangular shapes whereas the native savanna areas are often larger and present irregular boundaries, although exceptions occur. In the more dissected *serranía*, improved pastures are often introduced in the narrow valleys and their limits follow the landscape rather than geometric alignments. We have limited our test plots in the *serranía* landscape to flatter and higher areas, and expect that radiometric variations caused by the slope will complicate identifying improved pastures with radar in this area.

Identifying degraded areas is more complicated. In improved pastures, mismanagement can either result in loss of vegetative cover, caused by overgrazing, or in invasion by shrubs and native savanna species. The latter can be caused by undergrazing, in which case transitional vegetation starts to develop. It can also be caused by a lack of fertilization. Although shrub and weed-invaded pastures are expected to appear brighter than poorly covered plots in a radar image, the overgrazed, improved pasture fields appeared bright in both radar images because of the presence of clumps of grass and the roughness of the soils. The role of electro-optical images such as those from Landsat TM will be important in assessing pasture degradation; radar imagery will be a useful complement.

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Activity: Using JERS-1 SAR images to locate weaknesses in the riparian forest in the tropical lowlands of Colombia

✓ *Environmentally critical areas identified*

We used remote sensing to determine the distribution of riparian forests. A supervised classification of a 1996 Landsat TM image yielded a forest cover of 16% for the Yucao watershed. We are analyzing radar images taken in 1997, which are particularly useful for delimiting forest boundaries and possibly forest types. Apart from the percentage cover of forests in the landscape, describing and quantifying their distribution is important. Spatial analysis shows that forests are indeed limited to a narrow strip along the streams, where forest cover is still almost continuous. An interruption of forest cover immediately leads to fragmentation, with the risk of isolating plant and animal populations leading to a loss of biodiversity. Forest width is in many cases less than the 30-m-wide strip on either bank that Colombian legislation requires to protect streams (Beaulieu et al., 1997). Although part of this is probably because of limitations that the soil conditions and fire management impose, the legal width could be useful in enforcing the preservation of the riparian forest's continuity.

This study aims to locate sections where the riparian forest is either discontinuous or excessively narrow, in an area of savanna dominated by livestock agriculture. Our study area is located south of the Meta River, between the cities of Puerto Lopez and Puerto Gaitán, in the Meta Department, Colombia.

The L-band (wavelength of 23.5 cm) used by the Synthetic Aperture Radar (SAR) aboard the JERS-1 satellite provides excellent contrast between forest and either natural or improved pasture, independent of cloud or haze from burning. Two SAR images, acquired in March 1996, were georeferenced to an ARC/INFO database of the area containing streams digitized from

1:25 000 scale topographic maps, derived from aerial photographs. The National Space Development Agency of Japan (NASDA) made the SAR images available to CIAT for research purposes, under the Global Rain Forest Mapping Program. For the analysis of the narrow rivers draining the study area, a study buffer with a total width of 87.5 m, corresponding to 7 pixels of the JERS-1 images, was derived from the watercourse vectors, to examine an area slightly wider than that required for protection. A median filter was applied to the image mosaic to reduce speckle (a grainy noise typical of radar imagery); the image was then classified into forest and non-forest. Pixels of non-forest falling into the study buffer constitute the areas that potentially need reforestation, and that should be ground-checked.

Figure 8A shows a close-up of the unfiltered JERS-1 SAR image over an area of 6.4 km x 6.4 km southwest of Puerto Gaitán; the riparian forest appears bright. Figure 8B shows, in black, the areas potentially needing reforestation, overlaid onto the filtered SAR image, only shown in the 7-pixel-wide strips following the river courses. Areas not falling into the study buffer areas appear in white. Clusters of black on the extremities of streams are critical, because they show areas that allow contamination and sedimentation to directly enter the stream network. In Colombia, farmers can benefit from economic incentives for reforestation. The Corporacion Colombiana de Investigación Agropecuaria (CORPOICA), the national institution in charge of agricultural development, will use the results of this study to focus reforestation and conservation initiatives towards the most environmentally critical areas.

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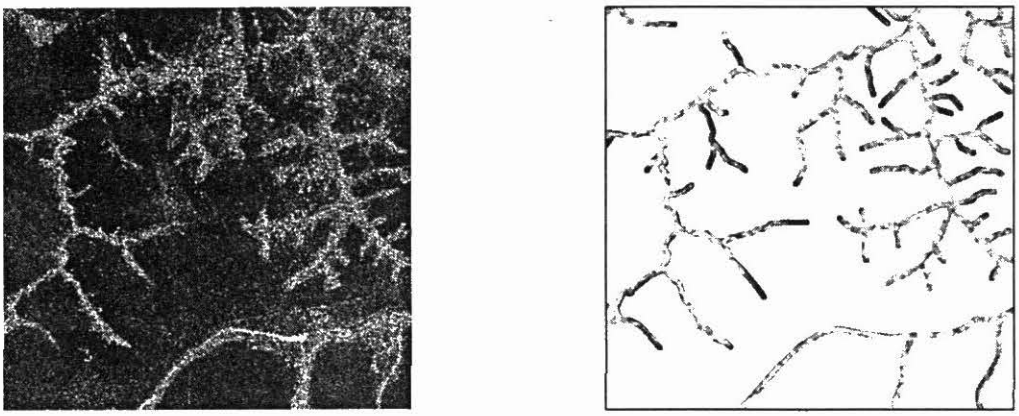

(A) (B)

Figure 8. Close-ups of the unfiltered JERS-1 SAR image with riparian forest (in A) appearing bright and areas (in B), potentially needing reforestation, showing black.

Output 3: Determinants, dynamics, and impacts of land use in Latin America characterized and strategic options assessed

3.1 Development of holistic framework for understanding land dynamics in Latin America

Activity: Gathering and management of information

✓ *Electronic databases available on request*

We completed bibliographic searches of both peer-reviewed and gray literature on: complex systems, definitions of sustainable agriculture, agroecosystem health, and multi-sectoral research and statistics from Pucallpa-Ucayali.

Results are organized in fully searchable electronic databases, implemented in Procite and Papyrus bibliographic software and are available on request. These databases are being updated on an ongoing basis.

The project ordered the digitizing of a base map for the Pucallpa-Ucayali study site, and provided the GIS laboratory at CIAT with georeferenced and historical information on biophysical features and land use in Pucallpa. The project team gathered this information in Peru. A characterization of land use in the Pucallpa study area is already underway in CIAT's GIS laboratory.

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3.2 Analyze historical land use changes

Activity: Land use in a western Amazon agricultural frontier – the case of Pucallpa Ucayali

✓ *New, richer view of land use in Pucallpa-Ucayali*

The understanding of the ecological-economic situation and history of Pucallpa-Ucayali was greatly emphasized. This effort resulted in a much richer picture of the region than the traditional official version held at CIAT and the Peruvian agricultural institutions (Figure 9).

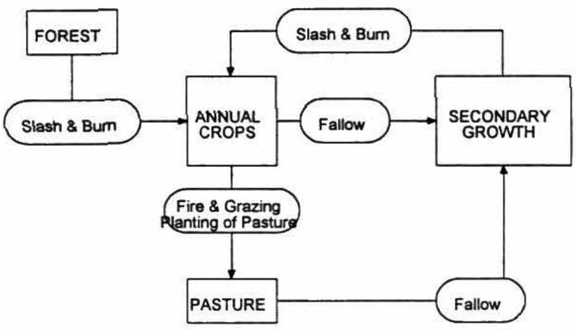

Figure 9. Traditional view (1960-1990) of land use dynamics in Pucallpa-Ucayali.

Our results could provide CIAT and its partners with a more solid reference base to decide on research priorities for integrated sustainable development in the region. Our current understanding developed from a careful revision of documents, field visits, and intensive interviews with national and international researchers with expertise in the region (Figure10). The substantial difference between this picture and the traditional understanding of land use in Pucallpa-Ucayali should guide a renewal of research and development priorities in the region.

Authorized by the government, timber companies exploit natural forests for few timber species of high market value. Logs are transported to sawmills in Pucallpa, and wood is later taken to Lima. Logging is usually performed without any silvicultural management for protection of future stocks, and the forest is abandoned once exhausted of the finest timber. Individual extractors also log the natural forests on a small scale and in a slightly less selective manner. Logging roads favor spontaneous encroachment of colonists into the forest.

In the land abandoned by the timber companies or in their own already logged lands, colonists slash-and-burn the forest and plant annual crops. Because labor and capital scarcity preclude soil conservation practices, the soil fertility, temporarily enhanced by forest ashes, falls in 1-2 years below profitable annual crop productivity. Some fallow-crop rotation may occur, but fallow is usually short-term, and eventually soil fertility falls well below annual crop productivity. Pastures are then planted or stimulated and new cropland is obtained by slash-and-burn. Pastures are largely established to protect land claims and increase land market value. Soil fertility keeps decreasing.

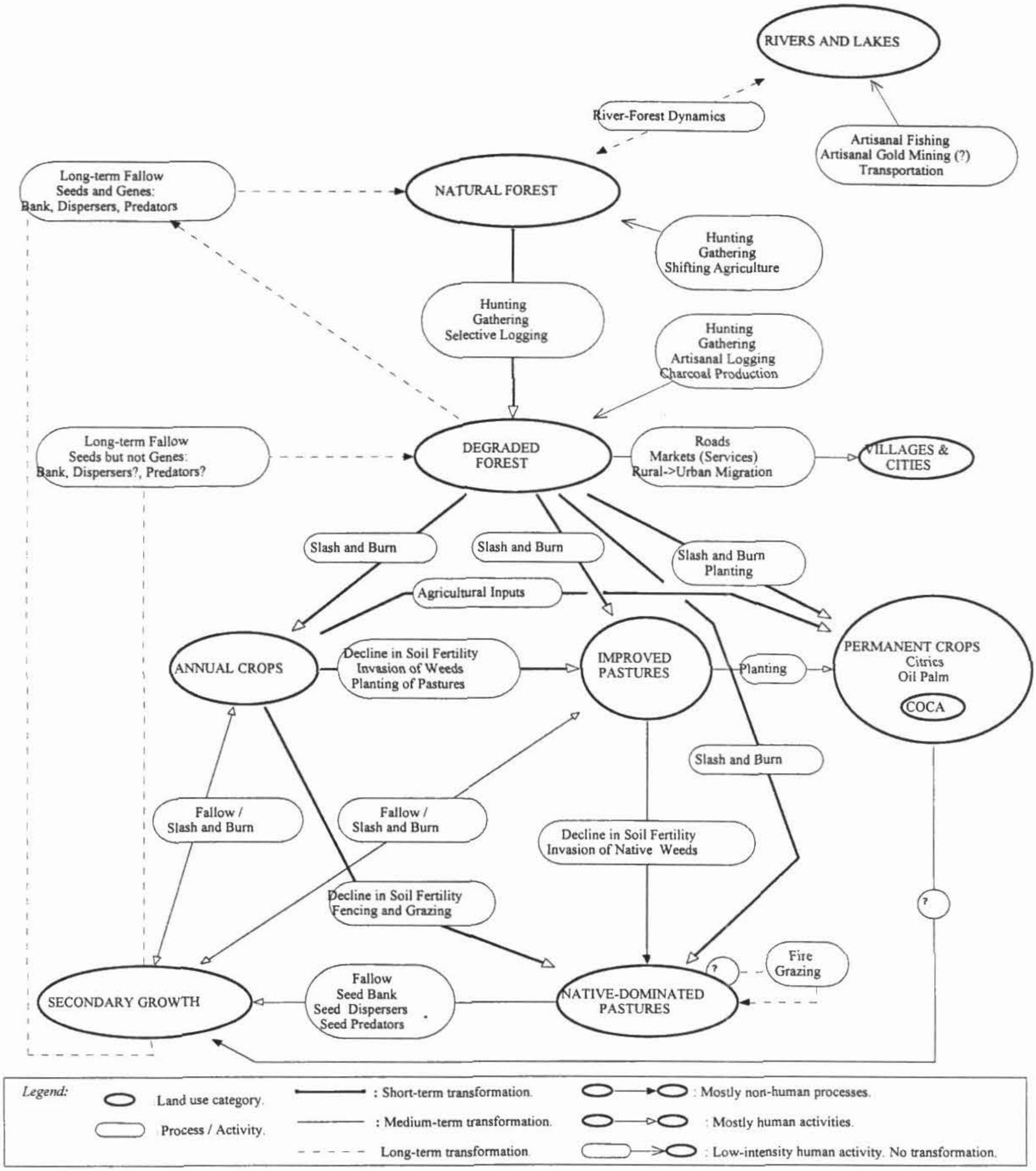

Figure 10. Current view of land-use dynamics in Pucallpa-Ucayali

Farmers usually try differing fallow-pasture schemes, but farmlands are eventually dominated by pastures of heterogeneous productivity or by fallow. Through time, land accumulates into several types of unproductive pastures and long-term secondary growth. Despite the ecological impact of pastures, only one of every five farmers with pastures owns cattle. Cattle densities and production are low. Cattle have value mostly as on-the-hoof savings, and provide social prestige to the owner. The main animal protein for human consumption in the region is freshwater fish, consumed about 10 times more than beef. The system reproduces and expands by the selective logging, occupation, and clear-cutting of more natural forest

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3.3 Identification of major ecological and socioeconomic determinants of land use and farmers' decision making. Assessment of ecological impacts of land use

Activity: Research process

✓ *First generalized diagram available*

We created a first generalized diagram of the research process required to achieve a complex systems view of an agroecosystem (Figure 11). The diagram identifies the steps required to integrate scientific and local knowledge, and to initiate actions to evaluate and improve agroecosystem health. The diagram is being critically used and revised on an ongoing basis. It provides an adaptive guide for future actions and specific outcomes of the project.

We reconstruct the history of the system to discover its dynamics, repeating patterns, critical processes, and cause-effect relationships. We separated key developments into ecological, economic, demographic, political, and cultural dimensions.

We identify the critical management goals and objectives. This helps to highlight the key issues or problems of interest to the stakeholders. Once the objectives are defined, the indicators that allow one to assess the performance of such objectives are identified.

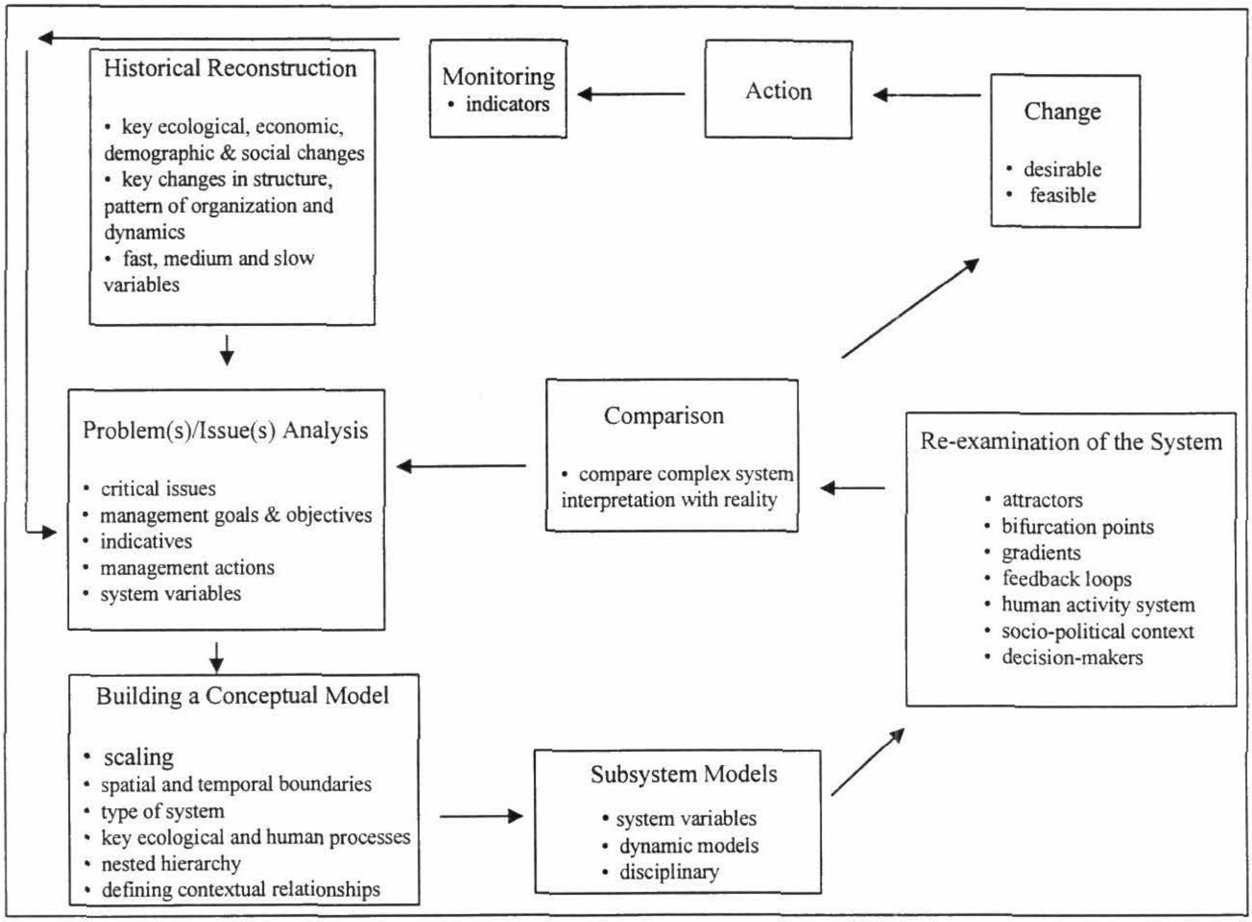

Figure 11. Diagram of the research process.

There are two parts to building a conceptual model. First the system of interest is defined and delimited, as not all its aspects can be included. The boundaries both in time and space are identified, i.e., the extent of the system and the time period concerned. We also identify what type of system it is, e.g., agricultural, fisheries, or forestry. This defines our perspective and clarifies what is of interest to the observer (trees, food, income). Second, the system is situated within a nested hierarchy and the key contextual relationships with higher and lower systems in this hierarchy are identified. This allows us to highlight the cross-scale interactions and the level at which important emergent properties become evident. More specifically, we identify the system or state variables that have to be included to fully comprehend the dynamics of the system. This is a critical task, because incorrect identification of variables will result in invalid models and flawed understanding in the future.

Problem analysis leads on naturally to the description of various subsystem models that detail the different system variables of interest. Focusing on subsystems allows us to simplify different processes across time and space, and to clarify the key interactions and influences in the system.

At the step of re-examination of the system, we apply complex systems theories (CST), which provides us with a different understanding of system behavior.

These interpretations, both the subsystem models and the CST applications, are brought into the real world and set against the perceptions of what exists there. This is done either in collaboration with stakeholders or with other tools such as GIS and remote sensing. This comparison is partly to generate a debate with concerned people in the region.

Stakeholders primarily drive the later steps of change, action, and monitoring. Once they are complete, the problems and critical issues are reassessed.

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Activity: Pucallpa: the regenerative capacity of lands

✓ *Parameters for the description of processes associated with degradation and regeneration selected (to be tested in the field late 1997)*

The natural vegetation around Pucallpa is Amazonian forest and provides evidence that sustained high primary production is possible in this region. This observation contrasts with the problems of agricultural production. Apparently the mechanisms working in natural ecosystems are not (or are only partially) active in cropped land or pastures: if the lands are not allowed to regenerate under fallow, they will progressively degrade. It seems, therefore, that natural and successional ecosystems have essential properties that enable plants to grow well and use their resources efficiently. After conversion of forests or fallows, the crops and pastures benefit from the fertility created by those ecosystems, but do not contribute (sufficiently) to its maintenance. This may theoretically be solved by fertilizing and other agronomic measures, but such inputs are not feasible in most cases in the Pucallpa region. Agricultural production therefore depends to an important extent on the natural capacity of the land to restore fertility. In a project recently begun, we aim at identifying key ecosystem properties in healthy, degrading, and recovering agroecosystems. To this end, we are sampling a broad range of agroecosystems of different age and history. The parameters determined for each site are of vegetation and soil that are expected to have indicator value, and cover biological, physical, and chemical aspects.

The productivity of land may be limited by the prevailing growth conditions or by the present species/cultivars being unsuitable. The latter may be the case in crops and pastures (e.g., poor adaptation of germplasm, competition with weeds, susceptibility to pests and diseases) but also in successional vegetation (failure of pioneer species to colonize fallow land, drastically altered site conditions).

Land use affects growth conditions in many different, interacting ways such as microclimate, soil moisture, soil structure, soil nutrients, soil macrofauna, and microbial activity. We are currently sampling a set of parameters that covers these main fields. At a later stage, we may add more parameters or investigate key factors with greater detail. The presence of seed banks in different agroecosystems is already being studied in some detail by a student of Ucayali university. In fallows, seeds from the seed bank will germinate when the conditions are appropriate. An impoverished seed bank or the presence of undesirable species within it may seriously limit the regeneration potential of lands, especially those that have been under intensive use during many years, distant from potential seed sources.

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Activity: Land-use choice after slash-and-burn in three Amazon colonies

✓ *Land use choices defined*

Settlers in the Amazon practice slash-and-burn agriculture in forest lands to produce annual crops. After cropping, lands are converted to pasture, planted to perennial crops, or fallowed in anticipation of future annual crop production. Land use was examined in three settlements— Pedro Peixoto in Acre and Theobroma in Rondonia, Brazil, and Pucallpa, Peru. Land use after slash-and-burn cultivation in forest lands differed among the colonies. Colonists in Pedro Peixoto converted lands to pasture for cattle production; Theobroma settlers adopted a strategy encompassing both dual-purpose cattle and perennial crop production; and the more heterogeneous settlers in Pucallpa included small-scale cattle ranchers and riverine and forest slash-and-burn farmers for whom perennial crops were important. Fujisaka (1997b) describes land use (Table 4), offers hypotheses regarding differences, and discusses implications for the adoption of agroforestry.

There appears to be little current potential for the promotion of more intensive, permanent, and diversified (and sustainable) land use in areas such as Pedro Peixoto, where abundant land and forest resources combined with isolation from urban markets tend to support the current exploitative pattern of the use of resources.

Table 4. Land use (%area), Pedro Peixoto and Theobroma, Brazil, 1994-5, and Pucallpa, Peru, 1995-96.

Land use	Pedro Peixoto		Theobroma		Pucallpa	
	1994	1995	1994	1995	1995	1996
Forest	69	66	54	50	35	32
Cleared	31	34	46	50	65	68
Pasture	20	25	26	29	25	25
Fallow	6	2	8	4	29	29
Annual crops	4	7	7	9	5	6
Perennial crops	1	<1	5	8	6	8
Mean farm size (ha)	88		76		35	

Yet decreasing farm sizes (perhaps because of intergenerational land fragmentation), combined with access to new market opportunities, appear to be associated with intensification and diversification. The establishment of perennials, and the settlers' associated perceptions of the high value in such establishment in Theobroma (coffee, cacao, and dual-purpose cattle successful) and Pucallpa (banana, oil palm, and exploitation of bolaina successful) should be seen as locally developed precursors to more sustainable agroforestry schemes.

Once herd numbers are rebuilt, the Pucallpa area may see an increase in pasture and a decrease in fallow area to proportions of land use more similar to that encountered in Theobroma. If the proposed highway connection between Acre and Peru, which would link Brazil to the Pacific Ocean, is completed then land use in Pedro Peixoto may become more exploitative (e.g., more deforestation for soybean production) or may become more diversified (and hopefully sustainable) with increased access to new markets.

Contributor:
Sam Fujisaka

Activity: Valuation of forest in the Peruvian Amazon.

✓ *Contingent Valuation Method used to show inhabitants perception of the total value of a tropical forest*

Tropical forests contain valuable resources and perform important ecological functions. Deforestation causes biodiversity loss, the release of large amounts of carbon to the atmosphere, and local and regional changes in hydrology and climate. Only part of these changes directly affects the people living in or near the forest. Do slash-and-burn farmers perceive that the forest is of little use except as a source of land? During late 1996, we attempted to quantify the value of forest according to farmers, and we explored the possibility of using future global environmental markets to stimulate an environmentally more beneficial land use.

The Contingent Valuation Method is a relatively new, survey-based methodology for estimating the economic value of non-market goods (Mitchell and Carson, 1989). Through the survey, a hypothetical market is constructed where the goods in question can be traded; then consumers' willingness to pay or willingness to accept payment for a change in the goods can be elicited. In the case of Pucallpa, the simulated market was based on the emerging global trade in carbon sequestration services (Pearce, 1996). As the amount of carbon sequestered by forests or agroforestry systems is higher than by the current slash-and-burn management, we presented to farmers the possibility that a global carbon market could eventually provide them with a compensation for changing from slash-and-burn agriculture to agroforestry, or for preserving forest. We then asked farmers how much recompense they would require for such a change in land use. This compensation is assumed to reflect the total value (market and non-market, use and non-use). Because an economic analysis of these different land uses was available, the value of environmental services could be inferred from the difference between the total and the economic values. We used additional data on the farm situation and on perceptions of environmental issues to further analyze the results.

The attitude of the 214 interviewed farmers towards the forest proved positive: 96% claimed it was important to preserve forests; and 76% had some knowledge of non-consumptive environmental services. These were more often related to quality of life than to agricultural productivity. Interestingly, only 27% agreed that forests are a source of crop land.

The average compensation farmers required to preserve a hectare of forest on their own land was US$237 per year (median US$195). Conversion of slash-and-burn land to agroforestry would require US$146 per year (median US$117). Of these total values, that attributed to environmental services was higher for forest preservation (US$70) than for agroforestry (US$43). These values are of the same order of magnitude as those obtained in other contingent valuation studies on ecosystem values, although no other study has attempted to estimate total values.

The results further indicated that farmers with positive environmental attitudes were indeed willing to forego more income to preserve forest. Also, farmers who tend to stay longer at a particular site gave higher values to the forest and to agroforestry; this may reflect their ability to recognize longer-term benefits.

Changing land use from slash-and-burn agriculture seems an economically efficient way to sequester carbon. For a 15-year window, we estimated the average carbon content of forest at 270 ton ha^{-1}, that of a developing multi-strata agroforestry system at 150 ton ha^{-1}, and that of a slash-and-burn system at 80 ton ha^{-1}. Considering the compensations farmers require to change their land use, these values indicate that the cost of sequestering 1 ton of carbon under these scenarios would be from US$0.5 to US$2, for both forest preservation and agroforestry. This is much lower than the cost of emission reduction by utility companies (US$50-US$400), suggesting considerable scope for gains from trade, even given the uncertainties associated with these estimates.

The study showed that farmers in the Peruvian Amazon are willing to change to more sustainable land management; that the amount of money required is relatively small compared to the cost of reducing carbon emissions; and that a global market for carbon may therefore benefit both the farmers and the industries.

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Activity: Impact of agriculture on water supply by a high Andean watershed, Carchi, Ecuador.

✓ *Hydrological features identified and quantified*
✓ *Impact of changed land use on water resources assessed*

The El Angel watershed of 300 km^2 is in the northern Andes of Ecuador at an altitude varying from 1500 to 4150 m. The lower range is dry and often degraded. In the central area irrigated agriculture uses water from the upper area. This is followed by a pasture/potato belt, and natural *páramo* vegetation higher up.

Water is a critical resource here, being abundant in the upper area and scarce in the lower. The climate within the region changes from dry (in the irrigated crop area, about 2500 m) to humid (in the nature reserve, above 3500 m) over a distance of a few kilometers. Annual precipitation in the higher areas (1300 mm) is more than twice the value in the lower (500 mm), and evapotranspiration is much lower because of lower temperatures, higher atmospheric humidity, and abundant cloudiness.

The agricultural frontier is advancing to higher altitudes where potato fields and managed pastures are replacing the natural *páramo* vegetation (a unique high-Andean grassland with some characteristic non-grass species). This creates a potential conflict between ecological services and agricultural production. The situation is representative of many *páramos* and *punas* in Venezuela, Colombia, Ecuador, and Peru, as confirmed recently during an electronic conference about high altitude Andean ecosystems (http://www.condesan.org/infoandi/foro/paramos.htm).

Given the ecological features of the *páramo* vegetation and the physical properties of the soils, the destruction of this ecosystem would probably be irreversible. *Páramos* are often compared to sponges, retaining large amounts of water, which are assumed to be released gradually, thus maintaining high base flows in the rivers. However, this hydrological behavior is poorly analyzed and the impact of changes in land use is uncertain. We are trying to provide reliable estimates of the water yield of intact *páramo* ecosystems and of lands converted to agricultural fields. We critically evaluated existing data and identified the key properties of climate, vegetation, and soil that explain the hydrological behavior of these ecosystems.

Roughly half of the rain input is potentially lost in evapotranspiration; the rest is the water surplus that eventually leaves the watershed as streamflow. The surplus water is more sensitive to changes in precipitation than in evapotranspiration. Only one short set of rainfall data exists for altitudes > 3500 m, making extrapolation of rainfall between 3000 m and 4000 m unreliable; and significant water input may occur through the deposition of fog (the so-called occult or horizontal precipitation), which is not measured by standard rain gauges.

We therefore needed to monitor these fluxes at selected sites in the watershed. We are currently measuring rain (with funnels) and fog (with fine-mesh, vertical cylinders mounted on funnels, and sheltered from rain).

The first data confirm the altitudinal increase in precipitation. Between May and August, the rainfall at 3500 m was 205 mm, at 3600 m it was 228 mm, and at 3700 m it was 257 mm. During the same period, the amount of moisture captured by the fog catchers at these three locations was 80, 780, and 1290 mL. This also suggests an altitudinal trend. Four sites at 3500 m had fog precipitation between 80 and 1700 mL (mean 800 mL), which indicates strong dependence on local conditions. Fog precipitation at 3000 m was negligible. Although these results clearly show that fog deposition does occur and that the amounts differ between sites, the results cannot be used to calculate the actual volumes of water that fog contributes to the water balance. This is because the interception of fog water depends largely on the amount and type of plant structures. *Páramos* and grasslands are of similar structure. Potato fields have more leaf area when full-grown but the canopy surface is much smoother. Forests have the greatest potential to capture fog because of their stature and diverse and abundant foliage.

The vegetation influences evapotranspiration mainly through differences in leaf area and the resistance to transpiration. Soil properties influence the rate at which water enters and moves through the soil; the amount of water it retains is the amount available for transpiration by the vegetation. As key properties we estimated the amount of leaf area, soil sorptivity and hydraulic conductivity, and the water retention curve

Table 5 provides a list of the land-use types sampled. The typical management of farmland is to grow two crops of potato followed by a fallow (mostly 'natural grassland', sometimes sown grassland), which lasts 3 or more years. Older fallows are invaded by shrubs and trees.

The original distribution limit between *páramo* and cloud forest (which must have covered much of the current potato zone, but is now absent except for some extremely small fragments) is unknown. The *páramo* ecosystem at higher altitudes does not seem different from that at 3500 m. However, in depressions, a wetland ecosystem develops with completely different hydrological characteristics.

Table 5. Sampling sites.

Land-use type	Vegetation	Altitude (m)
Páramos	Typical *páramo*, Graminae + *Espeletia*	3575
	Typical *páramo*, Graminae + *Espeletia*	3705
	Wetland, 'floating vegetation'	3700
Potato fields	Potato, recently planted	3480
	Potato, close to harvest	3500
Pastures	Fallow - aged 3 months	3450
	- aged 2 years	3510
	- aged > 3 years	3450
	Shrub-invaded abandoned pasture	3540
Forest	Cloud forest	3390

The transpiring leaf area of a potato crop depends on the phase of the crop, a relation that can be predicted from crop models and local information on sowing dates and crop duration. The *páramo* vegetation tends to have a constant leaf area but burning reduces the transpiring foliage to zero at irregular intervals (on the average several years). Full-grown potato crops probably use more water than the *páramo*, but young and senescent crops should use less.

All soils in the upper parts of the watershed are volcanic-ash derived. The hydraulic properties of these soils are largely unknown, and less so the changes that occur under different uses. They are known to have high organic matter content, low bulk density, and high water retention capacity. Sorptivity and hydraulic conductivity observed in the field were low. The loose soil of the elevated beds in which potatoes are grown is an exception. Under those beds, and between them, the soil is undisturbed and infiltration there was as slow as under *páramos* and pastures (Figure 12). A second exception was the high hydraulic conductivity of the forest soil.

Rooting is dense and reaches great depth (often > 1.5 m) even in grassland ecosystems. Poor infiltration can cause surface runoff. We have observed surface runoff in natural *páramo* and some gully erosion in potato fields that were ploughed parallel to the slope. However, poor infiltration is probably not important because rainfall is typically well-distributed and intensities are low at these altitudes (Pourrut, 1994). Therefore, most precipitation will infiltrate irrespective of land use. Lateral flow to streams may be faster in those situations where surface runoff occurs, but subsurface flows are probably independent on land use. In short, effects of land use on the hydraulic parameters are small. These conclusions do not take into account possible long-term indirect influences of land use, such as effects on soil loss through erosion, modification of soil structure caused by trampling, changes in soil organic matter, and soil fauna.

Caution must be exercised with regard to these soils because volcanic soils may easily be damaged in an irreversible manner.

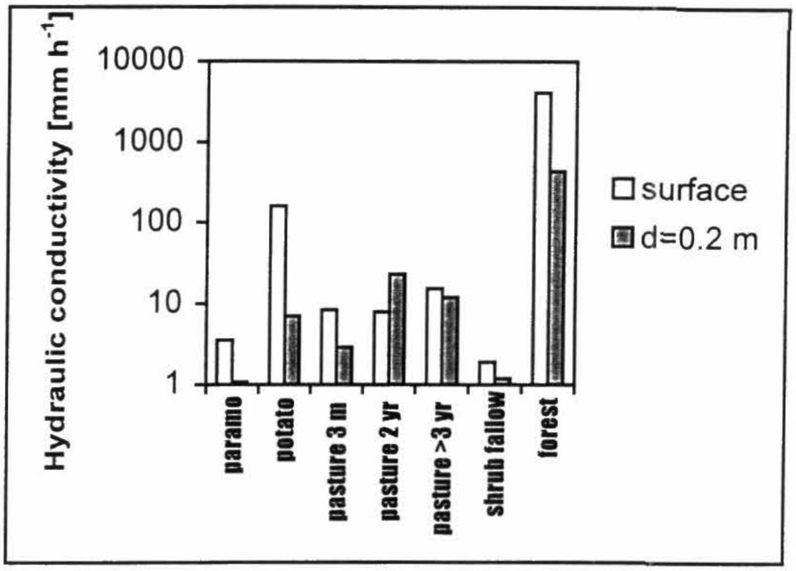

Figure 12. Saturated hydraulic conductivity of soils under different land uses at depths of 0 and 0.2 m, as estimated in the field using infiltration experiments.

We conclude that the substantial water-production of the El Angel *páramo* is largely determined by the climate: high precipitation (with evidence of fog contribution) and low evapotranspiration. Slow lateral flows caused by low hydraulic conductivity regulate the discharge. The preliminary results suggest that the effects of current types of land use on evapotranspiration and soil water movement are small. Pastures are similar to *páramo* in all their characteristics. Potato fields may consume more water but then plowing stimulates infiltration. A potentially important phenomenon in both *páramo* and potato fields is surface runoff, generated by poor infiltration combined with steep slopes. Whether it occurs more in potato fields than in *páramo* depends largely on tillage practices.

In assessing the overall effect of land use, the proportions of the lands in different uses must also be considered. The proportion of potato crops is limited by topographic conditions (steep slopes and depressions are unsuitable) and because a long fallow period is required after two crops.

Land use changes in the past may have had important impacts. One change was the cutting of forests at middle and high altitudes. The forest vegetation and soil are distinct in many ways. An important impact is that of the creation of many small channels that cross the landscape (following contour lines); these channels have changed the drainage paths and accelerate the discharge of water they collected. It would appear that instead of being the sponge once envisaged, the *páramo* acts much like a potato field. The damage has already been done by cutting the forest.

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3.4 Development of explanatory simulation models of land-use dynamics

Activity: Modeling

✓ *New, updated version available of simulation model of land-use dynamics in Pucallpa-Ucayali*

Through cooperative arrangements, we obtained a free license for the M programming language and interface from the Dutch National Institute of Public Health and Environmental Protection (RIVM). M allows the modeling of dynamic systems, and provides a flexible user interface that facilitates the evaluation of different scenarios by end-users.

A preliminary simulation model of land use dynamics in Pucallpa-Ucayali was created in February 1997 (Figure 13). A new and updated version of that model is already available. The new version, still based on a limited set of land-use transformations and decision structures, allows the heuristic assessment of impacts on land-use patterns and dynamics caused by farm size, crop technology, pasture technology, intensification, fallow management, and conservation of primary forest in farmlands, either factor by factor or in combination.

This first model only includes four land use categories: Primary forest (F1), annual crops (AC), secondary growth (F2), and pastures (P), and has a limited set of possible transformations. In the model, land transformations happen in discrete "quanta" of land, because there must be a minimum amount of land that is profitable to devote to crops or pasture. This simplifies the calculation of the rates of transformation from one to another land-use category. Thus, any given transformation rate will be either zero or an entire multiple of the corresponding quantum. In the model, producers have a permanent need to convert forest to agricultural land and cattle ranching. This is the non-mapped force that drives the system.

The only two explicit factors that control the system are land availability and soil fertility relative to annual crop or pasture land use. Thus, the model combines economic and ecological processes. Other economic or technological constraints are embodied in the model at two levels: first, in the concept of agricultural/pasture "quanta" of land; and second, in the decision structure for transformation of agricultural land into pastures or agriculture/pastures into secondary growth. In both cases, transformation happens when soil fertility reaches a specified low threshold, below which it is economically impractical to keep assigning the same use category to a given piece of land. Farm size is a parameter that partially indicates the socioeconomic identity of the landowner. Better-off landowners will have more land and are more likely to give priority to cattle. Farm size is also a key factor of sustainability, because a minimum size exists below which producing enough goods to sustain a family is impossible.

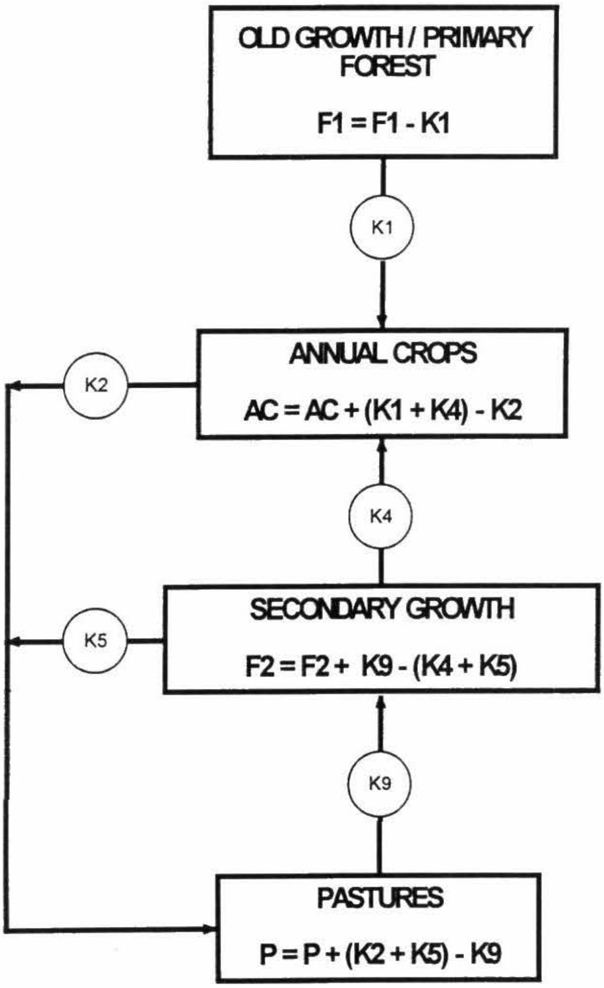
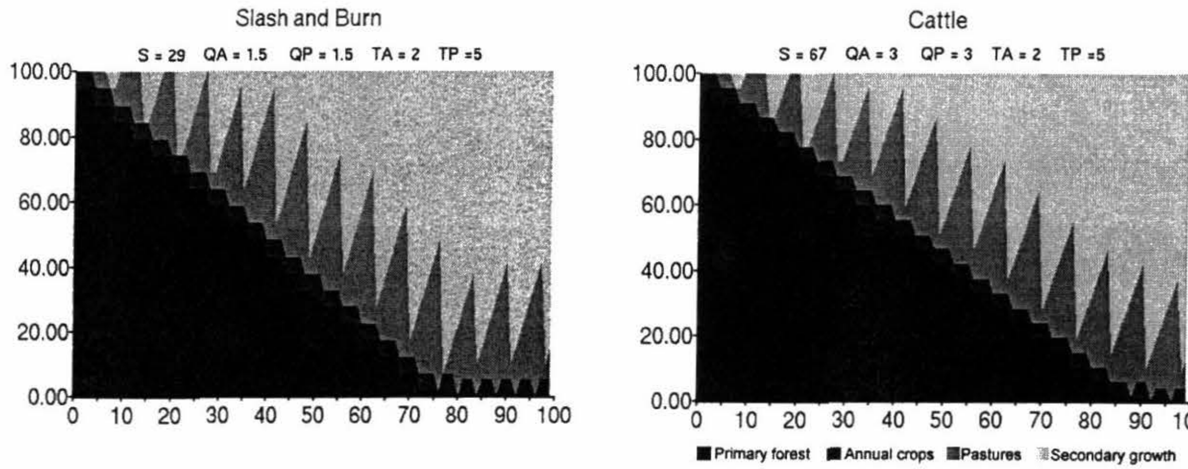


Figure 13. First model of land use on a Pucallpa farm.

The model simulates different land management schemes, by changing the value of two sets of parameters. First, it changes the land-use quanta, as differences in productivity caused by management can be reflected in differences in minimum profitable area. Second, it changes the fertility periods, or instance, protection of soils during the pasture period will prolong that period; or restoration practices will shorten the secondary growth recovery period. An obvious management strategy that the model allows us to assess is the manipulation of the periods themselves, to optimize fertility in the long-term.

In the model, fertility decreases exponentially under crops or pastures, and increases sigmoidally under secondary growth, relative to a maximum fertility that corresponds to that embodied in primary forest. A more detailed examination of the dynamics of fertility should yield more realistic (and complex) mathematical formulations. The same applies to the land-use transformation rates and land-use quanta.

Figures 14A and 14B compare a slash-and-burn farm with a cattle-oriented farm in terms of proportion (%) of land per land-use category. Typical values have been taken from Fujisaka (1997a). Parameters are as follows: S = farm size, QA = agricultural quantum, QP = pasture quantum, TA = profitable period of annual crop production, and TP = profitable period of pasture production. Units for area are hectares; time units are years. It is arbitrarily assumed that secondary growth takes 5 years to achieve 80% of the fertility embodied in the original forest.



(A) (B)

Figure 14. Comparison of slash-and burn farm (A) with a cattle-oriented farm (B), Pucallpa.

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Output 4: Environmental policy and sustainable indicators defined and reported

4.1 Promote a network of regional and national institutions that develop or demand indicators

Activity: Promoting cooperation

- ✓ *Agreements and activities with national, regional, and international institutions established*
- ✓ *An Internet homepage developed*

We consulted several regional institutions/organizations and governments to determine regional views regarding environmental indicators for sustainable development. We established agreements and activities with six institutions (national, regional, and international) cooperating to develop and use environmental and sustainability indicators, and to test and improve indicators frameworks. The institutions collaborating are:

Corporacion Autonoma Regional del Risaralda, Pereira, Colombia
Departamento Nacional de Planeacion, Bogotá, Colombia
Ministry of the Environment and Legal Amazonia, Brazilia, Brazil
IICA/Deutsche Gesellschaft für Techische Zusammenarbeit (GTZ) Project, IICA, San Jose, Costa Rica
WRI, Washington, D.C.
Department for Policy Coordination and Sustainable Development, (DPCSD), United Nations, New York.

At the same time, we developed and updated an Internet homepage for the project to promote networking activities and disseminate project activities. The homepage addressee is: Http://www.ciat.cgiar.org/indicators/project.html

To promote the CD-ROM (Winograd et al., 1997), we will distribute a flyer in English and Spanish during October broadly in the region using the network.

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Activity: Processed input to the GEO-1 and GEO-2 projects according to regional views and needs

✓ *Participating in and promoting the GEO 1 and GEO 2 processes*

We promoted a regional perspective and gave substantial input to the Global Environmental Outlook (GEO), UNEP. We produced and processed input to the GEO-1 project and participated in formulating and elaborating the GEO-2 project. We coordinated, using networking activities, the participation of the region in the GEO projects and the preparation of regional and/or sectoral, national, or local input for GEO.

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4.2 Development of conceptual framework in consultation with the network

Activity: Developing a conceptual framework

✓ *A conceptual framework developed at different scales - regional, national, local administrative, and local ecological*

For the CIAT-UNEP project we developed an analytical framework based on the Pressure-State-Impact-Response model. The framework has been presented to the Colombian Departamento Nacional de Planeación (DNP) to assess its usefulness. An agreement of technical cooperation has been signed by CIAT and DNP to develop a conceptual framework for a set of indicators to monitor the management of natural resources and the environment in Colombia and to elaborate an information system for environmental management and planning.

To test the efficacy of the framework, we developed a series of collaborative activities (Figure 15). Apart from the CIAT-DNP project, we developed and adapted an analytical framework for the savannas ecoregion in Colombia, in cooperation with the Tropical Lowlands Program, to obtain a set of indicators to monitor the state of the environment and development in the Meta Department.

We prepared a first draft of a methodological sheet indicating the steps to follow when using indicators (related to the DPCDS-United Nations methodological sheets) for the CIAT-DNP project. This sheet is intended to help countries, and regional and local institutions to develop and use indicators. Also, we collaborated in some activities with DPCSD, such as revising methodology sheets, making regional expert and institutions rosters, presenting and disseminating DPCSD activities in the region, and acting as facilitator in a regional meeting held in Costa Rica (March1997).

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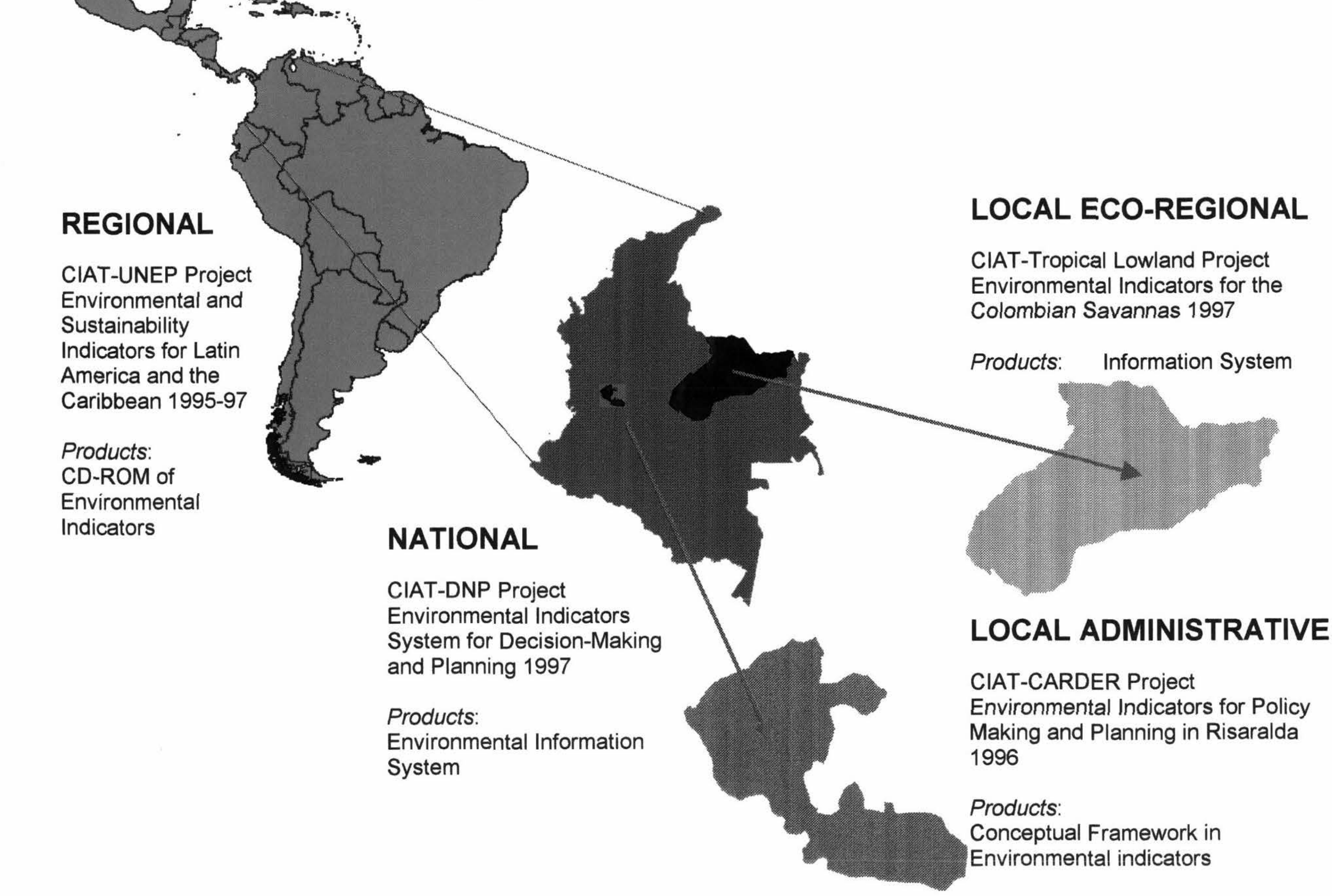
Figure 15. Environmental and Sustainability Indicators: Working Across Scales



4.3 Definition of sets of environmental and sustainability indicators at different scales

Activity: Defining the indicators

- ✓ *Indicators set at different scales: regional, national, local administrative, and local ecological*
- ✓ *Databases developed for environmental and sustainability indicators*
- ✓ *Others tools developed (i.e., GIS, land-use models)*

We contacted leading regional and international institutions working with environmental statistics and indicators to assess the availability of relevant data, databases, indicators, and digital maps. Thus we gathered new and existing environmental, social, and economic data. Amongst the institutions contacted were the: Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Costa Rica; Centro Latino Americano de Demografía (CELADE); CIAT; DPCSD; Economic Commission for Latin America and the Caribbean (ECLAC); Food and Agriculture Organization (FAO); Stockholm Environmental Institute (SEI); Instituto Interamericano de Cooperación para la Agricultura (IICA), Chile; RIVM; WRI; World Bank; United Nations Statistics division (UNSTAT); National Aeronautics and Space Administration (NASA); and UNEP.

Also, we extensively checked existing environmental data, databases, and digital maps at the national level (this included consulting with national institutions, and revising the national Sourcebook of Environmental report [SOE]) to develop the metadatabase for regional environmental and sustainability indicators.

We developed and integrated other appropriate tools and applied GIS techniques to analyze environmental, social, and economic linkages. We developed the interface for the indicators CD-ROM and the land-use model, which we adapted to the interface. We made and tested the beta version of the Biannual Report on the State of Sustainability in Latin America and the Caribbean on a CD-ROM.

In relation with the CIAT-DNP project, we made an extensive inventory of environmental and socioeconomic data, maps, and databases at national (ministries, national institutions) and local level (*corporaciones*) to create the Colombian database. We adapted the interface, made for the CIAT-UNEP project, to develop the information system for the DNP that includes 250 indicators.

For the savannas ecoregion, we made an extensive search of data in CIAT and in national institutions to develop the indicators set for the Meta department that includes 35 indicators.

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4.4 Development of a digital map of environmental and socioeconomic indicators at field level

Activity: Developing digital maps and socioeconomic indicators

✓ *Digital maps for indicators set at different scales (regional, national, local administrative, and local ecological)*

A set of 150 indicators was defined in consultation with regional and national institutions. Based on information available, we produced a series of 150 digital maps with basic information and environmental and socioeconomic indicators for the CD-ROM on Environmental and Sustainability Indicators for Latin America and the Caribbean (Winograd et al., 1997).

In the Colombian project with DNP, a set of 250 indicators was defined and developed and 100 maps developed. For the savannas ecoregion, 50 indicators were defined and 35 maps developed.

At the same time, we analyzed institutional data acquisition, analysis capabilities, and capacities to develop environmental and sustainability indicators, in consultation with the most relevant institutions in the region (Meta Department, Colombia) working with environmental statistics and data. We made a regional and national analysis on the quality, accessibility, synthesis, and comparability of data.

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4.5 Testing of selected agroecosystem indicators at field level

Activity: Identifying field level indicators - soil microbial DNA

✓ *DNA extracted from soil samples*
✓ *RAPD patterns produced*

Recently the research community has shown interest in working with soil bacterial DNA for several reasons. After 20 years of work we are reaching the limits of what the techniques that measure microbial biomass can show. This coincides with increasing interest in soil biodiversity and its effects on soil function. Microbial biodiversity may also correspond to soil quality. Torsvik (1996) suggests that in pristine soils a well-developed structure may provide a wide range of niches for soil bacteria and thus wider biodiversity. Bacterial diversity may also be related to the richness and variety of litter (Wardle and Giller, 1996).

The most common methods used to analyze soil bacterial diversity were through sequencing small subunits of ribosomal DNA (rDNA). These methods take advantage of phylogenic properties to give information about soil bacterial diversity. Borneman and Triplett (1997) used rDNA analyses to compare the bacterial communities from a pasture and forest soil in Para State, in the Brazilian Amazon. They found changes in the bacterial population with deforestation.

Although these methods are the most commonly used ones in soil bacterial DNA research, they are time-consuming and give information that is largely of taxonomic and ecological interest. Many of the clones analyzed are of uncharacterized microorganisms. Published papers that use these methods typically give results from one or two soil samples. We have thus concentrated our efforts on simpler and easier methods that will measure the overall diversity and similarity between populations but do not identify which groups are present.

The literature describes three potential methods of analyzing the total community DNA. First, reassociation, where DNA is heated to around 90 °C until it disassociates. Samples are then cooled to about 20 °C below their disassociation temperature and allowed to reassociate. The time needed for reassociation increases with complexity. Torsvik et al. (1996) used this method on forest soil samples and estimated that the population contained 10 000-12 000 species of bacteria. Bacterial diversity decreased by two orders of magnitude when land was used for a fish farm. Forest soil was found to have three to six times as many bacterial species as agricultural soil. Atlas et al. (1991) used this method to show that genetic diversity was reduced in soils exposed to 2,4,-dichlorophenoxyacetic acid (2,4-D). A disadvantage of this method is that soil DNA is so diverse that it can take more than a week for full reassociation.

Second, guanidine/cytosine (GC) profiles measure the GC profile of the whole community. Bisbenzimidazole binds preferentially to adenosine/typtophane (AT) nucleotide pairs. This increases the DNA density. If a sample of community DNA is then centrifuged in cesium chloride, the distribution of the DNA through the liquid will give the GC:AT profile of the community. This method has been shown to be sensitive to soil flooding and additions of plant litter. Unfortunately results are difficult to interpret for bacterial complexity. Producing GC profiles is also time consuming, requiring centrifugations of 3 days at 90 000 g (Holben and Harris, 1995).

Third, Xueqing et al.(1995) used random amplified polymorphic DNA (RAPD) to get a picture of the bacterial community and look for changes after the addition of 2,4-D on soils in Washington State, USA. They found similar levels of bacterial complexity under the same land use. However, adding 2,4-D produced no difference in RAPD pattern from these soils. A method similar to RAPD is rRNA intergenic spacer analysis (RISA), the main difference being that the primers used are from highly conserved ribosomal DNA. Borneman and Triplett (1997) used RISA to look at the effect of deforestation on the bacterial community of an Amazonian soil and found significant differences in community structure.

To apply these methods we first have to extract bacterial DNA from the soil. Any extraction method faces several potential problems. Does the extracted DNA represent all of the soil bacteria? Is the DNA extracted contaminated with eukaryotic or extra-cellular DNA? Is the DNA extracted clean enough for further analysis? Two approaches to extracting DNA from soil are used. In indirect extraction (also known as bacterial fractionation protocol), bacteria are first extracted from the soil usually by repeated centrifugation before being lysed and their DNA extracted and purified.

This method gives a sample of DNA that is relatively clean and completely prokaryotic; however, whether the bacteria extracted are representative of the soil population is uncertain. Normally no more than 40 % of the bacterial population is removed. There are indications that bacterial hydrophobicity and charge vary between species and with the stage in the feeding cycle. Holben (1994) says that recently grown bacteria are over-represented in the fraction extracted by this method. This method usually yields 1 to 2 μg of DNA per gram of soil.

In the second method, direct extraction, bacteria are lysed in place and their DNA extracted. This method gives a much higher yield of DNA from more of the soil population (the literature reports 70%-90% lysis and yields of 10- 20 μg g $soil^{-1}$). However, problems of contamination with humic substances often occur.

Previous worries were that direct extraction would result in extensive contamination by eukaryotic DNA. It has recently been shown that most directly extracted DNA is bacterial. Holben (1994) states this is because fungal DNA is protected by hyphae, and there is not enough protozoan DNA to seriously contaminate samples. Borneman et al. (1996) ascribe this to the low DNA content of most of the fungi in the soil. Both Holben and Borneman extracted DNA by shaking the soil with glass beads. Gentler, enzymatic methods would probably extract even less eukaryotic DNA. Holben (1994) recommends indirect extraction for soils that are high in OM or when a DNA sample of high purity is needed for polymerase chain reactions (PCRs). The advantages that he ascribes to direct extraction are that it provides a more representative sample of DNA and is faster and requires less time, soil, and labor than indirect extraction. If DNA from direct extraction is used for PCR, it usually needs further cleaning, often with cesium chloride centrifugation.

We began work with the direct extraction method of Zhou et al. (1996). This method uses enzymes and sodium dodecyl sulfate (SDS), a detergent, to break open bacteria. The DNA extracted is then cleaned by running it in a low melting point agarose gel and passing melted fragments of the gel that contain the DNA through a quik-prep column. This method has been extensively modified and it has proved possible to extract DNA pure enough for PCR amplification without any further cleaning. We have produced several RAPD patterns from samples of soil DNA, but we do not have consistent comparisons from different land treatments as yet. It has also proved possible to partially digest this DNA with restriction of the Eco R1 endonuclease.

Considerable potential remains to improve the purity of the DNA samples we use. To develop the method, we used 1-2 mm aggregates from the top 2-3 cm of soil in *leucaena* and bamboo woodland near CIAT, Palmira with OM contents of about 20%. We will carry out further extractions with soils with less OM from arable land. Our extraction method uses a 2-hr period of enzymatic extraction at 37 °C followed by 30 min of extraction with SDS at 65 °C. Most of the contaminants that we obtain go into solution during the 30 min at 65 °C. The next step will be to compare RAPD patterns of DNA extracted with and without the SDS treatment to see if we can eliminate or replace this step and increase the purity of the extracted DNA.

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Activity: Identifying field level indicators: soil carbon pools

- ✓ *Coarse fraction OM and oxidizable OM found most sensitive in cassava soils conservation project*
- ✓ *Farm samples taken, Meta Department*

We continued work on investigating soil carbon as an indicator of soil sustainability because it provides nutrients, improves structure, and reflects fertility. A decline in plant biomass production will reduce soil carbon levels.

Soil carbon levels themselves do not determine the sustainability of an agricultural system. Many tropical soils are inherently poor in organic carbon. Fertile soils that are unsustainably managed may contain a lot of organic carbon to begin with. Sustainability is determined by whether levels are at equilibrium or increasing or decreasing. Changes in organic carbon also occur slowly and by the time that trends in levels are measurable, it may be difficult to reverse them.

Early indicators of change in total carbon are fractions of the soil carbon that contain a disproportionate amount of recently added biomass. These can be expressed either as absolute values or as a ratio of total soil OM. The measures that we have worked with are particulate and $KMnO_4$ oxidizable OM.

We analyzed results from the collaborative work with the soil conservation project of the Cassava Program. At two sites, Santander de Quilichao and Mondomo, plots under pasture were ploughed up 8 years before soil sampling. In one treatment, the soil was kept completely free of vegetation for 8 years. A second treatment involved growing cassava for 8 years. In the three other treatments, cassava was grown for 6 years. After this, land was used for one of three soil-improving treatments: a legume-improved fallow, a forage, and beans that were heavily fertilized with chicken manure. After 8 years, all five treatments were planted to cassava and the soils were sampled to measure the residual effects of the treatments. Soils were sampled six times over the next 18 months.

Both OM fractions and soil physical properties were measured. Measurements of OM included: total organic carbon, oxidizable organic carbon, particulate OM (P.O.M) in the 2000-250, 250-125, and 125-53 μm fractions (both total and oxidizable carbon), and hot water extractable carbohydrates. Physical measurements included mean weight diameter, water stable aggregates, and water stable aggregates larger than 250 μm.

Total OM measurements only differed between the bare soil treatment and the other four treatments. The sensitivity of OM measurements was:

P.O.M. > oxidizable carbon > hot water extractable carbohydrates > total organic carbon.

Within the P.O.M. measurements, coarser fractions were more sensitive than finer fractions and oxidizable carbon measurements were more sensitive than total organic carbon.

Of the OM measurements, total organic carbon in the 125-53 μm fraction consistently correlated best with the soil physical properties. This is probably because the P.O.M. in this fraction size was mainly within aggregates acting to bind soil particles together. The organic fraction with the least correlation to the soil physical properties measured (with *r* values of as low as -0.12) was the oxidizable carbon in the 2000-250 μm P.O.M. This fraction corresponds to free P.O.M. that has not yet been incorporated into soil aggregates. Large differences also occurred in the ratio of oxidizable to total organic carbon between the three size fractions of P.O.M.

Work on the Mondomo and Santander de Quilichao sites has finished, and we have begun analyzing samples from the Soils Project's plots in Pescador. We are particularly interested in measuring the oxidizable to total organic carbon ratios for the whole soil. In Mondomo and Santander, these ratios were almost the same for both sites even though there is a climatically significant difference in altitude between them.

We have begun to sample on farms rather than the test plots at Matazul and Carimagua. This decision was taken because other projects have already invested considerable time and labor in these field plots so adding anything useful to their work will be difficult. We have also begun to analyze radar images of the area in a separate project, which will help us pick sampling sites on farmers' lands.

In June 1997, soil samples were taken across fence lines in the Meta Department of eastern Colombia, in areas where improved pasture had been planted alongside native savanna. Samples have been analyzed for total organic carbon and will be analyzed for sensitive fractions of soil carbon including: P.O.M., light fraction carbon, and oxidizable carbon. Results to date suggest that the increase in soil carbon reported on conversion from native savanna to improved pasture is much less marked, or even nonexistent on the sandier soils of the study area. This concurs with results from trial plots at Primavera (CIAT 1997, 61-3), where conversion to improved pasture reduced total, oxidizable, and particulate organic matter.

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4.6 Biannual report produced

✓ *A CD-ROM produced on environmental and sustainability indicators*

We produced a beta version of the CD-ROM on environmental and sustainability indicators and sent it for testing to WRI and UNEP during the first half of 1997. The CD-ROM will be released in November 1997. It includes a hypertext guide with software help, a conceptual framework description, a regional perspective on environment and development, a glossary, a series of tables and data, a bibliography and references, technical notes, and the indicators set (150 georeferenced indicators). To develop the CD-ROM, we used ESRI data publisher software for Arc view 2.1.

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References

Atlas, R. M.; Horowitz, A.;. Krichevsky, M.;. and Bej, A. K. 1991. Response of microbial populations to environmental disturbance. Microb. Ecol. 22:249-256.

Beaulieu, N.; Veneklaas, E. J; and Bell, W. 1997. Using JERS-1 SAR images to locate weaknesses in the riparian forest in tropical lowlands of Colombia. http://gis.ciat.cgiar.org/html/nath1.htm

Borneman, J. S. and Triplett. 1997. Molecular microbial diversity in soils from eastern Amazonia: evidence for unusual microorganisms and microbial population shifts associated with deforestation. Appl. Environ. Microbiol. 63: 2647-2653.

Borneman, J. S.; Skroch, P. W.; O'Sullivan, K. M.; Palus, J. A.; Rumjanek, N. G.; Jansen, J. L.; Nienhuis, J.; and Triplett, E. W. 1996. Molecular microbial diversity of an agricultural soil in Wisconsin. Appl. Environ. Microbiol. 62:1935-1943.

Chisholm, Michael. 1979. Rural settlement and land use: an essay in location. Humanities Press, Atlantic Highlands, NJ.

CIAT. 1997. Land Management Unit Annual Report 1995-96. CIAT, Cali, Colombia. 159 p.

Defense Mapping Agency. 1994. Digital Chart of the World. Digital data, scale 1:1 000 000. Arc/Info version produced by Environmental Systems Research Institute, Redlands, CA.

Deichmann, U. 1996. A review of spatial population database design and modeling. United Nations Environment Program (UNEP), Global Resource Information Database, (GRID). 58 p.

Eade, J. Feb 21 1997. The accessibility surface. < jeremy@epac.norway.ibm.com > < afarrow@gis.ciat.cgiar.org > (Accessed Feb 21 1997)

Eastman, J. R. 1990. IDRISI, a grid-based geographic analysis system. Version 3.2. Clark University, Graduate School of Geog., MA. 362 p.

Elvidge, C. D.; Baugh, K. E.; Kihn, E. A.; Kroehl, H. W.; and Davis, E. R. 1997. Mapping city lights with night-time data from the DMSP Operational Linescan System. Photogram. Engineer. Remote Sensing 63:727-734.

Fisher, M. J.; Rao, I. M.; Ayarza, M. A.; Lascano, C. E.; Sanz, J. I.; Thomas, R. J.; and Vera, R. R. 1994. Carbon storage by introduced deep-rooted grasses in the South American savannas. Nature 371:236-238.

Flowerdew, R.; Green,M.; and Kehris, E. 1991. Using areal interpolation methods in geographic information systems. Papers in Regional Science, 70:303-315.

Fujisaka, S. 1997a. Land-use strategies in Pucallpa, Peru. Paper prepared for Characterization Working Group, Alternatives to Slash-and-Burn (ASB),16-21 Aug, 1997, Bogor, Indonesia.

Fujisaka, S. 1997b. Pasture or permanent crops after slash-and-burn agriculture? Land-use choice in three Amazon colonies. Submitted to Agroforest. Syst.

Fujisaka, S.; Castilla, C.; Escobar, G.; Rodrigues, V.; Veneklaas, E.; Thomas, R.; and Fisher, M. 1997. Impacts of forest conversion: Estimates of carbon emissions and plant species loss in a Brazilian Amazon colony. Agric. Ecosyst. Environ. Forthcoming.

Goodchild, M.; Anselin, L.; and Deichmann. U. 1993. A framework for the areal interpolation of socioeconomic data. Environ. Planning 25:383-397.

Holben, W. E. 1994. Isolation and purification of bacterial DNA from soil. In: Weaver, R. W.; Angle, J. S.; and Bottomley, P. S. (eds.) Methods of soil analysis, Part 2. Microbiological and biochemical properties. Soil Science Society of America (SSSA) Book Series No. 5, p. 727-751.

Holben, W. E. and Harris, D. 1995. DNA based monitoring of total bacterial community structure in environmental samples. Molecul. Ecol. 4:627-631.

Holdridge, L. R. 1947. Determination of world plant formations from simple climatic data. Science, 105:367-8.

Hyman, G. 1997. Mapping maize and wheat distributions in Latin America. Seminar given at the International Center for Maize and Wheat Improvement (CIMMYT), Mexico City, Mexico, Sept 18, 1997.

Hyman, G.; Jones, P.; and Lema, G. 1997. Latin America crop distribution database. Internal document of the Ecoregional Program for Latin America. CIAT, Cali, Colombia.

Jones, P. G. and Bell, W. C. 1997. Administrative divisions of Latin America to the third order. Digital version 1.1, ARC/INFO data coverage. CIAT, Cali, Colombia.

Jones, P. G. and Thornton, P. K. 1993. A rainfall generator for agricultural applications in the tropics. Agric. For. Meteor. 63:1-19.

Jones, P. G. and Thornton, P. K. 1997. Spatial and temporal variability of rainfall related to a third order Markov model. Agric. Forest Meteor. 86:127-138.

Jones, P. G.; Galwey, N.; Beebe, S. E.; and Tohme, J. 1997. The use of geographical information systems in biodiversity exploration and conservation. Biodivers. Conserv. 6:947-958.

Klass, J. 1997. Vegpotmap.aml. Unpublished computer program in Arc Macro Language (AML). CIAT, Cali, Colombia.

Koppen, W. 1918. Klassifikation der Klimate nach Temperatur, Niederschlagund Jahreslauf. Petermanns Geographische Mitteilungen, 64:193-203, 243-48.

Langford, M.; Maguire D. J.; and Unwin, D. 1994. Generating and mapping population density surfaces within a geographical information system. Cartogr. J. 31:21-25.

Linacre, E. J. 1977. A simple formula for estimating evaporation rates in various climates using temperature alone. Ag. Met. 18:409-424.

Mitchell, R. C. and Carson, R. T. 1989. Using surveys to value public goods: the contingent valuation method. Resources for the Future, Washington.

Moxey, A. and Allanson, P. 1994. Areal interpolation of spatially extensive variables – a comparison of techniques. Internat. J. Geog. Inf. Syst., 8:479-487.

Pearce, D. 1996. Global environmental value and the tropical forests: demonstration and capture. In: Adamowicz, W. L.; Boxall, P. C.; Luckert, M. K.; Phillips, W. E.; and White, W. A. (eds) Forestry, Economics and the Environment. CAB International, UK. p. 11-48.

Pourrut, P. 1994. L'eau en Equateur. Principaux aquis en hydroclimatologie. ORSTOM Editions, Paris. 145 p.

Riehl, M. 1979. Climate and weather in the tropics. Academic Press, London.

Tobler, W. R. 1979. Smooth pycnophylactic interpolation for geographical regions. J. Amer. Stat. Assoc. 74:519-530.

Torrijos, P. 1996. La quema y la sucesión secundaria de la vegetación en sectores de la estación biológica de Carimagua en los *Llanos* Orientales de Colombia. Tesis Universidad Nacional, Bogotá

Torsvik, V.; Sorheim, R.; and Goksoyr, J. 1996. Total bacterial diversity in soil and sediment communities-a review. J. Indust. Microbiol. 17:170-178.

Wardle, D. A. and Giller, K. E. 1996. The quest for a contemporary ecological dimension to soil biology. Soil Biol. Biochem. 28:1549-1554.

Winograd, M. and Farrow, A. 1997. Environmental and sustainability indicators of Latin America and the Caribbean. Example 7, GIS Awareness Package in Agricultural Research. United Nations Environment Program (UNEP)/DEIA/RT.97-9. http://www.grida.no/cgiar/htmls/awpak.html

Winograd, M.; Farrow, A.; and Eade, J. 1997. Environmental and sustainability indicators outlook for Latin America and the Caribbean. CD-ROM with manual. 27 p. UNEP-CIAT, Cali, Colombia. Oct 1997.

Xueqing, X.; Bollinger, J.; and Ogram, A. 1995. Molecular genetic analysis of the response of three soil microbial communities to the application of 2,4-D. Molecul. Ecol. 4:17-28.

Zhou, J.; Bruns, M. A.; and Tiedje, J. A. 1996. DNA recovery from soils of diverse composition. Appl. Environ. Microbiol. 62(2):316-322.

Meetings and Workshops

(NB = N. Beaulieu, WB = W. Bell, SF = S. Fujisaka, GG = G. Gallopín, GH = G. Hyman, PJ = P. Jones, EV = E. Veneklaas, and MW = M. Winograd.)

1996:

Sept 23-24. (SF) Reunion Corporacion Colombiana de Investigación Agrocpecuaria (CORPOICA), University of Maryland and Univalle. Bogotá, Colombia.

Oct 1-8. (SF) Meeting on Alternatives to Slash-and-Burn. Nairobi, Kenya.

Oct 20-23. (PJ) Land Quality Indicators Meeting. World Bank, Washington (20^{th}) and CEISIN, Sagenaw, Michigan (21^{st} to 23^{rd}).

Oct 31. (PJ) GRID-Arendal Steering Committee Meeting. Washington.

Nov 13-15. (EV) Taller regional "Agrociencia y Tecnologia Siglo XXI, Orinoquia Colombiana". Villavicencio, Colombia.

Nov 20-21. (EV) Planning meeting Centro Internacional de la Papa (CIP)-Wageningen project "Regional scaling of field-level economic-biophysical models". Quito, Ecuador.

Dec 2-5. (PJ) Global Terrestrial Observation System (GTOS) Steering Committee Meeting. Rome, Italy.

1997:

Mar 3. (EV) First Internal Workshop of the CIAT/Guelph Project (Integrated conceptual framework for tropical agroecosystems research based on complex system theories). Cali, Colombia.

Mar 7-9. (MW) The Global Environmental Outlook (GEO) 2nd regional meeting, UNEP-Regional Office for Latin America and the Caribbean (ROLAC). Mexico, D. F.

Mar 10-12. (MW) Workshop on Indicators of Sustainable Development in Latin America and the Caribbean, DPCSD, Government of Costa Rica and the Interamerican Development Bank (IDB). San Juan, Costa Rica.

Apr 21-22. (MW) Workshop Desarrollo Sostenible: Una de las prioridades de El Salvador. World Bank. San Salvador, El Salvador.

Apr 29-May 2. (GG) First Workshop-Seminar on Planning of the Sustainable Development of the Agricultural Sector in the Peruvian Amazon. Iquitos, Peru.

May 6.	(GG) Local Workshop of the CIAT/Guelph Project. Pucallpa, Peru.
May 20-24	(PJ) Mid-term meeting GRID-Arendal Steering Committee. Cairo, Egypt.
May 26-28.	(EV) First International Workshop of the CIAT/Guelph Project (Integrated conceptual framework for tropical agroecosystem research based on complex system theories). Cali, Colombia.
Jun 14-21.	(PJ) GTOS Network Meeting. Bilbao, Spain.
Jun 24-27.	(EV) International workshop "Variation in growth rate and productivity of higher plants". Utrecht, The Netherlands.
Jly 19-23.	(GH) Conference of Latin American Geographers. Arequipa, Peru.
Jly 31-Aug 2.	(GG;MW) V International Seminar on Sustainable Systems for Agricultural Production. Cali, Colombia.
Aug 15-Sept 30.	(EV) Conferencia electronica sobre conservacion de páramos y punas. CONDESAN-Infoandina-Tropical Mountain Institute. http://www.condesan.org/infoandi/foro/paramos.htm
Aug 15-22.	(SF) Meeting on Alternatives to Slash-and-Burn. Jakarta, Indonesia.
Aug 18.	(GH) Workshop on Harmonization of Databases for GIS Analysis of Cropping Systems in the Asia Region. Hyderabad, India.
Aug. 20-29.	(GH) Training Program on Harmonization of Databases for GIS Analysis of Cropping Systems in the Asia Region. Hyderabad, India.
Sept 18-19.	(MW) National Workshop, Sistema de Indicadores de Gestion y Planificacion Ambiental, CIAT-DNP-Ministerio del Medio Ambiente. CIAT, Cali, Colombia.
Sept 22.	(PJ) System Wide Initiative Planning Group Meeting. CIAT, Cali, Colombia.
Sept 23-25.	(PJ; NB; WB, GH; and MW.) Fourth Annual Workshop "CGIAR/UNEP Cooperation on the Use of GIS in Agricultural Research". CIAT, Cali, Colombia.
Oct 7.	(MW) World Bank Indicators for Natural Resources Management Meeting, 5th Annual World Bank Conference on Environmentally and Socially Sustainable Development. Washington.
Oct 23-24.	(MW) The Fourth Expert Meeting on Sustainability Indicators of the DPCSD, United Nations, New York.

Publications

Book and Journal

Bruynzeel, L. and Veneklaas, E. J. 1997. Climatic conditions and tropical montane forest productivity: the fog has not lifted yet. Ecology 79 (1) Forthcoming.

Fujisaka, S. 1997. Pasture or permanent crops after slash-and-burn agriculture? Land-use choice in three Amazon colonies. Submitted to Agroforest. Syst.

Fujisaka, S.; Castilla, C.; Escobar, G.; Rodrigues, V.; Veneklaas, E.; Thomas, R.; and Fisher, M. 1997. Impacts of forest conversion: Estimates of carbon emissions and plant species loss in a Brazilian Amazon colony. Agric. Ecosyst. Environ. Forthcoming.

Fujisaka, S.; Escobar, G.; and Veneklaas, E. 1997. Plant community diversity relative to human land uses in an Amazon forest colony. Biodivers. Conserv. Forthcoming.

Gallopín, G. C. 1997. Indicators and their use: information for decision making. In: Scientific Committee for Problems of the Environment (SCOPE) 58, Sustainability indicators: a report on the project on indicators of sustainable development. John Wiley. p.13-27.

Gallopín, G. C. 1997. Indicators and their use: boxing situational indicators. In: Scientific Committee for Problems of the Environment (SCOPE) 58, Sustainability indicators: a report on the project on indicators of sustainable development. John Wiley. p. 63-68.

Jones, P. G. and Thornton, P. K. 1997. Spatial and temporal variability of rainfall related to a third order Markov model. Agric. Forest Meteor. 86:127-138.

Jones, P. G.; Galwey, N.; Beebe, S. E.; and Tohme, J. 1997. The use of geographical information systems in biodiversity exploration and conservation. Biodivers. Conserv. 6:947-958

Langford, M. and Bell, W. 1997. Land cover mapping in a tropical hillsides environment: a case study in the Cauca region of Colombia. Int. J. Remote Sensing 18:1289-1306.

Lapointe, S. L.; Serrano, M. S.; and Jones, P. G. 1997. Distribution in three dimensions and colony phenology of *Acromyrmex landolti* (Hymenoptera: Formicidae) in a neotropical savanna. Submitted to Environmental Entomology, April 1997.

Rowley, T.; Gallopín, G.; Waltner-Toews, D.; and Ráez-Luna, E. 1997. Development and application of an integrated conceptual framework for tropical agroecosystem research using complex systems theories. Ecosyst. Health J. 3:154-161.

Rubin, B. and Hyman, G. 1997. An estimate of the quantity and impacts of soil erosion in Costa Rica. In: Hall, C. (ed.) Geographic modeling and its application to economy, environment, and agriculture of Costa Rica. Academic Press. Forthcoming.

Saenz, F.; Schultz, S.; and Hyman, G. 1997. Uso de un sistema de infomación geográfica en la identificación de degradación de tierras y recursos hídricos. Revista Forestal Centroamericana 18:18-22.

Schultz, S.; Saenz, F.; and Hyman, G. 1997. Linking farms and people to soil conservation planning with a GIS: a case study of a pristine Central American watershed. Nat. Res. Soc. J. Forthcoming.

Smith J.; Winograd, M.; Gallopin, G. C.; and Pachico, D. 1997. Dynamics of the agriculture frontier in the Amazon and savannas of Brazil: simulating the impact of policy and technology. Environ. Modeling Assess. Forthcoming.

Thornton, P. and Jones, P. G. 1997. A conceptual approach to dynamic agricultural land use modeling. Agric. Syst. Forthcoming.

Thornton, P. K. and Jones, P. G. 1997. Towards a conceptual dynamic land-use model. In: Teng, P. S.; Kropff, M. J.; ten Berge, H. F. M.; Lansigan, F. P.; and van Laar, H. H. (eds.). Applications of systems approaches at the farm and regional levels. Vol. 1. Kluwer, Neths. p. 341-356.

Van den Boogaard R.; Alewijnse, D.; Veneklaas, E. J.; and Lambers, H. 1997. Growth and water-use efficiency of 10 *Triticum aestivum* cultivars at different water availability in relation to allocation of biomass. Plant Cell Environ. 20:200-210.

Van den Boogaard, R.; de Boer, M.; Veneklaas, E. J.; and Lambers, H. 1996. Relative growth rate, biomass allocation pattern and water-use efficiency of three wheat cultivars during early ontogeny as dependent on water availability. Physiol. Plant. 98:493-504.

Van den Boogaard, R.;Veneklaas, E. J;. and Lambers, H. 1996. The association of biomass allocation with growth and water-use efficiency of two *Triticum aestivum* cultivars. Austral. J. Plant Physiol. 23:751-761.

Van Laake, P. and Hyman, G. 1997. The geographic matrix: landforms, slope, and topographic characteristics of Costa Rica. In: Hall, C. (ed.) Geographic modeling and its application to economy, environment, and agriculture of Costa Rica. Academic Press. Forthcoming.

Veneklaas, E. J. and Poorter, L. 1997. Growth and carbon partitioning of tropical tree seedlings in contrasting light environments. In: Lambers, H. et al. (eds): Variation in growth rate and productivity of higher plants. Backhuys, Leiden. Forthcoming.

Winograd, M. 1997. Horizontal and vertical linkages in the context of sustainable development indicators. In: Moldan, B. and Billharz, S. (eds.) Indicators of sustainable development. Scientific Committee for Problems of the Environment (SCOPE). John Wiley. p. 40-46.

Winograd M. and Eade J. 1997. Environmental and sustainability indicators for Latin America and the Caribbean: the use of GIS (Geographic Information Systems). In: Moldan, B. and Billharz, S. (eds.) Indicators of sustainable development. Scientific Committee for Problems of the Environment (SCOPE). John Wiley. p. 92-95.

Winograd M. and Eade, J. 1997. Un marco conceptual para la definicion y uso de indicadores ambientales y de sustentabilidad para la toma de decisiones en America Latina y el Caribe. En: Furst, E. (ed.) Hacia una operacionalizacion del desarrollo sostenible: nuevos enfoques de contabilidad, valoracion e indicadores en los paises en desarrollo. Centro Internacional de Politica Económico para el Desarrollo Sostenible (CINTERPEDS)- Instituto Interamericano de Cooperación para la Agricultura (IICA)- Deutsche Gesellschaft für Techische Zusammenarbeit (GTZ), Costa Rica. Forthcoming.

Conference Papers

Fujisaka, S. 1997. Land-use strategies in Pucallpa, Peru. Paper prepared for Characterization Working Group, Alternatives to Slash-and-Burn (ASB),16-21 Aug, 1997, Bogor, Indonesia.

Gallopín, G. C. and Gomez, I. A. 1997. Potencial agricola y oferta ecologica de America del Sur. En: Memorias de la Conferencia de Santafe de Bogotá, Oct. 17-18, 1996. Integracion fluvial de Sur America (IFSA). p. 49-63.

Hyman, G. 1997. Mapping crop distributions. In: Pande, S. (ed.) Procs. Workshop Harmonization of Databases for GIS Analysis of Cropping Systems in the Asia Region. International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) Asia Center, Hyderabad, India, 18 Aug, 1997. Forthcoming.

Jones, P. G.; Sawkins, M. C.; Maass, B. L.; and Kerridge, P. C. 1997. GIS and genetic diversity case studies in *Stylosanthes*. Procs. XVIII International Grassland Congress, June 8-19, Winnipeg, Canada. Forthcoming.

Jones, P. G.; Thornton, P. K.; and Hill, P. 1997. Agro-meteorological models: Crop growth and stress indices. In: Crop Yield Forecasting Methods. Procs. of Seminar, Villefranche-sur-Mer, 24-27 Oct, 1994. Eurostat Joint Research Center. Office for Official Publications of European Communities, Luxembourg. p. 53-67.

Murray, T. and Gallopín, G. (eds.) 1997. Procs. First Internal Workshop, Integrated Conceptual Framework for Tropical Agroecosytem Research Based on Complex Systems Theories, 3 Mar, 1997. Cali, Colombia. CIAT, Cali, Colombia Working Document No. 166. 51 p.

Murray, T. and Gallopín, G. 1997. Procs. First International Workshop. 26-28 May, 1997. Cali, Colombia. CIAT, Cali, Colombia Working Document No. 167. 215 p.

Ráez-Luna, E. (ed.) 1997. Proceedings of the First Workshop with CODESU Directors. 5 May, 1997, Pucallpa, Ucayali, Peru. Consorcio para el Desarrollo Sostenible de la Región Ucayali (CODESU) and CIAT. CIAT, Cali, Colombia Working Document No 169. 44 p.

Ráez-Luna, E.; Gallopín, G. C.; Fujisaka, S.; Murray, T.; and Waltner-Toews, D. 1997. Evaluacíon de alternativas productivas en la Amazonía Peruana. In: V International Workshop-Seminar on Sustainable Systems of Agricultural Production. Livestock Research for Rural Development J. Hypertext. 695 kb, 4½ diskette. Distributor Centro para la Investigación en sistemas sostenibles de Producción Agropecuaria, Colombia.

Other

Beaulieu, N.; Veneklaas, E.; and Bell, W. 1997. Using SAR images to locate gaps in the riparian forests of Colombian tropical lowlands. Example 16, GIS Awareness Package in Agricultural Research. United Nations Environment Program (UNEP)/DEIA/RT.97-9. http://www.grida.no/cgiar/htmls/awpak.html

Gallopín, G. C. 1997. Planetary solidarity: premises, values, and principles for sustainable development. In: Earth Charter Project, March, 1997. p. 1-14.

Gallopín, G. C.; Hammong, A.; Raskin, P.; and Swart, R. 1997. Branch points: global scenarios and human choice. In: A resource paper of the global scenario group. Stockholm Environment Institute (SEI). Polestar Series Report No. 7. p.1-47.

Hyman G. 1997. Small-scale landform mapping of South America with a Digital Elevation Model. Paper presented at the Conference of Latin Americanist Geographers, Arequipa, Peru, Jly 19-23, 1997.

Hyman, G.; Mayfield, M.; and Velasquez, S. 1997. Delineating effective riparian buffer widths for water quality protection. Example 31, GIS Awareness Package in Agricultural Research. United Nations Environment Program (UNEP)/DEIA/RT.97-9. http://www.grida.no/cgiar/htmls/awpak.html

Hyman, G.; Nelson, A.; Jones, P.; and Bell, W. 1997. Mapeo de poblacion de América Latina. Paper presented at the 8^{th} Latin American Symposium on Remote Sensing. 2-7 Nov, 1997, Merida, Venezuela.

Jones, P. G. 1997. The CGIAR Network and Research Programs. Paper presented at Global Climate Observing System (GCOS)/ Global Terrestrial Observation System (GTOS) Meeting of Experts on Ecological Networks of Sites. Bilbao, Spain 17-20 June.

Jones, P. G. and Bell, W. C. 1997. Administrative divisions of Latin America to the third order. Digital version 1.1, ARC/INFO data coverage. CIAT, Cali, Colombia.

Montegranario, H. 1997. The CIAT-University of Guelph Project. World Wide Web homepage. URL: http://gis.ciat.cgiar.org/~hmontegra/cida.html.

Nelson, A.; Hyman, G.; Jones, P.; and Bell, W. 1997. La conversion de vector a raster aplicada a datos de poblacion de América Latina. Paper presented at 8th Latin American Symposium on Remote Sensing. 2-7 Nov, 1997, Merida, Venezuela.

Ráez-Luna, E.; Gallopín, G. C.; Fujisaka, S.; Murray, T.; and Waltner-Toews, D. 1997. Development, resources and perverse resilience: the case of Ucayali, eastern Peru. CIAT Working Document No. 170. 24 p.

Smith, J.; Mourato, S.; Veneklaas, E. J.; Labarta, R.; Reategui, K.; and Sanchez, G. Forthcoming. Willingness to pay for environmental services among slash-and-burn farmers in the Peruvian Amazon: implications for deforestation and global environmental markets. Centre for Social and Economical Research on the Global Environment (CSERGE), London and CIAT, Technical Report. CIAT, Cali, Colombia.

Veneklaas, E. J. 1997. Growth and carbon partitioning of tropical tree seedlings in contrasting light environments. Paper presented at International workshop "Variation in growth rate and productivity of higher plants". Utrecht, The Netherlands, Jun 24-27.

Veneklaas, E. J. 1996. La intensificación del uso de tierras en la Altillanura: análisis del posible impacto. Paper presented at Taller regional "Agrociencia y Tecnologia Siglo XXI, Orinoquia Colombiana", Villavicencio, Nov 13-15.

Veneklaas, E. J. 1997. Key ecological processes in Ucayali. Paper presented at First International Workshop of the CIAT/Guelph Project (Integrated conceptual framework for tropical agroecosystem research based on complex system theories). Cali, May 26-28,

Winograd, M. and Farrow, A. 1997. Environmental and sustainability indicators of Latin America and the Caribbean. Example 7, GIS Awareness Package in Agricultural Research. United Nations Environment Program (UNEP)/DEIA/RT.97-9. http://www.grida.no/cgiar/htmls/awpak.html.

Winograd, M.; Farrow, A.; and Eade, J. 1997. Environmental and sustainability indicators outlook for Latin America and the Caribbean. CD-ROM with manual. 27 p. United Nations Environment Program (UNEP)-CIAT, Cali, Colombia. Oct 1997.

Winograd, M..; Salazar, H.; Fonseca, O.; Pescador, A.; and Riascos, J. C. 1997 Marco concpetual para un sistema de indicadores de gestion y planificacion ambiental. Proyecto CIAT-Progama de las Naciones Unidas para el Medio Ambiente (PNUMA)/Unidad de Politica Ambiental (Departamento Nacional de Planeacion), CIAT, Cali, Colombia. 70 p.

Oral Presentations

Hyman, G. 1997. Mapping maize and wheat distributions in Latin America. Seminar speaker at the International Center for Maize and Wheat Improvement (CIMMYT), Mexico City, Mexico, Sept 18, 1997.

Hyman, G. 1997. Tendencias en el uso de sistemas de información geográfica con censos en América Latina. Invited lecture given at the Instituto Nacional de Estadistica y Informatica, Peru, Jly 18.

Land Management Unit Personnel

* Left CIAT during 1996-97
† Arrived at CIAT during 1997
% Time on project

	%		
Peter G. Jones	60	PhD, Agricultural Geography	Project Manager from July 1997 Senior Staff
* Gilberto C. Gallopín		PhD, Ecology	Project Manager to July 1997. Senior Staff
William C. Bell	20	PhD, GIS and Databases	Senior Staff
Samuel Fujisaka	20	PhD, Rural Anthropology	Senior Staff
Manuel Winograd	100	PhD, Ecology	Senior Staff
Glenn G. Hyman	100	PhD, Geography	Postdoctoral Fellow
Erik J. Veneklaas	100	PhD, Tropical Ecology	Postdoctoral Fellow
Nathalie Beaulieu	20	PhD cddte., Remote Sensing	Senior Research Fellow
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Abbreviations and Acronyms Used

2,4-D	dichlorophenoxyacetic acid
ASB	Alternatives to Slash and Burn project
AML	Arc Macro Language
AT	adenosine/typtophane
AVHRR	advanced very high resolution radiometer
BGMV	bean golden mosaic virus
CARDER	Corporación Autonomo Regional de Risaralda, Colombia
CATIE	Centro Agronómico Tropical de Investigación y Enseñanza, Costa Rica
CELADE	Centro Latino Americano de Demografía
CGIAR	Consultative Group on International Agricultural Research
CIFOR	Center for International Forestry Research, Indonesia
CIMMYT	Centro Internacional de Mejoramiento de Maiz y Trigo, Mexico
CINTERPEDS	Centro Internacional de Politica Económica para el Desarrollo Sostenible, Costa Rica
CIP	Centro Internacional de la Papa
CODESU	Consorcio para el Desarrollo Sostenible de la Región Ucayali, Peru
CONDESAN	Consorcio para el Desarrollo Sostenible de la Ecoregión Andina
CORPOICA	Corporación Colombiana de Investigación Agropecuaria
CSERGE	Centre for Social and Economical Research on the Global Environment, University College, London
CST	complex systems theories
DCW	Digital Chart of the World
DEM	A digital elevation model
DMSP	Defense Meteorological Satellite Program
DNP	Departamento Nacional de Planeación, Colombia
DPCSD	Department for Policy Coordination and Sustainable Development, United Nations, New York.
ECLAC	Economic Commission for Latin America and the Caribbean
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuaria, Brazil
FAO	Food and Agriculture Organization of the United Nations, Rome, Italy
GC	guanidine/cytosine
GCOS	Global Climate Observing System
GEO	Global Environmental Outlook, UNEP
GIS	Geographic Information System
GO	Government Organization
GPS	global positioning system
GRID	Global Resource Information Database, Arendal, Norway
GTOS	Global Terrestrial Observation System
GTZ	Deutsche Gesellschaft für Techische Zusammenarbeit
ICRAF	International Centre for Research in Agroforestry, Kenya
ICRISAT	International Crop Research Institute for the Semi-Arid Tropics, India
IDB	Interamerican Development Bank, WA
IDEAM	Instituto de Estudios Ambientales, Colombia
IFSA	Integracion fluvial de Sur America

IGAC	Instituto Geográfico Augustín Codazzi, Colombia
IIASA	International Institute for Applied Systems Analysis, Austria
IICA	Instituto Interamericano de Cooperación para la Agricultura, Chile
IILA	Instituto Italo-Americano, Rome
ILRI	International Livestock Research Institute, Kenya
INEI	Instituto Nacional de Estadística e Informática, Peru
INIA	Instituto Nacional de Investigación Agraria, Peru
INIAP	Instituto Nacional de Investigaciónes Agropecuarias, Ecuador
IVITA	Instituto Veterinario de Investigaciónes Tropicales y de Altura, Peru
JERS	Japanese Synthetic Aperture Radar Satellite
NARS	National Agricultural Research Systems
NASA	National Aeronautics and Space Administration, USA
NASDA	National Space Development Agency, Japan
NOAA	National Oceanic and Atmospheric Administration
OM	organic matter
ORSTOM	Office de la Recherche Scientifique et Technique d'Outre-Mer, France
PCR	polymerase chain reaction
PNUMA	Progama de las Naciones Unidas para el Medio Ambiente
P.O.M.	particulate organic matter
RAPD	random amplified polymorphic DNA
rDNA	ribosomal DNA
RISA	rRNA intergenic spacer analysis
RIVM	Rijksinstituut Voor Volksgezondheid en Millienhygiene (National Institute of Public Health and Environmental Protection), Netherlands
ROLAC	Regional Office for Latin America and the Caribbean, UNEP
SAR	Synthetic Aperture Radar
SCOPE	Scientific Committee for Problems of the Environment
SDS	sodium dodecyl sulfate
SEI	Stockholm Environmental Institute, Sweden
SOE	Sourcebook of Environmental report
SSSA	Soil Science Society of America
TCA	Tratado de Cooperación Amazónica, Peru
TSBF	Tropical Soils Biology and Fertility Program, Kenya
UNEP	United Nations Environment Program, Geneva
UNESCO	United Nations Educational, Scientific, and Cultural Organization
UNSTAT	United Nations Statistics division
USGS	The United States Geological Survey
WRI	World Resources Institute, Washington